Travel Demand Modeling Methodology Recommendations for the Link21 Program

March 2022

Prepared By:

Giovanni Circella, Ran Sun, Tho V. Le, Jaime Soza-Parra,
Xiaodong Qian, David Bunch, Miguel Jaller

UC DAVIS
INSTITUTE OF TRANSPORTATION STUDIES

About the UC Institute of Transportation Studies

The University of California Institute of Transportation Studies (UC ITS) is a network of faculty, research and administrative staff, and students dedicated to advancing the state of the art in transportation engineering, planning, and policy for the people of California. Established by the Legislature in 1947, ITS has branches at UC Berkeley, UC Davis, UC Irvine, and UCLA.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein, and not necessarily those of the Link21 program or the funding agencies. This document is disseminated under the sponsorship of the State of California in the interest of information exchange. The State of California assumes no liability for the contents or use thereof. Nor does the content necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as an actual or implied endorsement of such products.

Acknowledgments

This study is funded by a grant from the Transit and Intercity Rail Capital Program (TIRCP) administered by the California State Transportation Agency. Additional funding for the research was provided by the 3 Revolutions Future Mobility Program of the University of California, Davis. The study was also made possible with funding received by the University of California Institute of Transportation Studies from the State of California through the Public Transportation Account and the Road Repair and Accountability Act of 2017 (Senate Bill 1). The authors would like to thank Andrew Tang (San Francisco Bay Area Rapid Transit District), Camille Tsao and Jim Allison (Capitol Corridor Joint Powers Authority) for their time and insights throughout this study. The authors would also like to thank Farzad Alemi, Marcus Chan, Rosa Dominguez-Faus, Seth Karten, Kailai Wang and Xiaoyang Xue (University of California, Davis) for their contributions to the report. The following experts from various academic institutions, national labs, and regional, state and federal planning agencies provided valuable information and feedback throughout the study: Chandra Bhat (University of Texas at Austin), Ram Pendyala (Arizona State University), Stefan Reul and Andrew Desautels (travel modeling consultant to the California High Speed Rail Authority), Mark Mukherji and Masroor Hasan (travel modeling consultant to the California State Transportation Agency), Monique Stinson (Argonne National Laboratory), Guy Rousseau (Atlanta

Regional Commission), Alan Miller (California Department of Transportation), Chad Edison (California State Transportation Agency), Jeremy Raw (Federal Highway Administration), Lyle Leitelt and Peter Schwartz (Federal Railroad Administration), Ken Cervenka, Jeff Roux and Jim Ryan (Federal Transit Authority), Vladimir Livshits (Maricopa Association of Governments), Shengyi Gao, Bruce Griesenbeck and Yanmei Ou (Sacramento Area Council of Governments), Hsi-Hwa Hu (Southern California Association of Governments), Wu Sun (San Diego Association of Governments), Joe Castiglione, Drew Cooper, Bhargava Sana and Dan Tischler (San Francisco County Transportation Authority), and Bill Davidson (San Francisco Metropolitan Transportation Commission).

Table of Contents

List of Figures

List of Tables

Glossary

Acronym	**Definition**
ABM	Activity-Based Model
ACE	Altamont Corridor Express
ADAS	Advanced Driver Assistance Systems
AMBAG	Association of Monterey Bay Area Governments
ARC	Atlanta Regional Commission
AV	Automated Vehicle
BART	(San Francisco) Bay Area Rapid Transit District
BRT	Bus Rapid Transit
CalSTA	California State Transportation Agency
Caltrans	California Department of Transportation
CAV	Connected and Automated Vehicle
CBSA	Core Based Statistical Area
CCJPA	Capitol Corridor Joint Powers Authority
CCSCE	Center for Continuing Study of the California Economy
CHSR	California High Speed Rail
CHSR-BPM	California High-Speed Rail Business Plan Model
CONNECT	CONceptual NEtwork Connections Tool
CSFFM	California Statewide Freight Forecasting Model
CSTDM	California Statewide Travel Demand Model
CTPP	Census Transportation Planning Products
DTA	Dynamic Traffic Assignment
ETM	External Travel Model
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration

Acronym	Definition
FTA	Federal Transit Administration
GTFS	General Transit Feed Specification
HCV	Human-Controlled Vehicle
HOV2	High Occupant Vehicle with Two persons in the vehicle
HOV3+	High Occupant Vehicle with Three or more persons in the vehicle
HSIPR	High Speed and Intercity Passenger Rail
HSR	High-Speed Rail
LACMTA	Los Angeles County Metropolitan Transportation Authority
LDPTM	Long-Distance Passenger Travel Model
MaaS	Mobility as a Service
MPO	Metropolitan Planning Organization
MTC	Metropolitan Transportation Commission
MTC TM	(San Francisco Bay Area) MTC Travel Model
NAICS	North America Industry Classification System
NRT	Non-Rail Transit
OD	Origin-Destination
PDA	Priority Development Area
RDM	Regional Dynamic Model
RTDM	Regional Travel Demand Model
SACOG	Sacramento Area Council of Governments
SAE	Society of Automobile Engineers
SANDAG	San Diego Association of Governments
SAV	Shared Automated Vehicle
SCAG	Southern California Association of Governments
SDPTM	Short-Distance Passenger Travel Model

Acronym	Definition
SF-CHAMP	San Francisco-Chained Activity Modeling Process
SFCTA	San Francisco County Transportation Authority
SOV	Single Occupant Vehicle
TAP	Transit Access Point
TAZ	Transportation Analysis Zone
TBEST	Transit Boardings Estimation and Simulation Tool
TCM	(Northern San Joaquin Valley) Three Counties travel demand Model
TNC	Transportation Network Company
VMT	Vehicle Miles Traveled

Abstract

This project aims to provide recommendations on the methodology and design specifications for the travel demand model to be built for the Link21 program in the Northern California megaregion. The Link21 program is a major rail investment program that will considerably improve and upgrade the passenger rail services in the Northern California megaregion, centered around the Transbay Corridor between Oakland and San Francisco in the San Francisco Bay Area. To support this effort, we reviewed the current and potential travel markets for the Link21 program, assessed the available travel demand models that could be used to support the modeling efforts for the Link21 program, and conducted interviews with experts from academic institutions, metropolitan planning organizations, state and federal agencies, and US DOE national labs. Considering the goals and objectives of the Link21 program, a list of 20 critical, important, and optional modeling features were identified, which should be considered for the Link21 program. We reviewed 11 existing travel demand models based on the evaluation of their modeling features, and present four proposed modeling approaches which could be considered to support the Link21 program. For each modeling approach, we summarize pros and cons in terms of fulfilling the requirements of the Link21 program. The four modeling approaches include: 1) building on the Metropolitan Transportation Commission (MTC) TM 2.1 regional travel demand model without a dedicated long-distance travel model component; 2) building on the MTC TM 2.1 regional travel demand model with a dedicated long-distance travel model component; 3) building on the San Francisco County Transportation Authority (SFCTA) regional travel demand model with or without a dedicated long-distance travel model component; and 4) building on the California High Speed Rail (CHSR) or the new statewide rail model that is currently under development. The study also discusses some sources of uncertainties that might affect future travel demand and the modeling practice in the Link21 regions. These include the impacts of the COVID-19 pandemic on work patterns and activity/travel choices, the introduction of shared mobility services, micromobility, the potential deployment of Mobility as a Service (MaaS) solutions, and the forthcoming deployment of connected and automated vehicles (CAVs). Given the complexity of the Link21 program and the requested 18-month timeline for developing a new travel demand model to support the program, we recommend that the model development for the Link21 program build on an existing modeling framework and adopt a modular system, which can be updated over time. An initial model release would become available in the proposed timeline of 18 months, while future updates and improvements in the model components could be added in future model updates. This process also would be well-suited to address eventual modeling issues that could arise with the initial model release, and it would benefit from the development and updates of other models in the Northern California megaregion that are being carried out in parallel.

Executive Summary

The San Francisco Bay Area Rapid Transit District (BART) is a heavy-rail public transit system and a major component of the transportation systems in the San Francisco Bay Area and the Northern California megaregion. Up until the onset of the COVID-19 pandemic in March 2020, BART was operating at capacity in the only existing passenger rail crossing of the San Francisco Bay (the BART Transbay Tube). Meanwhile, the Capitol Corridor intercity passenger rail service and other regional rail services lack a direct connection between the locations they serve in Northern California and the San Francisco Peninsula. As a result, passengers on these other rail services must transfer to BART or bus services that cross the San Francisco Bay via bridge to travel to and from the San Francisco Peninsula. (For example, Capitol Corridor passengers must transfer to an Amtrak Bus Shuttle in Emeryville or BART in Richmond, and Caltrain passengers must transfer to BART at Millbrae). To expand BART capacity as well as improve connectivity and service on regional rail, a second railway crossing project between San Francisco and Oakland is proposed as part of the Link21 program. By improving connectivity between the East Bay and the San Francisco Peninsula, a second rail crossing would benefit not only BART and regional rail but would considerably expand the availability of public transportation connections over the entire 21-county Northern California megaregion. The project is considered beneficial as it would provide an alternative to the high congestion levels on the highway network in the region, address the current limitations of the existing public transportation system, and support future transportation needs associated with the future population and employment growth expected in the megaregion.

Travel demand modeling plays an important role in project assessment. It helps forecast future travel demand and travelers' response to the availability of the new services and produce accurate evaluation of the projected expenses and expected returns from the investments. However, there is currently no existing model that covers the entire 21-county area in the Northern California megaregion and has the level of detail required for evaluating the impacts of the infrastructure investment and service upgrades proposed by the Link21 program. It will therefore be necessary to build travel demand modeling capability that adequately addresses the goals and objectives of the Link21 program. The purpose of this research report is to provide modeling methodologies for a travel demand model that covers the 21 counties of the study area and will effectively support the evaluation of the potential impacts, including benefits and costs, associated with a large program of this nature.

In this report, we first summarize current information available on the travel markets within and surrounding the Link21 Northern California megaregion. We provide summary information on the forecasted volumes of travel in the megaregion, by travel mode and component of travel. These forecasts are based on evidence from a recent Link21 travel market analysis and the modeling results from the application of the California Statewide Travel Demand Model (CSTDM) built and maintained by the California Department of Transportation (Caltrans). Existing travel demand estimates (that were built without taking into consideration the Link21 program) show that in both the current year and 2040 scenario year, car travel dominates transportation flows in the 21-county megaregion, accounting for approximately 95 percent of megaregional-relevant trips (not including very short-distance trips made by active modes), according to data from the Link21 travel market analysis and the CSTDM forecasts for 2040. This status quo is associated with high traffic congestion levels on the highway network in the megaregion and several limitations of the current public transportation system—which operated at capacity during peak time on its major corridors in the pre-pandemic period and lacks connectivity and good level of service on other corridors. The analysis of data from the Link21 travel market analysis for 2040 highlights how the vast majority of rail trips within the Northern California megaregion happens within the nine Bay Area counties in the MTC region. When we account for all major modes that are relevant for travel in the megaregion (i.e., auto, rail, and non-rail transit), the nine Bay Area counties contribute almost two thirds of all trips within the megaregion. The spatial distribution of trips centered around the nine counties in the San Francisco Bay Area together with the characteristics of the current MTC travel demand model—which is designed with an advanced activity-based travel demand modeling structure and will be (in its MTC 2.1 version) well equipped to model public transportation—suggests that a model that builds upon the MTC model structure (or other models that primarily focus on the San Francisco Bay Area) could be a desirable solution. However, the eventual inclusion of a proper long-distance modeling component could be beneficial to model improved rail services and potential mode choice shift for regional and interregional travel. While these components of travel account for a relatively small portion of total trips, these trips could be particularly important on commuter and intercity rail corridors of relevance for the Link21 study area.

In this study, we reviewed and evaluated the modeling features of 11 existing travel demand models that eventually could be useful for the development of the travel model for the Link21 program. The diverse set of modeling tools includes:

- three models that operate at the statewide level (the California Statewide Travel Demand Model, the California High-Speed Rail [CHSR] Business Plan Model, and a new statewide rail model that is being developed by Caltrans);
- four models that operate at the regional/metropolitan planning organization (MPO) level (the San Francisco Bay Area MTC Travel Model (MTC TM), the Sacramento Activity-Based Travel Simulation Model, the Northern San Joaquin Valley Three-County Model, and the San Francisco County Transportation Authority [SFCTA] Travel Demand Forecasting Model); and
- four models dedicated to transit ridership forecasting (the Transit Boarding Estimation and Simulation Tool, the Simplified Trips-On-Project Software, the Regional Dynamic Model, and the Conceptual Network Connections Tool).

This model overview helps provide a background of the capabilities, limitations, and uncertainties of these travel demand modeling frameworks.

In this study, we also interviewed experts for their advice on modeling practices, modeling uncertainties, and potential risks associated with various modeling approaches—all as they specifically pertain to the Link21 modeling needs. We worked in close collaboration with the funding agency to expand and converge on a final list of experts that included individuals from academic institutions and the public sector. In the expert interviews, we asked for opinions on various topics including the feasibility and requirements for a brand new “blue sky” modeling system vs. building on the modeling features of existing travel demand models; the minimum required characteristics and ballpark budget for a realistic model development; the potential importance of new transportation technologies and emerging mobility services; and approaches to incorporate them in the travel demand modeling framework. The majority of the experts recommended building on an existing travel demand model as the most promising and practical option, especially given the limited timeline of 18 months.

Based on the information from the review of the travel markets, the available travel demand modeling tools existing to date, the recommendations from the experts, and the goals and objectives of the Link21 program, we propose a list of 20 *critical*, *important*, and *optional* modeling features that should be considered for the Link21 program. The list of modeling features includes timeline for the model development and running time, geographical considerations, rail service modeling, service integration modeling, travel time, travel cost, hours of operation, service frequency, crowding and capacity constraints, reliability, impacts of future land use, transit ridership, mode choice modeling, vehicle miles traveled (VMT) estimation, job accessibility, transit options accessibility by different groups, access and egress modes, impacts of new communication technologies, impacts of new transportations options, and freight transportation.

We then assess the eleven existing models based on the list of 20 modeling features. Even though these models are developed and deployed each with their unique intended use cases and no model could directly satisfy all requirement and present all modeling features, some modeling features of the existing models included in this review could be useful to support the development of the Link21 travel demand model. Based on the knowledge developed for this study, we identify and discuss four modeling options that could be considered for the Link21 program, namely:

1) building on the MTC TM 2.1 regional model without a dedicated long-distance travel model component;
2) building on the MTC TM 2.1 regional model with a dedicated long-distance travel model component;
3) building on the SFCTA regional model with or without a dedicated long-distance travel model component; and

4) building on the CHSR or the new statewide rail model that is currently under development.

In summary, Option 2, i.e., building on the MTC TM 2.1 regional model with a dedicated long-distance travel model component, emerges as a very desirable and comprehensive option to implement. It builds on an operational advanced regional travel demand model and has a fine level of spatial resolution with its detailed zoning system and network representation, which is important to capture local and regional travel. The MTC TM 2.1, which should become available in April 2022, will also already include many desirable modeling features that would be extremely useful to model the impacts of public transportation improvements. Expanding the geographic scope of the model to the entire 21-county megaregion, and adding a long(er)-distance travel demand component to this modeling framework would enhance the capacity of this model to account for the different components of travel beyond short-distance trips (that are already well modeled in an advanced multimodal regional activity-based travel demand model).

Option 1 would be an alternative, as this modeling approach would also benefit from all valuable modeling features in the MTC TM model structure. However, it may underperform in its ability to model longer-distance travel components. Thus, it would lack the ability to evaluate scenarios that integrate investments for intercity/longer-distance rail services with other regional public transportation investments. The model, though, would be simpler to develop and would eliminate the complications associated with running the two model components in a unified travel demand modeling framework.

The two options could somehow be combined, eventually, if a first model release for the Link21 model system is prepared largely based on Option 1, while a proper long-distance travel model component could be included in a future model update. Option 3, on the other hand, is less preferable because the model currently maintained and operated by SFCTA has several limitations compared to the MTC TM, in particular, its lack of various modeling features that are important to model public transportation. However, this option would be a low-uncertainty approach that builds on an operational model and would not rely on the timeline for (and be subject to any potential delays in) the development of MTC TM 2.1. The least preferable option is certainly Option 4. The current structure of these large-scale models that are designed to forecast travel demand at the statewide level has relatively low spatial resolution, and does not include enough detail and modeling components to properly model local/regional travel. Thus, considerable efforts would be required to add detail in many modeling aspects and upgrade the modeling features of such a model to meet the Link21 modeling needs. However, one of these large-scale travel demand models could represent a source for the long-distance travel component that could be integrated in one of the other options that have been previously described.

Last, we discuss several sources of uncertainties that will likely affect future travel demand, including the impacts of the COVID-19 pandemic and the eventual persistence of telework (among other changes in activity and travel choices), and the way emerging transportation technologies and new mobility options are revolutionizing transportation.

The recommendations contained in this report are expected to help the funding agency and its modeling consultants develop the Link21 modeling framework and build future travel demand forecasts for the program. Given the complexity of the Link21 program, the model needs to integrate various components of travel demand and travel forecasts for complex long-term scenarios. In line with the modeling practice in the transportation field, we recommend that the model development for the Link21 program should be a modular system, which can be updated over time. While an initial modeling system for the Link21 program could be released in the initial proposed timeline of 18 months, future model releases and updates could include additional features and improvements in the model components. This process also would be well-suited to address eventual modeling issues that could arise with the initial model release but harvest the additional benefits from the development and updates of other models in the Northern California megaregion that are carried out in parallel, e.g., for the MTC TM version 2.2 (and following versions of the model) and/or the new statewide rail travel model that is being developed by Caltrans.

1 Introduction

Bay Area Rapid Transit (BART) is a major component of the transportation systems in the San Francisco Bay Area and the Northern California megaregion. It was operating at capacity in the only existing rail crossing of the San Francisco Bay (the BART Transbay Tube) in the years just before the COVID-19 pandemic started in March 2020. Similarly, the Capitol Corridor intercity passenger rail service and other regional rail services lack a direct connection between the locations they serve in Northern California and the San Francisco Peninsula, forcing passengers to transfer (in Emeryville, with the Amtrak Bus Shuttle service, in Richmond, with BART, and in Millbrae between Caltrain/BART). To expand BART capacity as well as improve connectivity and service on regional rail, a second railway crossing project between San Francisco and Oakland is proposed as part of the Link21 program.

By improving connectivity between the East Bay and the peninsula where the City of San Francisco is located, a second rail crossing would benefit not only BART and regional rail but would considerably expand the availability of public transportation connections over the entire 21-county Northern California megaregion (see Figure 1.1). The project is considered beneficial by its proposers in multiple ways, as it would provide an alternative to the high congestion levels on the highway network in the region, address the current limitations of the existing public transportation system (including expanding capacity of the system, extending coverage and operating hours, and providing increased flexibility for scheduling maintenance), and support future transportation needs associated with the forecasts for future population and employment growth in the San Francisco metropolitan area.

Transportation projects and investments require large efforts and commitments—in terms of both financial resources and coordination of multiple agencies and stakeholders, e.g., for securing the appropriate right of way, environmental reviews, etc. Such efforts require long-term planning and forecasting to understand future travel demand and travelers' response to the availability of the new services, and to produce accurate evaluation of the projected expenses and expected returns from the investments. Travel demand modeling will therefore play an important role in this project assessment. However, there is currently no existing model that covers the entire 21 counties and has the level of detail required for evaluating the Link21 program. It will therefore be necessary to build travel demand modeling capability that adequately addresses the goals and objectives of the Link21 program. This, in turn, requires careful consideration of what the options are for developing such a model, given both the timeline and requirements of the Link21 program. The purpose of this research report is to provide suggestions and analysis of alternative modeling methodologies for a travel demand model that covers the 21 counties of the study area and effectively accounts for the future benefits for a project of this nature.

1.1 The Link21 Program

The Northern California megaregion, spanning the Bay Area to Sacramento and the San Joaquin Valley, is home to over 12.5 million people and is the fifth-largest U.S. megaregional economy, with the highest GDP per capita. These numbers have increased significantly over the last 30 years and the population is expected to reach 16 million by 2050. The existing transportation network, and in particular the Transbay Corridor between Oakland and San Francisco, is unable to effectively meet the needs of the 21-county megaregion, which encompasses a vast area of over 24,000 square miles with around 63 million daily trips projected for 2040, according to the forecasts produced with the California Statewide Travel Demand Model (CSTDM), the statewide travel demand model maintained by the California Department of Transportation (Caltrans). The highway network is already affected by heavy traffic congestion for large portions of the day. Before the COVID-19 pandemic, in some of the busiest corridors, including the bay crossing between San Francisco and Oakland, many people chose rail over other options, but trains were frequently overcrowded, with limited alternative routes, and operated at capacity during peak time (so that any disruptions to the service would negatively impact the travelers in the region). BART trains also had limitations to the hours of operations imposed by the need of performing scheduled maintenance during the night hours.

The Link21 program will substantially improve the rail network in the Northern California megaregion through a new rail crossing between Oakland and San Francisco as well as improvements to rail infrastructure and services connecting to the new crossing in both the West Bay and the East Bay and beyond. With key investments that leverage the existing network and increase capacity and system reliability, rail and transit will become a more convenient travel mode throughout the megaregion.

1.2 Area of study

The Link21 program has the potential to affect travel throughout Northern California in many ways. The study area includes 21 counties in Northern California, as shown in Figure 1.1. These counties are already associated with planning regions and metropolitan planning organizations that use existing modeling tools to support their decision making. These include:

- Nine counties in the Metropolitan Transportation Commission (MTC) region and included in the MTC model (in green color in Figure 1.1): Alameda, Contra Costa, Marin, Napa, Solano, Sonoma, San Mateo, San Francisco, and Santa Clara;

- Six counties in the Sacramento Area Council of Governments (SACOG) region and included in the SACSIM model (in light blue color in Figure 1.1): El Dorado, Placer, Sacramento, Sutter, Yolo and Yuba;

- Three northern counties in the California San Joaquin Valley and included in the Three Counties Travel Demand Model (TCM) (in dark purple color in Figure 1.1): Merced, San Joaquin and Stanislaus; and

- Three counties in the Association of Monterey Bay Area Governments (AMBAG) region and included in the Regional Travel Demand Model (RTDM) (in gold color in Figure 1.1): Monterey, San Benito, and Santa Cruz.

The San Francisco region is also the focus of the San Francisco-Chained Activity Modeling Process (SF-CHAMP), maintained by the San Francisco County Transportation Authority (SFCTA), which is mainly used to forecast travel demand at the local level in the City of San Francisco and to/from neighboring areas. The main characteristics, as well as the pros and cons of these modeling tools, are included and discussed in the following chapters of this report.

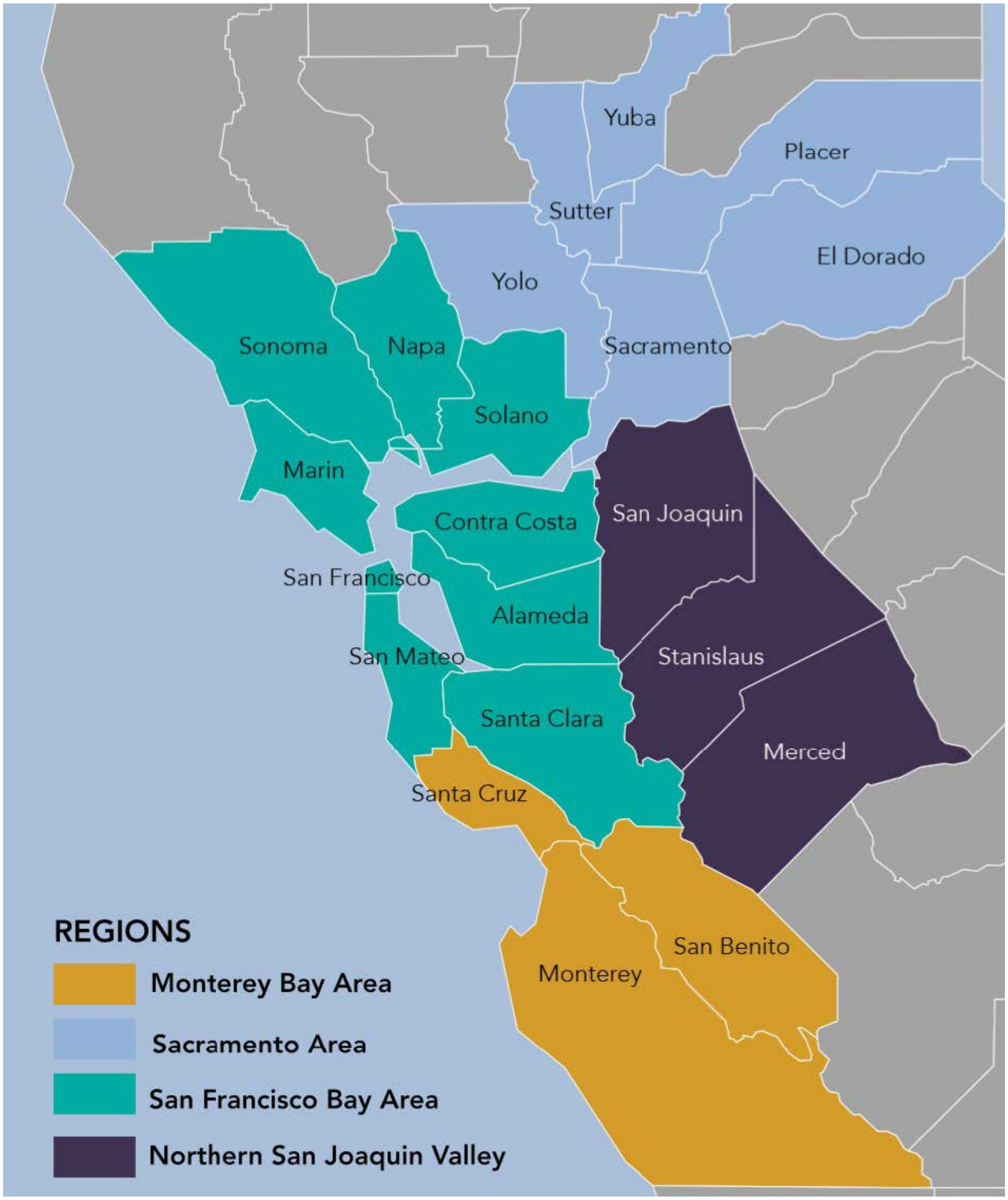


Figure 1.1 The study area of the Link21 program (21 counties in the Northern California megaregion)

1.3 Scope of work

This project aims to provide recommendations on the travel demand modeling methodology, to facilitate contractor recruitments as well as support the determination of design specifications for the travel demand model to be built for the Link21 program. Specifically, this project provides guidelines for future travel demand model development in the Northern California megaregion to support the Link21 needs. The project started by investigating the current travel markets within the study. Then, current modeling tools that are potentially useful inputs for this process were assessed. Moreover, we conducted interviews with experts to obtain knowledgeable advice on modeling approaches and modeling components of interest for the Link21 program. Based on these investigations, and considering the goals and objectives of the Link21 program, a list of 20 modeling features was developed and evaluated as either critical, important, or optional for the Link21 needs. Then, 11 existing models were evaluated using this framework. Using these results, four modeling options were developed for further consideration. In addition, sources of uncertainty that potentially affect future travel demand were discussed. Finally, recommendations for future travel modeling approaches were provided. Our recommendations follow the Link21 expectations that this travel demand model should be built within approximately 18 months.

1.4 Modeling Challenges

No existing travel demand forecasting model that covers the entire 21 counties has a level of detail sufficient for evaluating the Link21 program. While some regional models operate at a high-enough level of detail, they only partially cover the study area and are not easily integrated with other models. Conversely, statewide models subsume the study area but are not sufficiently granular to address the travel demand modeling needs for the Link21 program. These limitations are particular limiting for a project such as Link21, as the project would affect both regional travel (e.g., inside the San Francisco Bay Area) as well as intercity and interregional travel that might be impacted by the availability of the new rail infrastructure (e.g., travel on the rail corridors connecting the Sacramento region, and the northern portion of the California San Joaquin Valley, with the San Francisco Bay Area). In addition, the desired model faces some challenges that may not be adequately addressed by any of the existing models, such as accounting for rail vehicle capacity, rail station parking capacity, and appropriate representation of transit station access/egress modes, among other limitations.

A sizeable benefit of the Link21 program would result from the relaxation of transit capacity constraints and reduced transit crowding that would occur from adding Transbay capacity. However, there is likely to be additional latent demand that would emerge in response to this increase in capacity, but existing models would be unable to account for these benefits.

Therefore, it is important for a new Link21 model to properly account for the full effect of a sizeable increase in rail service coverage and capacity.

Another challenge relates to station access, including rail station parking capacity. On an average day before the beginning of the COVID-19 pandemic, all BART parking facilities were 100% occupied by approximately 9 AM, and many well before 9 AM. The Link21 program may not be able to address these parking capacity issues, nor are existing models able to account for parking capacity benefits, and therefore cannot assess their impact on travel demand and passenger choices.

While some existing model approaches account, to some degree, for the use of various access/egress modes to transit stations, this capability is often limited, and models are often unable to account for the benefits of better integration across modes. Having such ability will be important in the model used for Link21, not only to account for existing (conventional) transit access/egress modes, but also due to the rise in popularity of new mobility options that are disrupting transportation. The transportation sector has recently undergone and will likely continue to undergo revolutionary changes, with the growth of smartphone app-based on-demand mobility and solutions including ridehailing, e-bikes, scooter-, bike-, and car-sharing services, as well as the expected advent of automated vehicles. These changes in available transportation alternatives and the rise of on-demand mobility are changing and will continue to change transportation in multiple ways, including the way passengers can access and egress transit stations and connect to public transportation services.

1.5 Methodology and Structure of this Project Report

In this study, the research team at the UC Davis Institute of Transportation Studies provides travel demand modeling methodology recommendations for the Link21 program. When we first evaluated current travel patterns in the Northern California megaregion, we focused on the San Francisco Bay Area as a destination and considered trip patterns and mode shares, among other parameters. We first considered current and future travel demand estimates obtained from the Link21 travel market analysis, and compared them to other existing sources, to assess the market for transportation to/from the region, and the extent to which this market is currently served by existing public transportation options vs. the use of private vehicles on the highway network.

We then reviewed currently existing tools used for forecasting travel demand in California and reviewed selected planning and modeling approaches being used in other regions and/or states, especially considering approaches that are well suited for modeling demand for rail transportation and, more generally, multimodal transportation. These included: how the models are used, the assumptions and modeling approaches employed ("How" they model travel demand), the scale at which the models operate, and what travel modes and components of behavioral choices they include ("What" they model). We summarize key features of these models in Section 3 of this report. The investigation of models at regional and statewide levels facilitated the extraction of their pros and cons to using certain features that are present in some of these models for the Link21 program.

Given project contexts and challenges, we consulted experts and requested their opinions about feasible approaches to improve travel demand forecasting for the Link21 program. Experts were also asked whether the impacts of transportation technologies and emerging mobility services (e.g., connected and automated vehicles, micromobility, teleworking, etc.) should be accounted for in the new Link21 travel demand model. The experts included well-established colleagues from academia, regional, state, and federal transportation agencies, and US Department of Energy national labs who have experience in developing and/or applying travel demand models focusing on car/highway travel and those who have experience in transit and/or freight modeling.

To guide future modeling efforts, we developed assessment criteria by reviewing the Link21 goals and objectives and created a list of modeling features that the future travel demand model should have. Each modeling feature was rated as critical, important, or optional. Next, each of the 11 models considered was assessed on how it fits into the proposed criteria and presents the critical, important, and optional modeling features. The assessment, consequently, provided thorough insights and comparisons, leading to the final evaluation of four alternative modeling options. By using this structured, detailed approach, the project provides the funding agency and decision-makers guidelines and recommendations on the travel demand modeling methodology that addresses the goals and objectives of the Link21 program.

This report is organized into seven sections. After this brief introduction, Section 2 presents the proposed infrastructure for the Link21 program together with the current and future travel demand forecasts obtained from the application of some models currently used in California. Section 3 presents the summary, models' highlighted features, as well as pros and cons of existing travel demand models. Section 4 summarizes the opinions provided by the modeling experts in the interview process. Section 5 conceptualizes the desirable modeling features for the Link21 model development and assesses current models based on their fit with the proposed criteria. It then discusses long-term modeling options for the Link21 model development and provides recommendations for the Link21 program. Then, Section 6 discusses sources of uncertainties associated with the impact of the COVID-19 pandemic and new transportation technologies that should be considered in the Link21 program. Finally, Section 7 provides final conclusions on this work.

2 Link21 Program Background

2.1 The Need for a New Rail Crossing and Other Infrastructure Improvements

Before the COVID-19 pandemic, the existing Transbay BART crossing suffered from capacity constraints during peak hours, and the BART system as a whole experienced widespread delays when the core of the system, including the Transbay crossing, was congested. Additionally, BART has limited ability to expand service hours of operation without alternate routes in the core and additional track capacity in key locations. For regional rail, which includes commuter, intercity, and high-speed train service, there currently is no crossing in the Transbay Corridor, a major gap in the Northern California passenger rail network that was identified in the 2018 California State Rail Plan. All these reasons have led to the creation of the Link21 program, of which a key improvement includes a second rail crossing connecting San Francisco with the East Bay. Other infrastructure projects will be identified as part of the Link21 program to enable improved rail service in the Northern California megaregion ("the megaregion") and accommodate future growth in demand in the Transbay Corridor. A recent report by the Bay Area Council Economic Institute summarizes many reasons for which a second rail crossing could be beneficial to the Northern California megaregion.[1]

There are three proposed options to enhance the Transbay rail service from downtown San Francisco and downtown Oakland and the rest of the East Bay along the Link21 corridor:

1) **A new double-track BART (Indian-gauge) crossing (one track in each direction):** provides more capacity and reliability for existing BART service;
2) **A new double-track standard-gauge crossing (one track in each direction):** adds capacity and new regional connections on standard gauge rail systems, providing opportunities for Caltrain, Capital Corridor and future high-speed rail services;
3) **A new four-track crossing (or two double-track crossings, i.e., the combination of the two options above) that could carry both BART and standard-gauge tracks:** combines option 1 and 2, offering more redundancy and flexibility, but requires more financial effort and complexity in the construction projects.

To support the evaluation of this proposed infrastructure, more investigation is required to understand how proposed infrastructure improvements could best serve the unmet travel demand in the megaregion, relieve congestion on the transit network, provide an alternative to congested roadways, and provide benefits through improved regional transportation services.

As part of this process, there is a need to understand the study region and travel demand when considering the long-term planning process for railway and related infrastructure. When

---

[1] http://www.bayareaeconomy.org/report/megaregionimpactsofnewtransbayrailcrossing/

considering service expansion and infrastructure evaluation, in particular, the integration with the current existing transit network, roadway network, and related infrastructure is an important design metric. However, no appropriate modeling tools currently exist at the 21-county megaregional level (that is relevant for the proposed Link21 program) to support these planning efforts.

The proposed Link21 crossing will serve the high-population and rapidly-growing Northern California megaregion, which is one of the most dynamic economic regions in the country. The megaregion is expected to experience further economic and population growth in the next decades. Table 2.1 and Figure 2.1 summarize the distribution of population in 2020 across the 21 counties in the study region. The megaregion contains several large cities and extended residential communities and employment centers between them. It is currently served by a network of rail services—BART, Capitol Corridor, Caltrain, ACE, SMART and the San Joaquin service—as well as several long-distance Amtrak train routes. Light rail and bus systems, provided by San Francisco MTA (Muni), Sacramento RTD, VTA, and other bus-only agencies provide local transit service. Additionally, a network of busy freeways that have been affected by high congestion levels for many years provides transportation options for travelers in the region.

Table 2.1 Population by county

No	Name	Population (2020)	No	Name	Population (2020)
1	Alameda	1,656,754	12	San Joaquin	742,603
2	Contra Costa	1,142,251	13	San Mateo	767,423
3	El Dorado	188,563	14	Santa Clara	1,927,470
4	Marin	259,943	15	Santa Cruz	273,962
5	Merced	271,382	16	Solano	441,829
6	Monterey	433,410	17	Sonoma	499,772
7	Napa	139,623	18	Stanislaus	543,194
8	Placer	385,512	19	Sutter	96,109
9	Sacramento	1,524,553	20	Yolo	217,352
10	San Benito	60,376	21	Yuba	76,360
11	San Francisco	874,961			

The distribution of the population, housing scarcity, and high housing costs in the San Francisco region, together with the strong connections between the major economic and population centers in the megaregion, generate high volumes of trips for both commuting and non-commuting purposes on several major corridors in the megaregion.

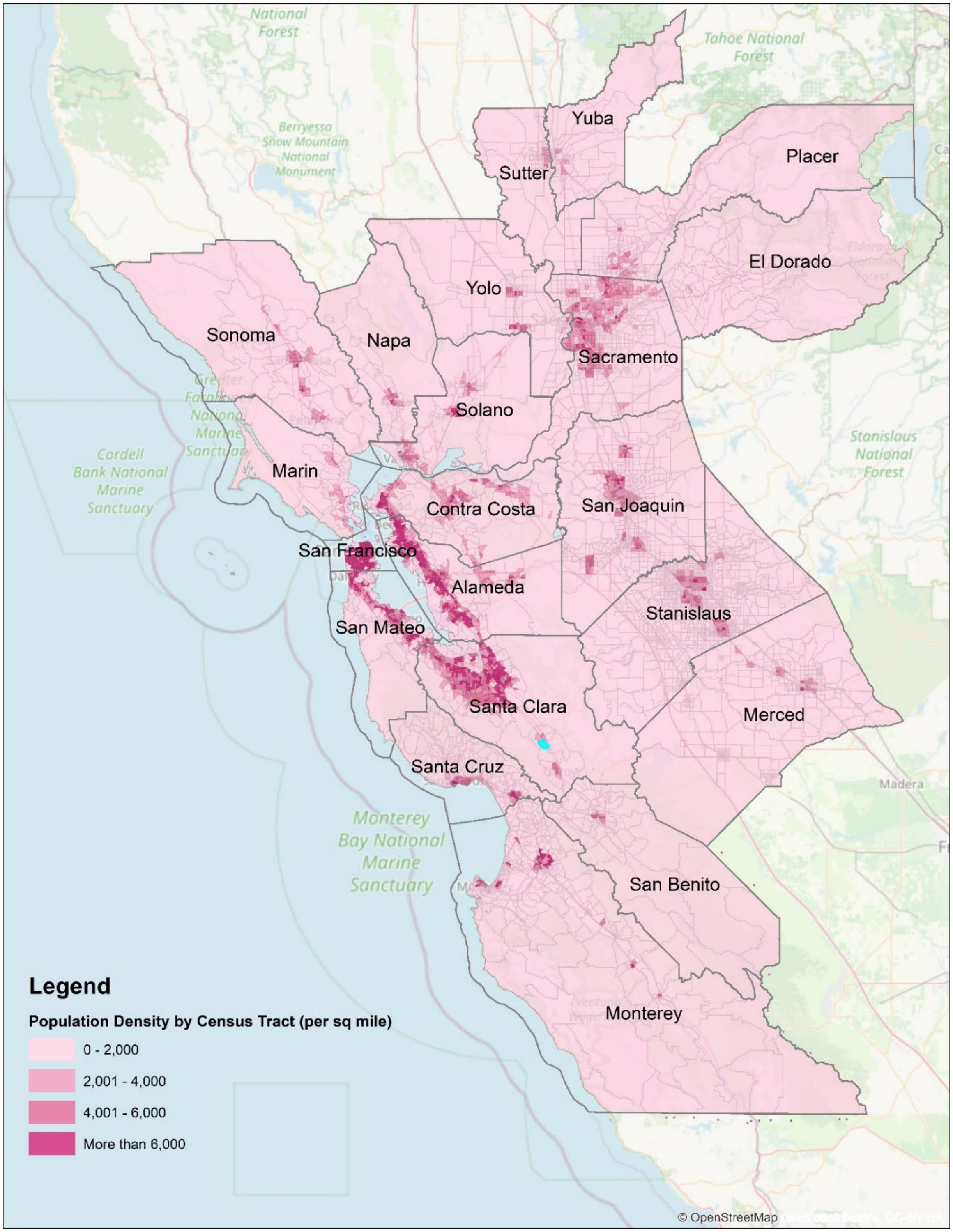


Figure 2.1 Population Density by Census Tract (Source: Created by the authors, using data from American Community Survey 2015-2019)

2.2 Current and future travel demand

Understanding the current and future travel demand patterns on the major transportation corridors in the megaregion is a challenging task. To date, no travel demand model exists that is specifically designed to forecast travel demand in the entire megaregion, let alone create reliable forecasts for public transportation ridership (and the related impacts on car travel and road congestion) associated with major rail infrastructure upgrades planned for the region, including the proposed rail infrastructure investments from the Link21 program.

Figure 2.2 highlights the forecasts for daily total traffic volume (measured in daily vehicle trips) on the major highway corridors in the region for year 2040 from the output of the California Statewide Travel Demand Model Version 3.0 (CSTDM V3.0), overlapped with the density of total trip generation (i.e., the number of daily person trips originated, per square mile) for year 2040 from the travel market analyses developed by Link21 consultants.[2] The figure highlights the high volume of forecasted traffic in the region. (Only freeways, expressways, and major arterials are reported in the figure, while minor arterials and local roads are omitted.)

The following group of figures highlights the similar forecasts for future travel demand during the different times of the day, respectively during: 1) the Off-peak time (3 AM to 6 AM and 7 PM to 3 AM) in Figure 2.3; 2) the AM peak (6 AM to 10 AM) in Figure 2.4; 3) the Midday (10 AM to 3 PM) in Figure 2.5; and 4) the PM peak (3 PM to 7 PM), in Figure 2.6.

---

[2] Link21 Program Management Consultants (2021) “NTRC strategic program plan: Trip table development methodology and validation memo.”

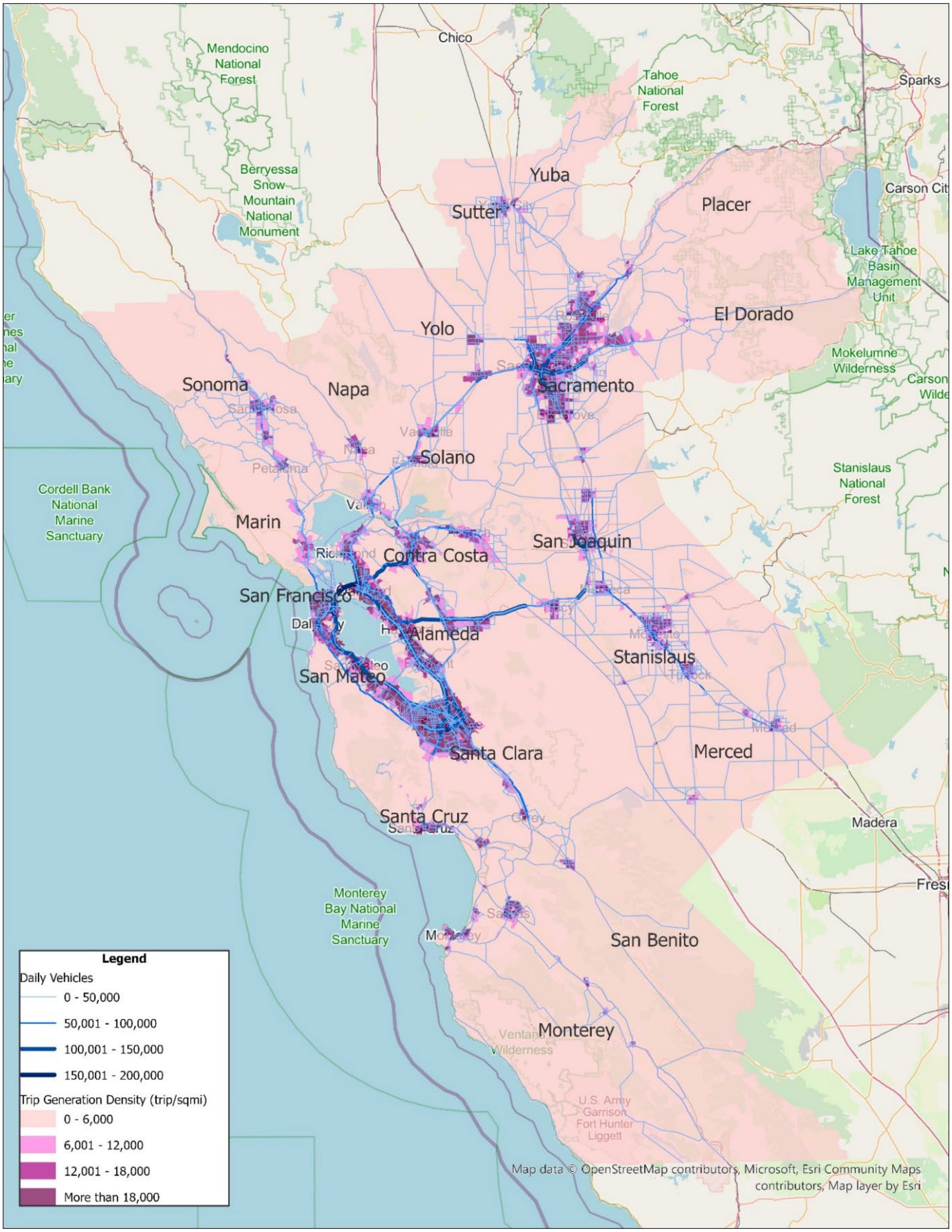


Figure 2.2 Daily volumes of vehicle travel on highway network and daily trip generation density forecasts for 2040

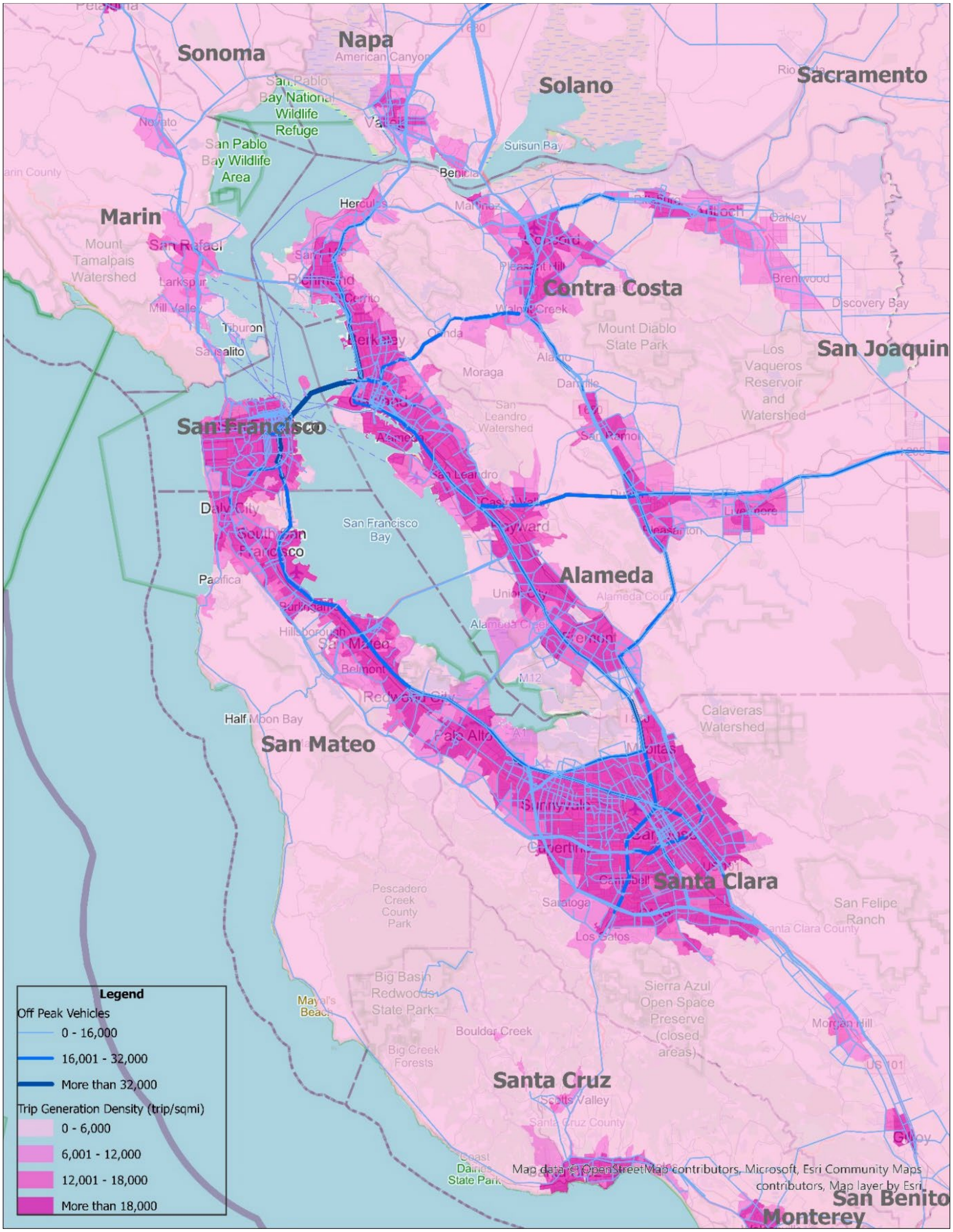


Figure 2.3. Off-peak volumes of vehicle travel on highway network and daily trip generation density forecasts for 2040 in the San Francisco Bay Area

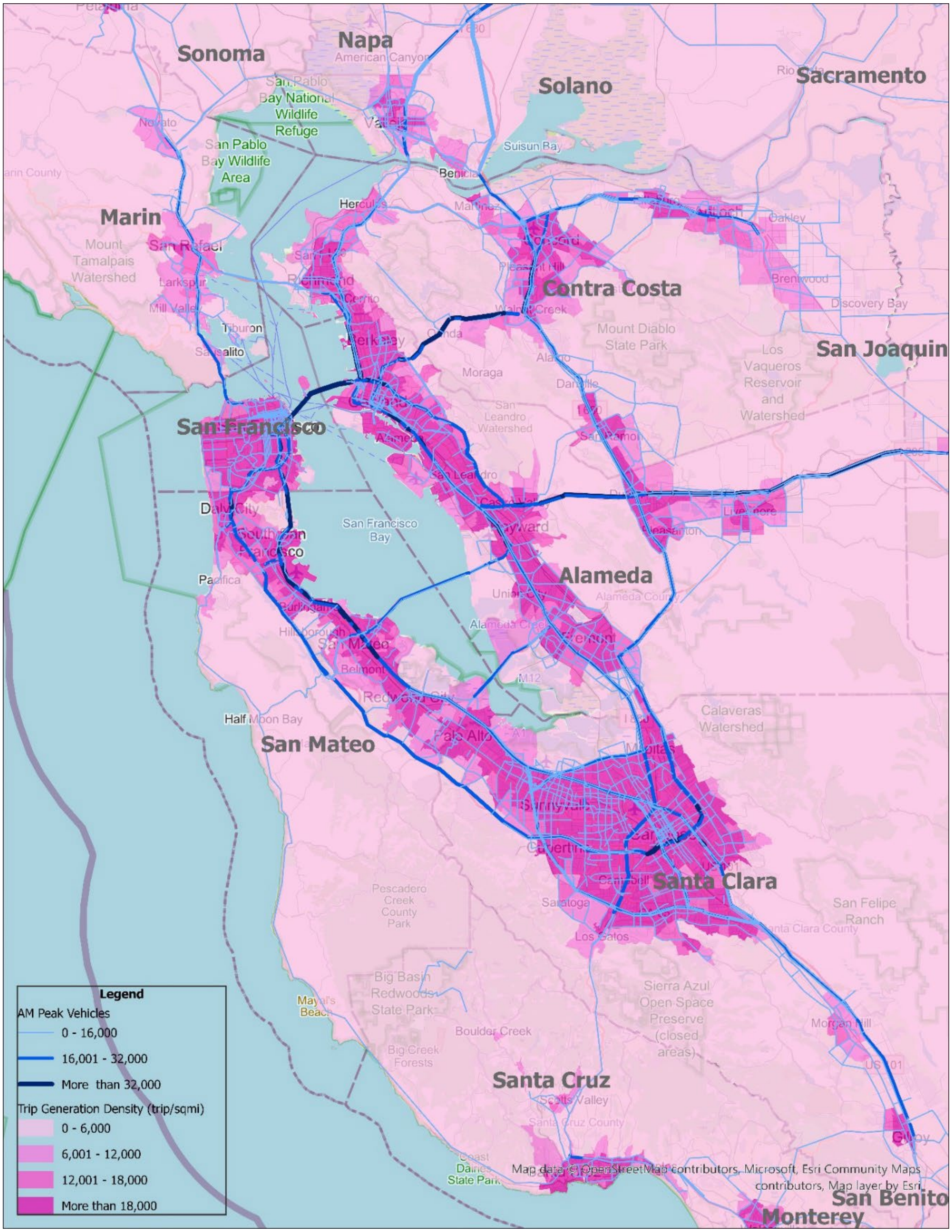


Figure 2.4 AM-peak volumes of vehicle travel on highway network and daily trip generation density forecasts for 2040 in the San Francisco Bay Area

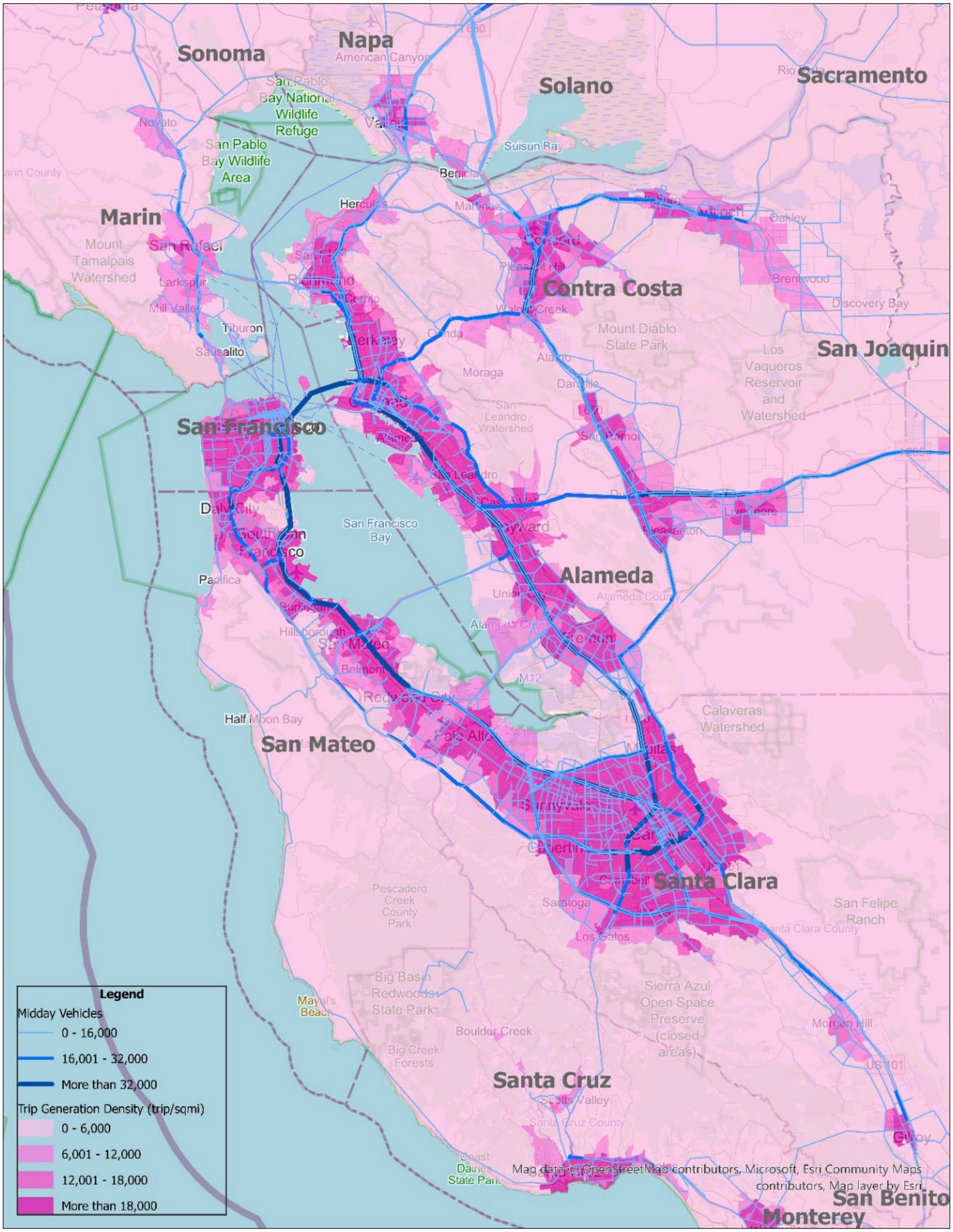


Figure 2.5 Midday volumes of vehicle travel on highway network and daily trip generation density forecasts for 2040 in the San Francisco Bay Area

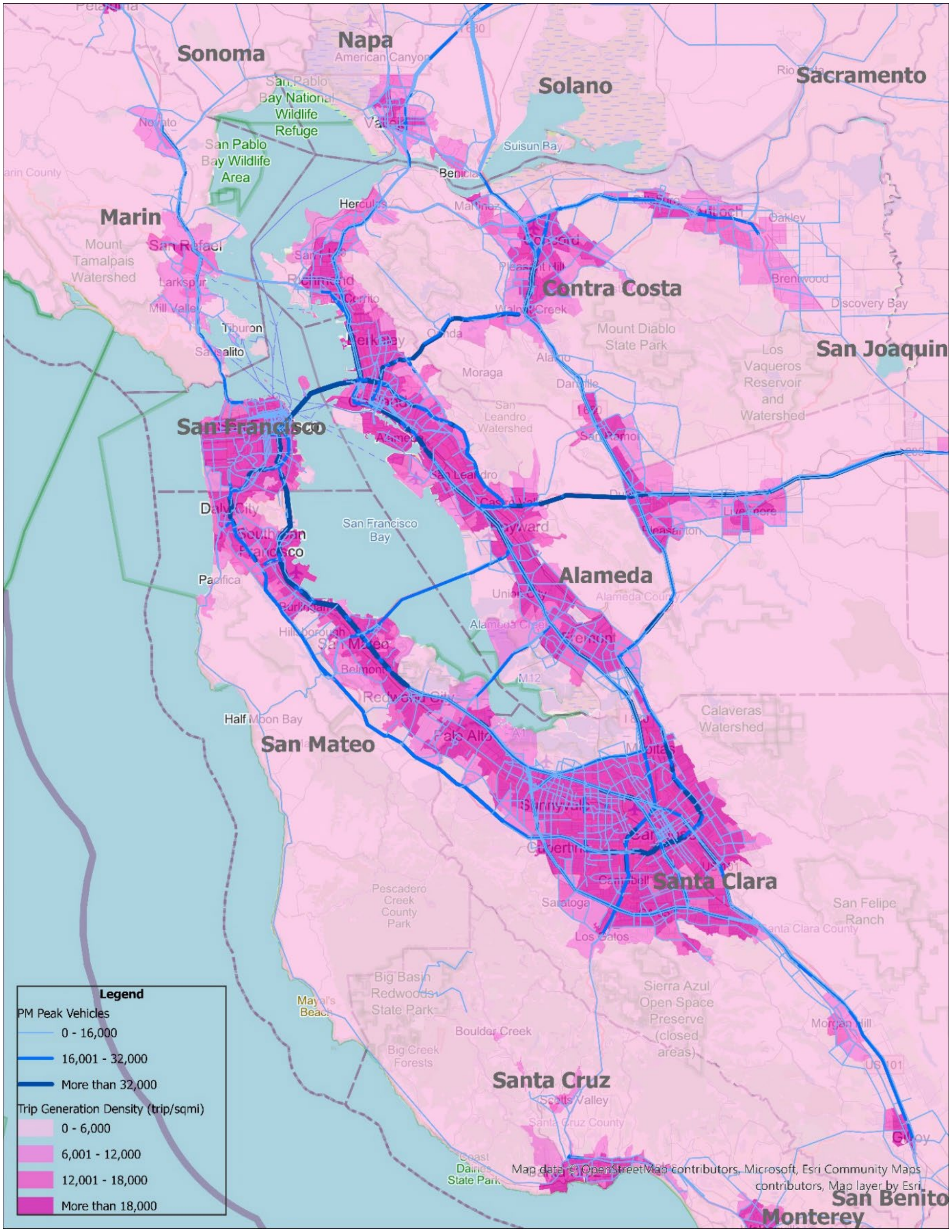


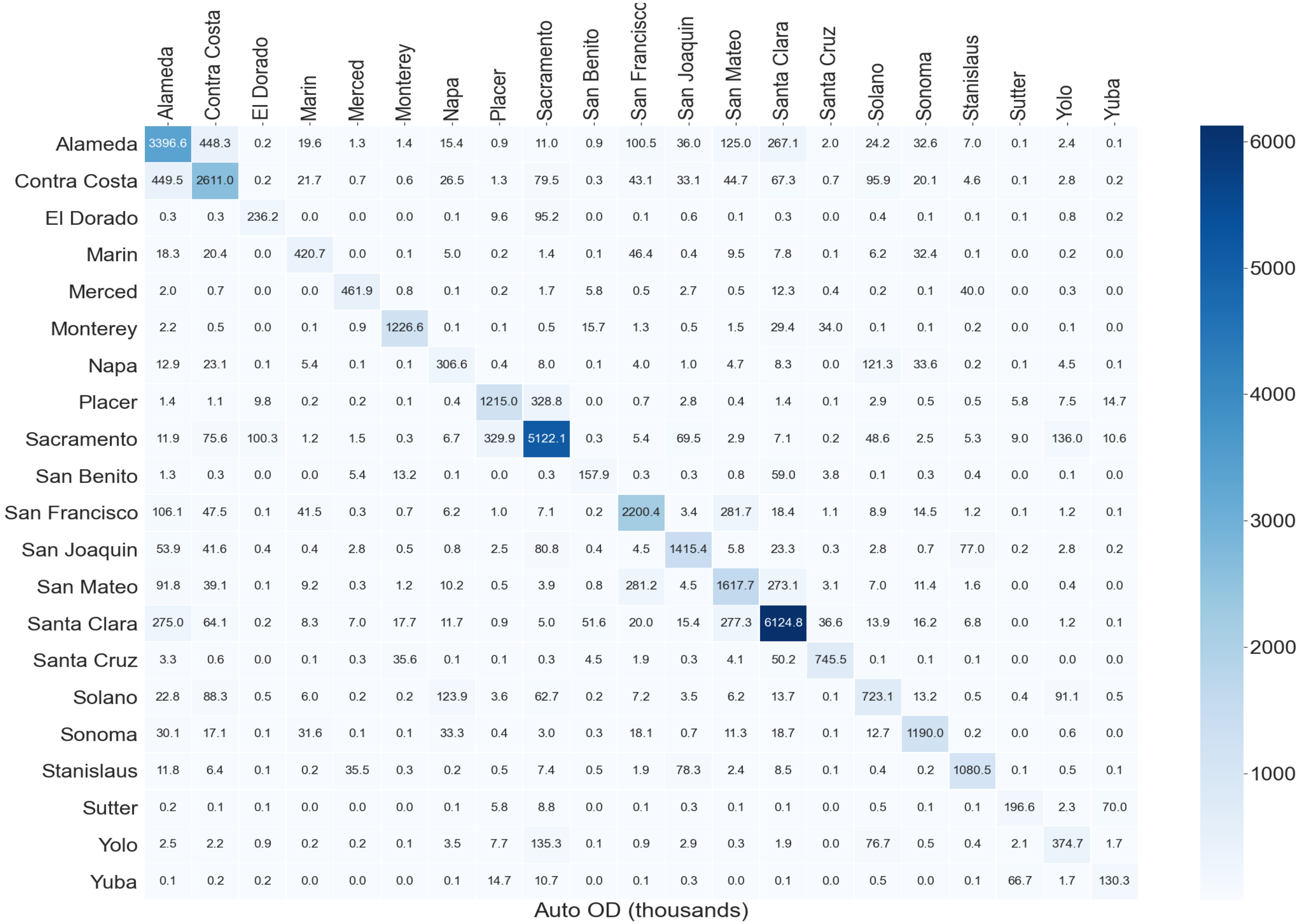
Figure 2.6 PM-peak volumes of vehicle travel on highway network and daily trip generation density forecasts for 2040 in the San Francisco Bay Area

The information contained in the Link21 travel market analysis focuses on internal travel within the 21-county region. Internal-external trips, having either the origin or destination outside of the megaregion, are not included in the statistics created using that source. Similarly, external-external trips, i.e., trips that cross the 21-county megaregion but do not have an origin or destination inside the megaregion, are not included. To better position (and evaluate) the proportion of travel demand that happens inside the megaregion vs. trips involving the megaregion but having at least one end outside of the boundaries of the 21-county region, we also analyzed forecasts available from the CSTDM, the official model maintained by the Caltrans, which includes all components of travel within California.

The CSTDM V3.0 is an activity-based travel demand model that forecasts all personal travel made by every California resident and all commercial vehicle travel for a typical weekday in fall/spring in a certain target year. Each forecasting year is coded as one specific scenario, and the required model input includes the scenario-specific files for the corresponding future target year. In the CSTDM framework, the entire state of California is divided into 5,454 transportation analysis zones (TAZs) for internal travel and 53 external zones to represent entry/exit points on the state boundaries. The CSTDM V3.0 model includes four main model components: 1) Short-distance passenger travel model (SDPTM); 2) Long-distance passenger travel model (LDPTM); 3) California statewide freight forecasting model (CSFFM); and 4) External travel model (ETM). The SDPTM component considers eight travel modes: 1) SOV (single-occupant auto); 2) HOV2 (high-occupant auto with two persons in the vehicle); 3) HOV3+ (high-occupant auto with three or more persons in the vehicle); 4) walk access local transit; 5) drive access local transit; 6) walk; 7) bicycle; and 8) school bus. The LDPTM component considers five travel modes: 1) SOV; 2) HOV2; 3) HOV 3+; 4) rail (conventional rail and future high-speed rail); and 5) air. The long-distance passenger model component only includes person trips longer or equal to 100 miles, while all trips shorter than 100 miles are handled by the short-distance passenger model component.

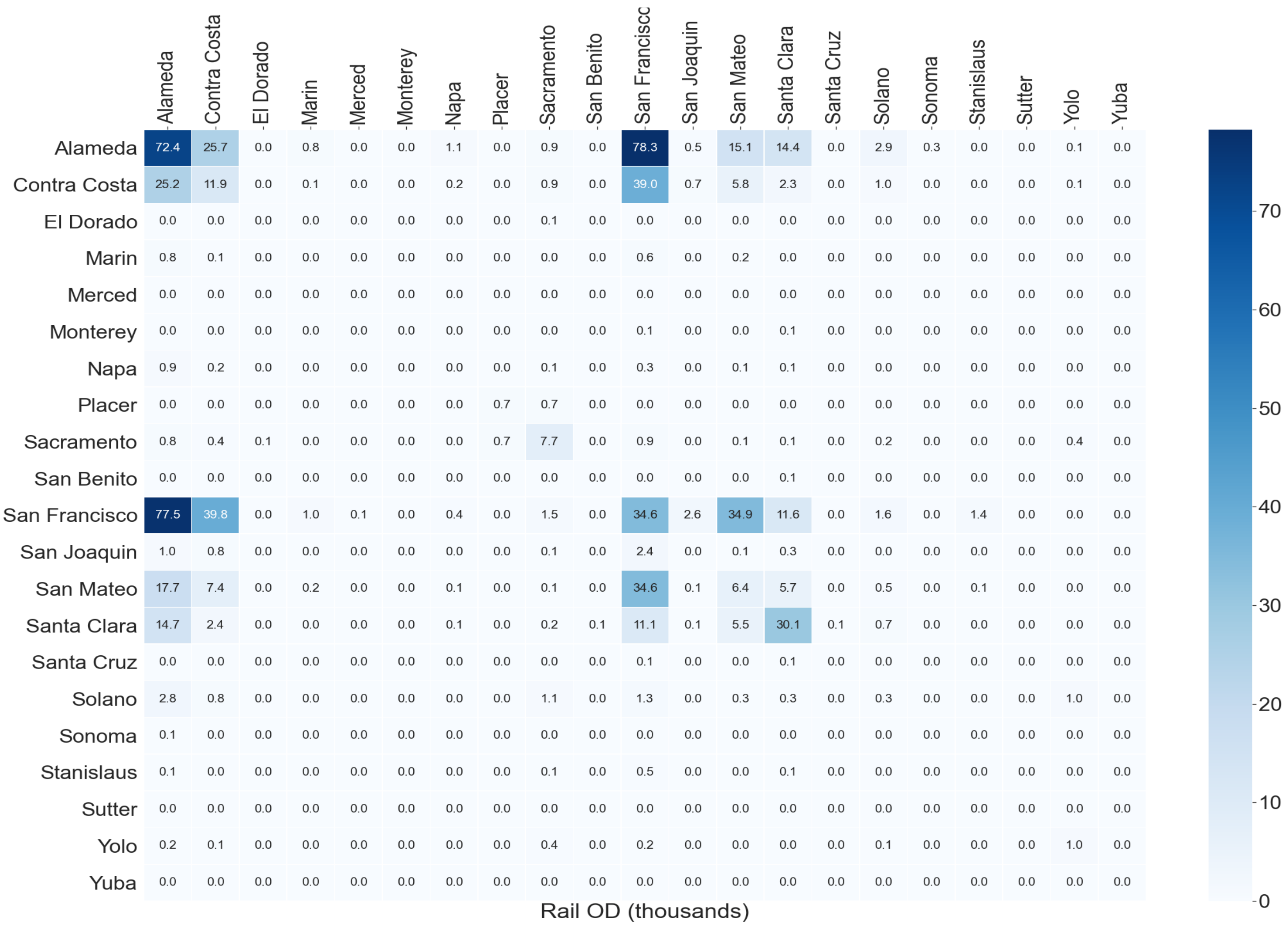
The Link21 travel market analysis highlighted how the vast majority of regional trips that are *relevant for the Link21 program* (i.e., not including local trips carried out by walking or bicycling, and trips to/from destinations that are further away from the proposed new infrastructure) are currently mainly carried out by car in the region. Mode shares for those trips across the entire 21-county megaregion in the year 2015 are 1) 95.0% for auto; 2) 1.4% for rail; and 3) 3.6% for non-rail transit. The daily trips for these three modes, when combined, total more than 32 million. For the forecasting year 2040, the mode shares are expected to vary only slightly from 2015 (if no major upgrades are made to rail infrastructure), with forecasts for modes shares of 1) 94.1% for auto; 2) 1.7% for rail; and 3) 4.3% for non-rail transit, with a total exceeding 41 million trips per day. This will cause extremely high pressure on the transportation infrastructure in the region, and likely exacerbate congestion problems and inefficiencies in transportation.

The following figures summarize the county-level origin-destination (OD) forecasts, by mode, from the Link21 travel market analysis for 2040. These figures provide a high-level overview of the trip distribution in the megaregion for different travel modes. The county-level OD flows for auto, rail, and non-rail transit (NRT) are shown in Figure 2.7, Figure 2.8, and Figure 2.9, respectively. Six counties are likely to be heavily affected by the proposed Link21 Transbay crossing project (Alameda, Contra Costa, Santa Clara, San Francisco, San Mateo, and Solano), though the impacts of the new infrastructure would likely be observed on travel demand for numerous other corridors in the megaregion. These counties are responsible for very heavy travel demand volumes. Also, for these flows, the auto mode dominates the trip mode share. Rail and non-rail transit modes contribute to less than 5% of the total trips within the 21-county region.



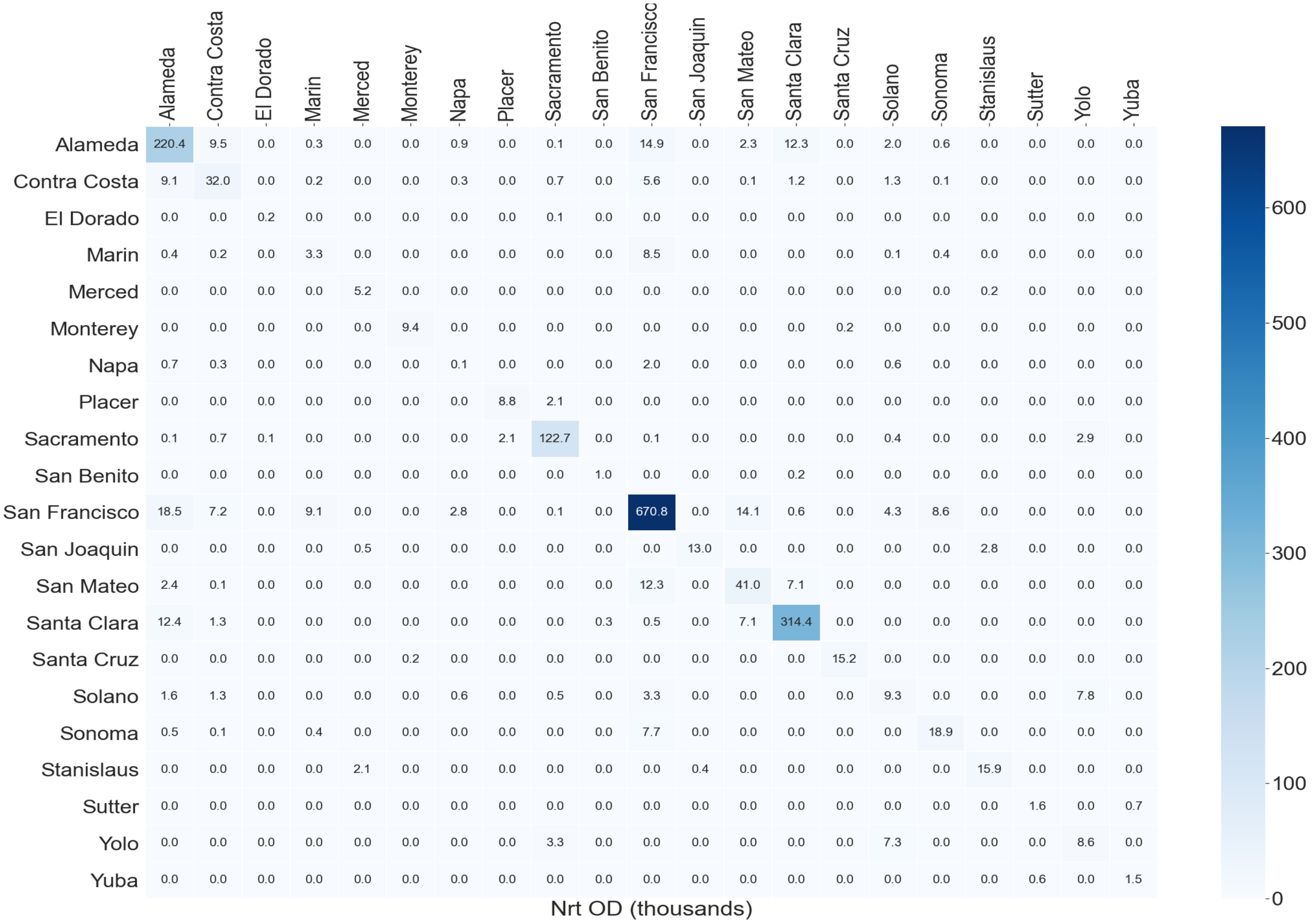
	Alameda	Contra Costa	El Dorado	Marin	Merced	Monterey	Napa	Placer	Sacramento	San Benito	San Francisco	San Joaquin	San Mateo	Santa Clara	Santa Cruz	Solano	Sonoma	Stanislaus	Sutter	Yolo	Yuba
Alameda	3396.6	448.3	0.2	19.6	1.3	1.4	15.4	0.9	11.0	0.9	100.5	36.0	125.0	267.1	2.0	24.2	32.6	7.0	0.1	2.4	0.1
Contra Costa	449.5	2611.0	0.2	21.7	0.7	0.6	26.5	1.3	79.5	0.3	43.1	33.1	44.7	67.3	0.7	95.9	20.1	4.6	0.1	2.8	0.2
El Dorado	0.3	0.3	236.2	0.0	0.0	0.0	0.1	9.6	95.2	0.0	0.1	0.6	0.1	0.3	0.0	0.4	0.1	0.1	0.1	0.8	0.2
Marin	18.3	20.4	0.0	420.7	0.0	0.1	5.0	0.2	1.4	0.1	46.4	0.4	9.5	7.8	0.1	6.2	32.4	0.1	0.0	0.2	0.0
Merced	2.0	0.7	0.0	0.0	461.9	0.8	0.1	0.2	1.7	5.8	0.5	2.7	0.5	12.3	0.4	0.2	0.1	40.0	0.0	0.3	0.0
Monterey	2.2	0.5	0.0	0.1	0.9	1226.6	0.1	0.1	0.5	15.7	1.3	0.5	1.5	29.4	34.0	0.1	0.1	0.2	0.0	0.1	0.0
Napa	12.9	23.1	0.1	5.4	0.1	0.1	306.6	0.4	8.0	0.1	4.0	1.0	4.7	8.3	0.0	121.3	33.6	0.2	0.1	4.5	0.1
Placer	1.4	1.1	9.8	0.2	0.2	0.1	0.4	1215.0	328.8	0.0	0.7	2.8	0.4	1.4	0.1	2.9	0.5	0.5	5.8	7.5	14.7
Sacramento	11.9	75.6	100.3	1.2	1.5	0.3	6.7	329.9	5122.1	0.3	5.4	69.5	2.9	7.1	0.2	48.6	2.5	5.3	9.0	136.0	10.6
San Benito	1.3	0.3	0.0	0.0	5.4	13.2	0.1	0.0	0.3	157.9	0.3	0.3	0.8	59.0	3.8	0.1	0.3	0.4	0.0	0.1	0.0
San Francisco	106.1	47.5	0.1	41.5	0.3	0.7	6.2	1.0	7.1	0.2	2200.4	3.4	281.7	18.4	1.1	8.9	14.5	1.2	0.1	1.2	0.1
San Joaquin	53.9	41.6	0.4	0.4	2.8	0.5	0.8	2.5	80.8	0.4	4.5	1415.4	5.8	23.3	0.3	2.8	0.7	77.0	0.2	2.8	0.2
San Mateo	91.8	39.1	0.1	9.2	0.3	1.2	10.2	0.5	3.9	0.8	281.2	4.5	1617.7	273.1	3.1	7.0	11.4	1.6	0.0	0.4	0.0
Santa Clara	275.0	64.1	0.2	8.3	7.0	17.7	11.7	0.9	5.0	51.6	20.0	15.4	277.3	6124.8	36.6	13.9	16.2	6.8	0.0	1.2	0.1
Santa Cruz	3.3	0.6	0.0	0.1	0.3	35.6	0.1	0.1	0.3	4.5	1.9	0.3	4.1	50.2	745.5	0.1	0.1	0.1	0.0	0.0	0.0
Solano	22.8	88.3	0.5	6.0	0.2	0.2	123.9	3.6	62.7	0.2	7.2	3.5	6.2	13.7	0.1	723.1	13.2	0.5	0.4	91.1	0.5
Sonoma	30.1	17.1	0.1	31.6	0.1	0.1	33.3	0.4	3.0	0.3	18.1	0.7	11.3	18.7	0.1	12.7	1190.0	0.2	0.0	0.6	0.0
Stanislaus	11.8	6.4	0.1	0.2	35.5	0.3	0.2	0.5	7.4	0.5	1.9	78.3	2.4	8.5	0.1	0.4	0.2	1080.5	0.1	0.5	0.1
Sutter	0.2	0.1	0.1	0.0	0.0	0.0	0.1	5.8	8.8	0.0	0.1	0.3	0.1	0.1	0.0	0.5	0.1	0.1	196.6	2.3	70.0
Yolo	2.5	2.2	0.9	0.2	0.2	0.1	3.5	7.7	135.3	0.1	0.9	2.9	0.3	1.9	0.0	76.7	0.5	0.4	2.1	374.7	1.7
Yuba	0.1	0.2	0.2	0.0	0.0	0.0	0.1	14.7	10.7	0.0	0.1	0.3	0.0	0.1	0.0	0.5	0.0	0.1	66.7	1.7	130.3

Figure 2.7 Forecasts for 2040 County-level Auto OD Flows in the Link21 Travel Market Analysis



	Alameda	Contra Costa	El Dorado	Marin	Merced	Monterey	Napa	Placer	Sacramento	San Benito	San Franciscc	San Joaquin	San Mateo	Santa Clara	Santa Cruz	Solano	Sonoma	Stanislaus	Sutter	Yolo	Yuba
Alameda	72.4	25.7	0.0	0.8	0.0	0.0	1.1	0.0	0.9	0.0	78.3	0.5	15.1	14.4	0.0	2.9	0.3	0.0	0.0	0.1	0.0
Contra Costa	25.2	11.9	0.0	0.1	0.0	0.0	0.2	0.0	0.9	0.0	39.0	0.7	5.8	2.3	0.0	1.0	0.0	0.0	0.0	0.1	0.0
El Dorado	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marin	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Merced	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monterey	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Napa	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Placer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sacramento	0.8	0.4	0.1	0.0	0.0	0.0	0.0	0.7	7.7	0.0	0.9	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.4	0.0
San Benito	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
San Francisco	77.5	39.8	0.0	1.0	0.1	0.0	0.4	0.0	1.5	0.0	34.6	2.6	34.9	11.6	0.0	1.6	0.0	1.4	0.0	0.0	0.0
San Joaquin	1.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	2.4	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
San Mateo	17.7	7.4	0.0	0.2	0.0	0.0	0.1	0.0	0.1	0.0	34.6	0.1	6.4	5.7	0.0	0.5	0.0	0.1	0.0	0.0	0.0
Santa Clara	14.7	2.4	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.1	11.1	0.1	5.5	30.1	0.1	0.7	0.0	0.0	0.0	0.0	0.0
Santa Cruz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solano	2.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	1.3	0.0	0.3	0.3	0.0	0.3	0.0	0.0	0.0	1.0	0.0
Sonoma	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stanislaus	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sutter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yolo	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.0	0.0
Yuba	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 2.8 Forecasts for the 2040 County-level Rail OD Flows in the Link21 Travel Market Analysis



	Alameda	Contra Costa	El Dorado	Marin	Merced	Monterey	Napa	Placer	Sacramento	San Benito	San Franciscc	San Joaquin	San Mateo	Santa Clara	Santa Cruz	Solano	Sonoma	Stanislaus	Sutter	Yolo	Yuba
Alameda	220.4	9.5	0.0	0.3	0.0	0.0	0.9	0.0	0.1	0.0	14.9	0.0	2.3	12.3	0.0	2.0	0.6	0.0	0.0	0.0	0.0
Contra Costa	9.1	32.0	0.0	0.2	0.0	0.0	0.3	0.0	0.7	0.0	5.6	0.0	0.1	1.2	0.0	1.3	0.1	0.0	0.0	0.0	0.0
El Dorado	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marin	0.4	0.2	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0
Merced	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Monterey	0.0	0.0	0.0	0.0	0.0	9.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Napa	0.7	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
Placer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sacramento	0.1	0.7	0.1	0.0	0.0	0.0	0.0	2.1	122.7	0.0	0.1	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	2.9	0.0
San Benito	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
San Francisco	18.5	7.2	0.0	9.1	0.0	0.0	2.8	0.0	0.1	0.0	670.8	0.0	14.1	0.6	0.0	4.3	8.6	0.0	0.0	0.0	0.0
San Joaquin	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0
San Mateo	2.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.3	0.0	41.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Santa Clara	12.4	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5	0.0	7.1	314.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Santa Cruz	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.2	0.0	0.0	0.0	0.0	0.0	0.0
Solano	1.6	1.3	0.0	0.0	0.0	0.0	0.6	0.0	0.5	0.0	3.3	0.0	0.0	0.0	0.0	9.3	0.0	0.0	0.0	7.8	0.0
Sonoma	0.5	0.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0	0.0	0.0	0.0	18.9	0.0	0.0	0.0	0.0
Stanislaus	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	15.9	0.0	0.0	0.0
Sutter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.7
Yolo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.0	0.0	0.0	8.6	0.0
Yuba	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	1.5

Figure 2.9 Forecasts for 2040 Non-rail Transit (NRT) OD Flows in the Link21 Travel Market Analysis

Major trip generation and attraction locations include the Alameda, Sacramento, San Francisco, and Santa Clara counties, with Alameda, Sacramento and Santa Clara having relatively large shares of auto trips for both intra-county trips and trips having the origin or destination in one of these counties. San Francisco, as a major transportation hub, generates and attracts a high volume of rail and NRT trips. A few counties, including El Dorado, San Benito, Sutter, and Yuba generate relatively small trip volumes. Important existing rail flows are observed on the intra-county OD pairs for Alameda–San Francisco, Contra Costa–San Francisco, and San Francisco–San Mateo.

As mentioned before, for this project, we also extract passenger travel information, including data for both short- and long-distance trips from CSTDM, to provide insights on the large-scale travel patterns in the Link21 megaregion, including information on trips that might extend beyond its boundaries. Note that in CSTDM all trips shorter than 100 miles using public transit, whether by bus or rail, are modeled as the public transit mode. This definition of public transit mode in the CSTDM differs from that used in the Link21 travel market analysis. These different travel mode definitions, together with the focus of the travel market analysis only on trips inside the Link21 region that are relevant for the Link21 program, make it difficult to directly compare the origin-destination (OD) flows (defined as aggregated travel flow, measured in number of trips by mode, from one origin county to one destination county) between the CSTDM forecasts and the travel market analysis. Still, the two sources are largely consistent in their output, and highlight similar travel patterns in the region.

When analyzing the travel forecasts available from the CSTDM, the OD flows within the 21-county region can be extracted from the statewide travel forecasts in the model. In the 2040 forecast year, the total number of trips with both origins and destinations in the Link21 megaregion exceeds 62.9 million for all passenger modes for both short-distance and long-distance travel. Total trips for auto, bus, and rail modes are forecasted to exceed 57.2 million, considerably growing from 46.5 million in 2020. In 2040, the model forecasts that the auto mode will account for approximately 95.5% of these trips, with approximately 4.5% of trips made by all transit modes combined. These mode shares are only slightly different from the 95.8% for auto and 4.2% for transit in 2020. The total number of trips in the CSTDM forecasts are larger, and the mode shares slightly different, than the trip data in the travel market analysis, due to the inclusion of local trips made on very short distances (“intra-zonal trips”) that might be less relevant for the purposes of the Link21 program. This tends to produce larger number of short auto trips, i.e., trips whose origins and destinations are close, and a resulting slightly higher mode share for private cars. This is verified using the relative difference in the county-level OD tables from the CSTDM and the travel market analysis in 2040, where the larger differences are observed along the diagonal elements of the OD matrix (short-distance trips with origin and destination in the same county), representing local trips inside a county.

Next, we compare the distribution of trips in the various sub-regions inside the Link21 megaregion, using the data contained in the Link21 market analysis. Table 2.2 and Table 2.3 highlight the relative proportion of trips that are contained inside the nine-county Bay Area used in the MTC region vs. the rest of the trips in the Link21 megaregion.

Table 2.2 Trip distribution by subregion in the Link21 Travel Market Analysis for 2040 (in thousand trips)

	Auto	Rail	Non-Rail Transit	Total
Internal trips in the MTC nine counties (internal-internal)	23,140	644	1,508	25,293
Trips in Link21 megaregion with one end in the MTC nine counties (internal-external)	1,154	22	19	1,194
Trips in Link21 megaregion with both ends outside the MTC nine counties (external-external)	14,296	12	222	14,530
Total (internal to Link21 megaregion)	38,590	678	1,749	41,017

The nine counties in the MTC region are Alameda, Contra Costa, Marin, Napa, San Mateo, Santa Clara, Solano, Sonoma, and San Francisco. We distinguish among internal-internal trips (having both origin and destination in the nine-county MTC region), internal-external trips (having either the origin or the destination in the nine-county MTC region, and both trip ends inside the Link21 megaregion) and external-external trips (having neither origin nor destination in the nine-county MTC region, but having both trip ends inside the Link21 megaregion). Note that this comparison is restricted to the trips that are fully contained within the Link21 megaregion, meaning that any trips that involve travel to/from outside of the Link21 megaregion are ignored.

Table 2.3 Proportion of trips by subregion in the Link21 Travel Market Analysis for 2040 (in thousand trips)

	Auto	Rail	Non-Rail Transit	Total
Internal trips in the MTC nine counties (internal-internal)	60.0%	95.0%	86.2%	61.7%
Trips in Link21 megaregion with one end in the MTC nine counties (internal-external)	3.0%	3.2%	1.1%	2.9%
Trips in Link21 megaregion with both ends outside the MTC nine counties (external-external)	37.0%	1.8%	12.7%	35.4%
Total (internal to Link21 megaregion)	100.0%	100.0%	100.0%	100.0%

As shown in these tables, the nine counties in the MTC region account for the majority of travel within the Link21 megaregion. For all modes combined, the trips that are entirely contained inside the MTC region represent approximately 61.7% (~25.3 million) of the total number of trips inside the Link21 megaregion (~41.0 million). This share increases to 64.6% (totaling 26.4 million) when internal-external trips that have only one trip end in the 9-county MTC region are added. For the auto mode, the 9-county region (internal-internal plus internal-external trips) accounts for approximately 63.0% (~24.3 million) of the trips in the Link21 megaregion. And when focusing on trips that are carried out with rail and non-rail transit (NRT) modes, the proportion of trips that are internal (i.e., internal-internal) to the MTC region is even higher (95.0% of total rail trips, and 86.2% for non-rail transit).

It is important to note that while there is a sizable volume of trips (in particular, auto trips) in the Link21 megaregion that do not involve the MTC region (e.g., trips that are completely internal to the Sacramento region would fit in this category), daily auto trips to/from the nine Bay Area counties in the MTC region that have origins or destinations in other parts of the megaregion account for only approximately 3.0% of the trips in the megaregion. Still, with approximately 1.2 million daily trips, they represent a sizable volume of travel that relies on the road network and the auto mode, and contributes to traffic congestion, especially on the major interregional corridors and freeways that give access to the MTC region. Further, due to their longer average distances, these trips account for a larger percentage of vehicle miles traveled in the megaregion than their share of trips would suggest, and they could be the target for mode shift if sufficient improvements in the commuter rail network were introduced in the region in conjunction with the Link21 program.

To assess the proportion of trips that extend beyond the boundaries of the Link21 megaregion and that might be of interest for the Link21 planning purposes, we analyze the proportion of trips completely internal to the Link21 megaregion (i.e., with both trip ends inside the megaregion) and compare them to the total number of trips made statewide, focusing on both auto and public-transportation modes of interest (i.e., local public transit, long-distance conventional rail, and high-speed rail, or HSR). For this analysis, we use the trip table forecasts for 2040 from the CSTDM, the only source of information available for this statewide analysis. The results are classified as 1) internal-internal trips (i.e., having both origin and destination inside the 21-county megaregion); 2) internal-external trips (i.e., having only one trip end in the 21-county megaregion, and having both origin and destination within California), 3) external-external (i.e., trips having both trips ends outside of the 21-county megaregion, but entirely inside California), and 4) total trips inside California, as shown in Table 2.4 and Table 2.5.

Table 2.4 Trip comparison from CSTDM in 2040 (in thousand trips)

	Auto	Total Public Transportation	Total
Link21 megaregion (internal-internal)	54,701	2,582	57,283
Link21 megaregion (internal-external, within California)	494	53	547
In California, outside of Link21 megaregion	112,343	3,441	115,784
Total in California	167,538	6,076	173,614

Table 2.5 Proportion of trips by subregion from CSTDM in 2040

	Auto	Total Public Transportation	Total
Link21 megaregion (internal-internal)	32.6%	42.5%	33.0%
Link21 megaregion (internal-external, within California)	0.3%	0.9%	0.3%
In California, outside of Link21 megaregion	67.1%	56.6%	66.7%
Total in California	100.0%	100.0%	100.0%

Considering the internal-internal trips made by either car or public transportation, the 21-county megaregion accounts for 33.0% (~57.3 million trips) of the total number of daily trips (~173.6 million) forecasted in 2040 in California. This proportion becomes 33.3% (for a total of 57.8 million trips), when internal-external trips are added to the intraregional flows. When separating trips for different travel modes, auto trips in the 21-county region (internal-internal plus internal-external) account for 32.9% (~55.2 million) of all auto trips in California (~167.5 million).

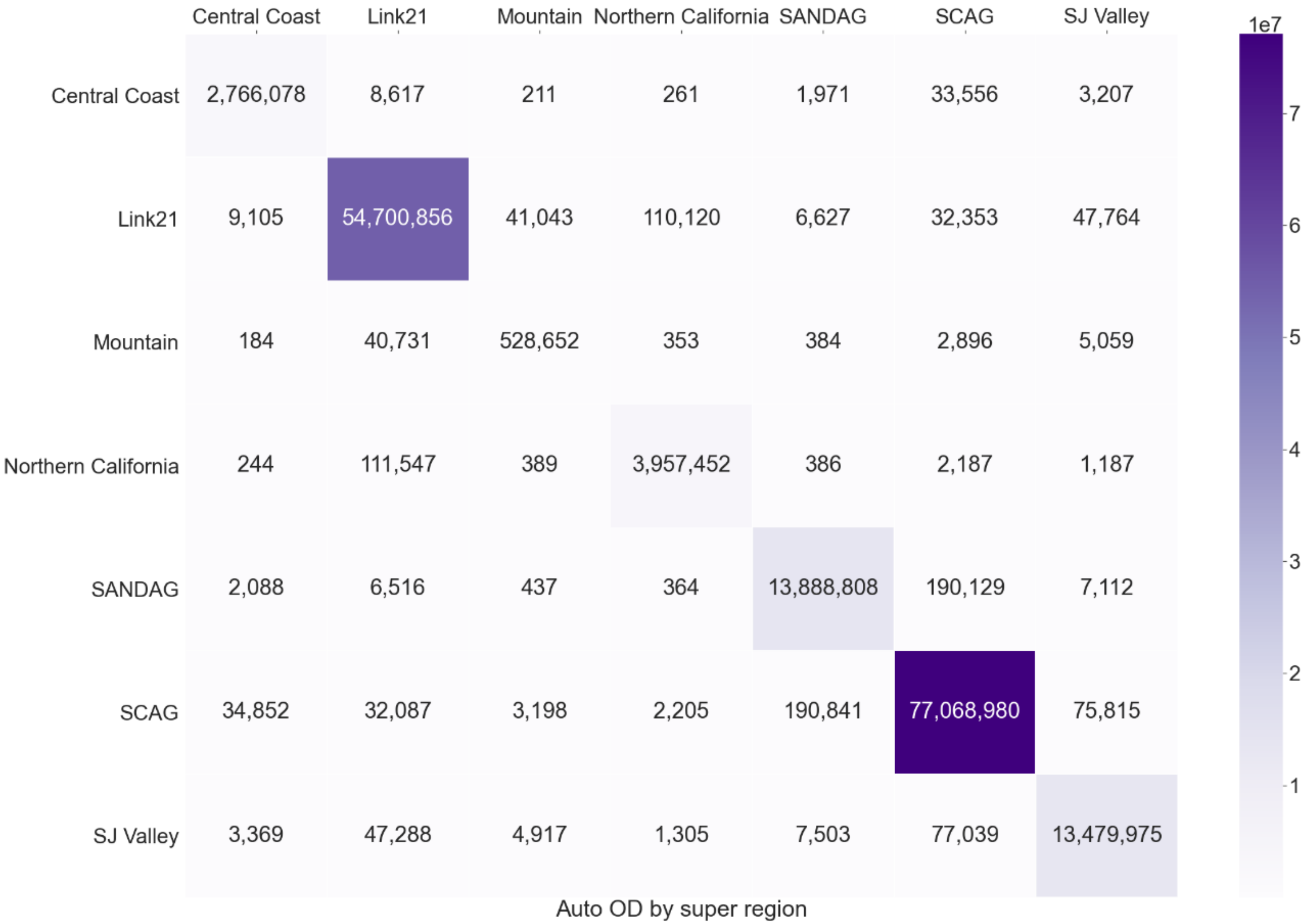
For the public transportation modes, the 21-county megaregion accounts for 43.4% (~2.6 million) of all transit trips in California (~6.1 million), highlighting the higher prevalence of transit in the megaregion, compared to other regions of California. Even if only accounting for a small percentage of total trips in the state, trips having the origin or destination in the Link21 megaregion and the other trip end in another region of California account for more than 500,000 daily trips, most of which are currently forecasted to be carried out by car in 2040. While not all these trips might involve the use of the proposed new Link21 rail infrastructure, this component of long-distance travel represents an important market for potential improved long-distance rail services, many of which have the San Francisco Bay Area as the trip origin or destination. Unfortunately, this long-distance component of travel typically cannot be studied with the application of current regional travel demand models. The inclusion of a true long-distance component in the Link21 travel demand forecasting model system would allow studying the responsiveness of travelers to the availability of new rail services in the region when making long-distance trips. Still, as long-distance trips spanning beyond the boundaries of the Link21 megaregion account for only a small percentage of trips and are outnumbered by local trips inside the megaregion (in a ratio of approximately 1 to 100 trips), it seems reasonable that only limited resources should be dedicated to explicitly modeling this long-distance component of travel.

To better classify the forecasted trips, in particular those having one trip end inside the Link21 megaregion, we further divided the state of California into seven major super regions, as shown in Table 2.6 and Figure 2.10. The breakdown of the 2040 CSTDM forecasts by super region, for auto mode and public transportation modes, is presented in Figure 2.11 and Figure 2.12, respectively. Among all super regions, the Link21 megaregion and the Southern California Association of Governments (SCAG, which includes the greater Los Angeles region) are by far the two largest trip generators and/or attractors in California.

Table 2.6 Aggregation of California counties by super region

Super Region	Counties
Central Coast	San Luis Obispo, Santa Barbara
Link21 megaregion	Alameda, Contra Costa, El Dorado, Marin, Merced, Monterey, Napa, Placer, Sacramento, San Benito, San Francisco, San Joaquin, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Stanislaus, Sutter, Yolo, Yuba
Mountain	Alpine, Amador, Calaveras, Inyo, Mariposa, Mono, Tuolumne
Northern California	Butte, Colusa, Del Norte, Glenn, Humboldt, Lake, Lassen, Mendocino, Modoc, Nevada, Plumas, Shasta, Sierra, Siskiyou, Tehama, Trinity
San Diego Association of Governments (SANDAG)	San Diego
Southern California Association of Governments (SCAG)	Imperial, Los Angeles, Orange, Riverside, San Bernardino, Ventura
San Joaquin Valley	Fresno, Kern, Kings, Madera, Tulare

Figure 2.10 Boundaries of super regions in California



	Central Coast	Link21	Mountain	Northern California	SANDAG	SCAG	SJ Valley
Central Coast	2,766,078	8,617	211	261	1,971	33,556	3,207
Link21	9,105	54,700,856	41,043	110,120	6,627	32,353	47,764
Mountain	184	40,731	528,652	353	384	2,896	5,059
Northern California	244	111,547	389	3,957,452	386	2,187	1,187
SANDAG	2,088	6,516	437	364	13,888,808	190,129	7,112
SCAG	34,852	32,087	3,198	2,205	190,841	77,068,980	75,815
SJ Valley	3,369	47,288	4,917	1,305	7,503	77,039	13,479,975

Figure 2.11 Auto trips by super region from 2040 CSTDM forecasts

	Central Coast	Link21	Mountain	Northern California	SANDAG	SCAG	SJ Valley
Central Coast	49,949	182	0	1	43	354	35
Link21	159	2,585,646	105	170	2,714	19,758	3,770
Mountain	0	96	716	0	4	258	18
Northern California	0	174	0	28,025	0	411	47
SANDAG	32	2,867	2	1	406,971	4,358	495
SCAG	333	19,425	256	400	4,422	2,723,055	4,793
SJ Valley	39	3,571	39	50	462	5,068	206,121

Total transit OD by super region

Figure 2.12 Public transportation trips by super region from 2040 CSTDM forecasts

Some relatively important flows of trips to/from the Link21 megaregion involve the Northern California region and the southern portion of the San Joaquin Valley region (including the southern counties in the San Joaquin Valley not included in the Link21 region). Approximately 44.6% of the internal-to-external auto trips originated inside the Link21 megaregion (i.e., the second row in Figure 2.11) involve Northern California, 19.3% of the trips go to the San Joaquin valley, 16.6% of the trips to the mountain region, 13.1% of the trips to SCAG, and only the remaining 6.4% to the central coast of California or SANDAG. (The distribution of Link21 external-to-internal auto trips, i.e., the second column in the heatmap, are very similar.) However, the total number of these interregional trips are orders of magnitude smaller than the volume of internal trips in the Link21 megaregion.

The spatial distribution of total public transportation trips among the seven super regions is considerably different from that of auto trips. For the Link21 internal-to-external trips (the second row in Figure 2.12), an extraordinary 74.1% of forecasted public transportation trips is headed to the SCAG region, with an additional 14.1% to the San Joaquin valley, 10.2% to SANDAG, and only the remaining 1.6% to the central coast, mountain, and Northern California regions combined. (The opposite direction, i.e., Link21 external-to-internal, in the second column in Figure 2.12, shows similar patterns). Different from auto trips, most of these long-distance public transportation trips have an origin or destination in the heavily populated southern California region. This is largely due to the presence (and attractiveness) of the high-speed rail option in the 2040 CSTDM scenarios, a factor that highlights the potential for rail to attract mode shares for long-distance travel if appropriate investments in rail infrastructure are made, and an important topic that could also be affected, and should be considered, in the evaluation of the Link21 rail infrastructure investment plans.

3 Assessment of current modeling tools

Current modeling tools that are used by various administrations and that could be useful to support the development of the modeling framework for the Link 21 project include:

- California Statewide Travel Demand Model
- California High-Speed Rail Business Plan Model
- New Statewide Rail Model
- San Francisco Bay Area Metropolitan Transportation Commission (MTC) Travel Model
- Sacramento Activity-Based Travel Simulation Model
- (Northern San Joaquin Valley) Three-County Model
- San Francisco Travel Demand Forecasting Model
- Transit Boarding Estimation and Simulation Tool
- Simplified Trips-On-Project Software
- Regional Dynamic Model
- Conceptual Network Connections Tool

The diverse set of tools includes models at the statewide level (the first three models in the list), regional/MPO level (the next 4 models in the list), and those mainly used in transit ridership forecasting (the last 4 models).

This section of the report presents an overview of these models through bulleted model summaries that introduce their scope, main characteristics and features. The model descriptions included in this section mainly focus on the features of the models that are of greater potential interest for the Link21 program. Accordingly, the summary descriptions mainly focus on the passenger travel components of the various models and highlight the ability (or lack thereof) of the models to forecast travel for various modes of travel and model the choice among various public transportation options vs. other travel modes (and means) of travel. For models that also include other components, such as freight and/or commercial vehicle model components, these other model components are mentioned in the model description, but without full details on how these model components work.

In the later Section 5 of the report, we will return on the evaluation of these models with a more systematic discussion of the specific capabilities and sensitivities of these models with regard to the Link21 forecasting needs and required vs. desirable modeling features.

3.1 California Statewide Travel Demand Model Version 3.0 (CSTDM V3.0, or CSF2TDM)

Description: CSF2TDM is an activity-based travel demand forecasting model that forecasts all personal travel made by every California resident and all commercial vehicle travel in California for a typical weekday in fall/spring.
Latest Model Version: CSF2TDM is the newest version of the model (Version 3.0).
Level of Complexity: Rather high.
Modeling Area: Entire state of California (58 counties).
Software Environment: CUBE, Python, Java.
Level of Spatial Details: The entire state of California is divided into 5,454 transportation analysis zones (TAZs) for internal travel and 53 external zones to represent entry/exit points on the state boundary.
Period of Analysis: A typical weekday in fall/spring.
Time Periods: The model considers four time periods: 1) AM peak from 6 AM to 10 AM; 2) midday from 10 AM to 3 PM; 3) PM peak from 3 PM to 7 PM; 4) off-peak from 7 PM to midnight and from 12 AM to 6 AM.
Model Structure: CSF2TDM has four major demand model components:

1. A Short Distance Personal Travel Model (for short-distance intra-California trips, shorter than 100 miles) (SDPTM);
2. A Long-Distance Personal Travel Model (for long-distance intra-California trips, equal to or greater than 100 miles) (LDPTM);
3. A Freight Forecasting Model (for commercial trips) (CSFFM);
4. An External Vehicle Trip Model (ETM; for trips with the origin or destination outside California).

Modeling Sequence: (1) Run population synthesizer; (2) Create zonal properties and build networks; (3) SDPTM, LDPTM, CSFFM, ETM; (4) Traffic assignment and skims.
Main Travel Modes: SDTPM: 1) SOV, single-occupancy vehicle; 2) HOV2, high-occupancy auto with two persons in the vehicle; 3) HOV3+, high-occupancy auto with three or more persons in the vehicle; 4) walk-access local transit (bus, light rail, heavy rail); 5) drive-access local transit; 6) walk; 7) bicycle; 8) school bus. LDPTM: car, rail, and air**.**
Access/Egress Modes:

1. In SDPTM: Walk-access local transit (bus, light rail, heavy rail) and drive-access local transit.
2. In LDPTM:
   a) main mode choice model: choose the primary mode among car, rail, and air;
   b) access mode choice: if a non-car mode is chosen, the access mode to the station is assigned as one of five alternatives (drive and park/passenger/transit/taxi/walk);
   c) egress mode choice: if a non-car mode is chosen, the egress mode is assigned as one of five alternatives (rental car/passenger/transit/taxi/walk).

Mode Choice Modeling Method*:*
SDPTM is designed to follow the procedure:

1. Long term decision
2. Day patterns
3. Primary destination choice
4. Tour mode choice
5. Secondary destination
6. Trip mode

LDPTM is designed to follow the procedure:

1. Travel choice model (multinomial logit model)
2. Party formation model (base party size, primary traveler model, solo traveler model, and group size model)
3. Tour property model (including tour duration model, travel day status model, and time of travel model)
4. Destination choice model (five logit models for different trip purposes)
5. Mode choice model (including main mode choice models and access/egress mode choice models, based on CAHSRA high-speed rail model)

Nested logit models are designed for the mode choice components for different tour purposes.
Future Scenarios' Considerations:
The CSF2TDM is the upgraded version of the previous CSTDM Version 2.0 from 2014, prepared by Cambridge Systematics. The current base year is 2015 and forecasting years range from 2020 to 2050.
Input Models & Files:

- Network: The roadway networks represent all freeways, expressways, and most arterial roadways, while collector and local roads are mostly covered through zonal connector links from/to centroids (geometrical centers of transportation analysis zones); All rail transit lines are explicitly coded in the model; Bus services are only included through a simplified local transit synthesizer.
- Population: The characteristics of the population include household size, housing type, household income groups, age categories, auto ownership categories, employed workers by occupation category, and students by education level.
- Employment: Based on the employment synthesizer originally developed for CSTDM Version 2.0.

Output Files: The default outputs include trip tables, travel times and costs, common network performance measures, mode shares, and summary travel statistics.

3.2 California High-Speed Rail Business Plan Model (CHSR-BPM V3-2016)

Description: CHSR-BPM, developed by Cambridge Systematics, Inc., provides support to the California High-Speed Rail Authority. The model was designed to forecast ridership and revenue for different high-speed rail (HSR) service options. The model covers all internal long-distance travel (equal or greater than 50 miles) within California and short-distance travel (less than 50 miles) in the San Francisco Metropolitan Transportation Commission (MTC) and the Southern California Association of Government (SCAG) regions.
Latest Model Version: CHSR-BPM V3. The report was provided in 2016.
Level of Complexity: Medium.
Modeling Area: Entire state of California (58 counties).
Software Environment: CUBE.
Level of Spatial Details: A total of 4,683 TAZs are analyzed in the long-distance model, with 14 regions included.
Period of Analysis: A typical weekday in the fall/spring.
Time Periods: The long-distance time periods derived from CSTDM2.0. The model considers four time periods: 1) AM peak from 6 AM to 10 AM; 2) midday from 10 AM to 3 PM; 3) PM peak from 3 PM to 7 PM; 4) off-peak from 12 AM to 6 AM and from 7 PM to midnight.
Model Structure: CHSR includes two submodules: Long-Distance Model and Short-Distance Intraregional Models.
Modeling Sequence:
Long-distance model (equal to or greater than 50 miles):

1. Trip frequency generation: Trip frequency rate at the household level.
2. Destination choice (home-based trips only)
3. Access/Egress and Main Mode Choice

Short distance intraregional models (shorter than 50 miles, apply to MTC and SCAG only):

1. Derive static trip tables from MTC and SCAG.
2. Mode choice: follows the MTC Baycast model
3. Assignment

Main Travel Modes: Long-distance model: HSR, air, car, and conventional rail. Short-distance model: walk, bike, motorized. Motorized modes include drive alone, shared-ride 2, shared-ride 3+, and transit. Transit services include: local bus; express bus; light rail; bus rapid transit (BRT); ferry; and other transit (i.e., fixed guideway, “Transitway Bus,” for SCAG, none for MTC); urban rail (e.g., Bay Area Rapid Transit [BART], Metrorail); commuter rail (e.g., Caltrain, Altamont Corridor Express (ACE), Metrolink, Pacific Surfliner); and high-speed rail.
Access/Egress Modes: long-distance model: drive-park, rental car, serve passenger, taxi, public transit, and walk-access.
Mode Choice Modeling Method: The long-distance model estimates the choice of main mode and access/egress mode following a nested logit structure. The short-distance models derive static trip tables from the MPOs and use them in a nested logit mode choice model for person trips. The trips are estimated at the individual level.
Future Scenarios’ Considerations: CHSR-BPM forecasts highway networks based on the assumptions of the CSTDM Version 2.0. Auto operating costs are forecasted based on US EIA. Socioeconomic data are forecasted with four independent forecasting sources, namely, the California Economic Forecast, Moody Analytics, metropolitan planning organization (MPO) data, and California Department of Finance. The forecasting years include 2029, 2033, and 2040.
Input Models & Files:
Long-distance model inputs:

1. Socioeconomic data: socioeconomic data inputs in CHSR-BPM are based on a household level, including household characteristics (number of workers, household size, income group, number of vehicles), geographical characteristics (TAZs, county, region), and employment status (by sector). The base year for the household data is 2010.
2. Highway network inputs: The base Year 2010 Network was built for the BPM-V2 model. For future scenarios, Master Network file forecasts were built from 2010 to 2040. The 2010 and Master Networks are still being used in the BPM-V3 model.
3. Air operating plans and fares are based on Aviation System Consulting, LLC. This information is used for the air mode in the mode choice components.
4. Transit operating plan and fares are based on MPO modeling files (e.g., SCAG Year 2008 Model, MTC 2010 Model, CHSRA Model Version 1&2, SANDAG Transit Route File).
5. Parking Costs: auto parking costs for each TAZs are based on SCAG, MTC, and SACOG data. The airport parking costs are obtained from the official website of each airport.

Short distance intraregional model inputs: MTC and SCAG static trip tables.
Output Files: Mode splits and zone-to-zone trip tables by trip purpose, ridership (station to station trip tables), and revenue.

3.3 New Statewide Rail Model

Description: The project aims to develop a travel demand model for intercity travel (over 40–50 miles), focusing on intercity rail, high-speed rail, airline, etc. The model is funded by Caltrans and is currently under development. It is expected to cover the entire California (58 counties) with a four-step modeling approach. Model documents have not yet been officially published. Therefore, we communicated with the model development team to discuss the model structure, major features, mode choice considerations, etc.

Latest Model Version: Under development. The information in this section is based on conversations with the model development team.

Level of Complexity: Medium/low. Many details are still unknown because the model is under development, but it is expected to have a simplified modeling system that is optimized for faster run time.

Modeling Area: Entire state of California (58 counties).

Software Environment: EMME.

Level of Spatial Details: About 1200 TAZs.

Period of Analysis: Unknown (to date).

Time Periods: Unknown (to date).

Model Structure: Simplified 4-step model for long-distance travel. The model is intended to forecast demand for intercity rail. New services and infrastructure modifications are added with additional input files (e.g., line files).

Modeling Sequence: Expected to follow 4-step model routine.

Main Travel Modes: Auto, HSR, conventional rail, intercity bus (Megabus , FlixBus, Greyhound), air.

Access/Egress Modes: Express bus (explicit access/egress mode for main modes). For other access/egress modes, default parameters for access/egress time to centroid connectors.

Mode choice Modeling Methods: Incremental logit model.

Future Scenarios' Considerations: They are considering including a variety of intercity travel services, such as HSR, airline, but also intercity buses, etc.

Input Models & Files: Unknown (to date).

Output Files: Still unknown. It will likely include main mode splits and zone-to-zone trip tables by trip purposes, ridership (station-to-station trip tables), etc.

3.4 MTC Travel Model (TM 1.5)

Description: The San Francisco Metropolitan Transportation Commission (MTC) developed the Travel Model (TM) to simulate the travel demand of nine counties in the Bay Area metropolitan area. It is an activity-based model and assumes people make decisions at four distinct levels: long-term, daily, tour- and trip-level decisions. The mode choices are decided in the tour-level and trip-level decisions.

Latest Model Version: TM 1.5 is the latest version, which is an improvement from TM 1.0. It has a largely improved representation of public transportation, and it includes some ability to account for emerging mobility options, i.e., autonomous vehicles and ridehailing. Currently, TM 2.1 is under development and expected to become available by April 2022.

Level of Complexity: High.

Modeling Area: This travel demand model covers the nine counties of the San Francisco Bay Area (Alameda, Contra Costa, Marin, Sonoma, Napa, San Francisco, San Mateo, Santa Clara, and Solano). The TM includes external trips, but external demand is fixed for each forecast year and does not respond to changes in land use or the transportation network.

Software Environment: Both the software and model structure are highly configurable and flexible; depending on the analysis needs, the required computing power could vary dramatically. TM needs Cube Voyager, Cube Cluster, Java and CT-RAMP, GAWK, Microsoft Excel, Python 2.7(64-bit). TM 2.2 is being transferred to EMME. TM2.3 will be converted from CT-RAMP to ActivitySim.

Level of Spatial Details: 1454 TAZs.

Period of Analysis: A typical weekday.

Time Periods: The TM has two levels of temporal resolution. The first level of resolution applies to the travel network and includes: early AM (3 AM to 6 AM), AM peak (6 AM to 10 AM), midday (10 AM to 3 PM), PM peak (3 PM to 7 PM), evening (7 PM to 3 AM). The second level of resolution applies to individuals' traveler decisions and is divided into one-hour intervals.

Model Structure: TM 1.5 includes four main levels of model components: long-term decisions, daily decisions, tour-level decisions, and trip-level decisions.

Modeling Sequence: TM follows this sequence of modeling: 1) population synthesizer; 2) long-term decisions; 3) daily decisions; 4) tour-level decisions; 5) trip-level decisions; and 6) traffic assignment. The third step (daily decisions) includes four sub-models: a) individual mandatory tours; b) joint non-mandatory tours; c) individual non-mandatory tours; d) at-work sub-tours.

Main Travel Modes: Drive alone, shared ride 2, shared ride 3+, taxi, transportation network company (TNC), shared TNC 2, shared TNC 3+, walk, bicycle, local bus, light rail, ferry, express bus, heavy rail, and commuter rail. Model updates were made to include: automated vehicle (AV), Shared AV 2, and Shared AV 3+.

Access/Egress Modes: TM considers walk-access and drive-access transit. The TNC modes are included as main modes, but not as access/egress modes to transit in the current version.

Mode Choice Modeling Methods: TM 1.5 simulates activities and trips of individuals by a series of discrete choices. After the latest model updates, it also makes assumptions about autonomous vehicle occupancy and ownership.

Future Scenarios' Considerations: Forecasting years are 2035 and 2050. TM 1.5 adds the TNC and autonomous vehicle modes to TM 1.0. TM 1.5 estimates the impacts of TNCs and taxis on the mode choice decision and makes assumptions on autonomous vehicle occupancies and ownerships, though these components are still quite simple. TM 2.1 will have improved ability to deal with emerging mobility options.

Input Models & Files: The input files include synthetic demographic data (household data, personal data), land use data (traffic analysis zone-specific data and walk access shares), network settings (i.e., highway network, transit network and services), initial trips of various modes.

Output Files: Simulated socio-demographic information for person and household, person trip table by time period and mode, loaded highway network, loaded transit network.

3.5 Sacramento Activity-Based Travel Simulation Model (SACSIM)

Description: SACSIM is an activity-based travel demand forecasting model developed by the Sacramento Area Council of Governments (SACOG) to forecast travel patterns for each resident in the Sacramento region.

Latest Model Version: SACSIM19 was released in 2020.

Level of Complexity: High.

Modeling Area: The entirety of Sacramento, Sutter, Yolo, and Yuba counties, and parts of Placer and El Dorado counties.

Software Environment: Cube Voyager 6.4.4, DAYSIM; Software needed to develop and maintain SACSIM19: Cube Base, ArcGIS, PopGen v1.1, SOL Server, Python, Notepad++.

Level of Spatial Details: SACSIM uses parcel level data to predict travel made by SACOG residents. Commercial and internal-external trips are estimated at TAZ level. The modeling area is divided into 1502 TAZs (six SACOG counties) and surrounding external zones by county (Amador, San Joaquin, Solano, Napa, Colusa, Butte, Nevada) or broader regions (Bay Area, Northern CA, Central and Southern CA), aggregated into 30 gateway TAZs.

Period of Analysis: Average mid-weekday (Tuesday to Thursday) during Spring or early Fall.

Time Periods:

- Demand time periods: AM 3-hour (7-10 AM), midday 5-hour (10 AM -3 PM), PM 3-hour (3 – 6 PM) and evening 13-hour (6PM – 7 AM).
- Trip assignment to highway networks: 9 time periods (7–8 AM, 8–9 AM, 9–10 AM, midday 10 AM–3 PM, 4–5 PM, 5–6 PM, evening 6–8 PM, and nighttime 8 PM–7 AM).
- Trip assignment for transit passenger users: 5 time periods (5–9 AM, 9 AM–3 PM, 3–6 PM, 6–8 PM, and 8–11 PM).

Model Structure: SACSIM19 includes four sub-models: Person-Day Travel Simulator (DaySim), Airport Passenger Ground Access Model, Commercial Vehicle Model, & External Travel Model. DaySim includes long- and short-term decisions.

Modeling Sequence:

1. Representative Population Generator (*PopGen*).
2. DaySim: Long-Term decisions: Once per household. Work and school location, and car ownership.
3. DaySim: Short-Term decisions: Once per person per day. Activities and home-based tours.
4. Person Trip List of Trip Aggregator.
5. Network Trip Assignment: This generates Level of Service Matrices, which are iteratively related with DaySim short-term decisions (by 9 time periods).

Main Travel Modes: Person trip modes considered in *DaySim*: walk, bike, drive (alone, shared ride [2 and 3+], walk-to-transit (rail, commuter bus, fixed route bus), drive-to-transit (rail, commuter bus, fixed route bus), and school bus. *External Travel Model:* drive (alone, shared ride [2 and 3+]). *Airport Passenger Ground Access Model:* auto drop-off, drive-and-park at the airport, return the rental car at the airport, taxi, van, transit walk access, transit drive access, and transit drop-off access.

Access/Egress Modes: *DaySim*: Walk-access and drive-access transit. *Airport passenger ground access model*: transit walk access, transit drive access, and transit drop-off access.

Mode Choice Modeling Methods:

DaySim and Airport passenger ground access model: Multinomial Logit Model. *External Travel Model:* Flat person-to-vehicle trip factor.

Future Scenarios' Considerations:

Forecasts for sociodemographic characteristics are based on the work from Center for Continuing Study of the California Economy (CCSCE) at regional level and ACS data at lower spatial level. SACOG updates long-range plans (MTP/SCS) every four years. SACOG uses SACSIM19 to forecast travel demand until the scenario year 2040 in the current adopted 2020 MTP/SCS.

Input Models & Files:

- Land Use Data: Each record in the parcel file contains information for an individual parcel, namely parcel identification, coordinates, area, TAZ, household, and K–12 student enrollment. The base year for the land-use model is 2016.
- Representative Population: Population is synthesized using PopGen at a household level allocated at a parcel level.
- Scenario description files.
- DaySim inputs: mode, mode/path possible combinations, impedance skim matrices, TAZ files, and mode choice parameters.
- Airport module input: Airport survey input for SACSIM airport module.
- Transit inputs: sub transit control files (the accessibility to transit between TAZs), and transit fares, and transit wait curves.
- Internal-external files: friction factors input and time-of-day factors by trip type.

Output Files:

- DaySim outputs: household table, person table, person day table, aggregated trips per household, tour table, and trip table.
- SACSIM outputs: loaded Cube trip skim matrices, loaded network files by time period, roadway pricing costs (i.e., the effect of roadway pricing to travel), and transit boardings/alightings files.

3.6 Three-County Model (TCM) in the San Joaquin Valley

Description: This four-step travel demand model covers the Merced County Association of Governments, San Joaquin Council of Governments, and Stanislaus Council of Governments. A newer activity-based model (ABM) might be available in the future.

Latest Model Version: The updated version is from 2017.

Level of Complexity: Medium.

Modeling Area: Covers the three Northern counties in the San Joaquin Central Valley, namely Merced, San Joaquin, and Stanislaus.

Software Environment: Cube 6.4 and ArcGIS 10.2.

Level of Spatial Details: The modeling area is divided in 6,600 TAZs plus 100 gateway TAZs to represent entry/exit points on the region boundary. This is a relatively fine level of spatial resolution.

Period of Analysis: A typical weekday.

Time Periods: For auto: AM peak (6–9 AM), midday (10 AM–2 PM), PM peak (3–7 PM), and night (8 PM–5 AM). For transit: peak and off-peak.

Model Structure: There are four components, which are trip generation and attraction, mode split, and trip distribution.

Modeling Sequence: Expected to follow 4-step model routine, with transition to activity-based approach in newer version.

Main Travel Modes: Drive alone, shared-ride 2, shared-ride 3+, transit, bike, walk.

Access/Egress Modes: Walk-access and drive-access transit (bus and rail).

Mode Choice Modeling Methods: The mode choice is estimated by multinomial logit models by trip purposes, vehicle availability, and household sizes.

Future Scenarios' Considerations: This model can estimate scenarios up to 2040.

Input Models & Files:

Census data and American community survey for household characteristics and land use inputs.

The trip generation and mode choice components are estimated using data from the 2012 California Household Travel Survey.

Travel analysis zones, including TAZ characteristics and accessibility.

Network, including highway and transit networks.

Output Files: This model exports worksheets reporting land use, trip generation (production – attraction balance), person trips per household, vehicle availability, mode split by purpose, purposes by mode, travel time, VMT, and trip distribution.

3.7 San Francisco Travel Demand Forecasting Model (SFCTA 2002)

Description: This ABM was developed by the San Francisco County Transportation Authority to provide travel demand forecasts to support long-range transportation planning, transportation project and policy evaluation, transit planning and land use planning activities.

Latest Model Version: SF-CHAMP 6.

Level of Complexity: High.

Modeling Area: Covers San Francisco in greater details with travel to/from the surrounding nine counties in MTC region.

Software Environment: SF-CHAMP (San Francisco Chained Activity Modeling Process) is an ensemble of models and tools, including Python, Cube, and DaySim that is iteratively executed to achieve a stable solution.

Level of Spatial Details: The core models use approximately 40,000 block-sized "microzones" as the basic spatial unit. For assignment, these microzones are aggregated to 2245 TAZs. Within San Francisco, TAZs are approximately census block- and block group-size. Outside of San Francisco, the TAZs are approximately census tract-size. The newer Transit Access Points (TAPs) provide better resolution but also increase complexity (and runtime, from one hour for the base scenario to eight hours with TAPs).

Period of Analysis: A typical weekday, though a weekend model has been developed to support planning activities for Treasure Island.

Time Periods: 5 time periods: early (3–6 AM), AM peak (6–9 AM), midday (9 AM–3:30 PM), PM peak (3:30–6:30 PM), evening (6:30 PM–3 AM).

Model Structure: There are four primary sources for regional demand in SF-CHAMP: By far the most important source of demand is the "DaySim" core, an activity-based model system that includes a suite of sub-models to predict all travel decisions for regional travelers, including all location, mode, and time-of-day choices at the tour and trip level at the block-level, using a synthetic population that represents all regional travelers. A simple truck/commercial vehicle model is adapted from MTC. A simple visitor model predicts visitor travel within San Francisco. A simple model predicts internal-external, external-internal, and external-external vehicle trip demand. The demand from the four sources is aggregated by TAZs and time periods, and combined prior to network assignment.

Main Travel Modes: Drive alone (free), drive alone (toll), shared ride 2 (free), shared ride 2 (toll), shared ride 3+ (free), shared ride 3+ (toll), TNC, AV, walk, bicycle, local bus, light rail, express bus / Caltrain, ferry, and BART.

Access/Egress Modes: Walk-access transit and drive-access transit.

Mode Choice Modeling Methods: The mode is identified for tours and all trips as part of the tours. The mode choice is modeled as a nested logit model and its logsum (accessibility) is used in the destination choice models. The mode choice model in the visitor model is borrowed from Honolulu which is a multinomial logit model.

Future Scenarios' Considerations: The 2002 model can forecast travel demand for years 2000, 2005, 2010, 2015, and 2020. A newer version of this model is being developed. The future scenario considerations will be updated in the newer version.

Input Models & Files: Includes a block-level microzone file with information on employment by industrial sector, land use and urban form attributes, and other spatial attributes such as parking capacity, detailed roadway and transit networks including all regional transit operators, and model coefficients estimated from the Bay Area travel diary survey information.

Output Files: The core activity-based model components produce detailed tour- and trip-level outputs with all relevant traveler attributes (which can be used to support detailed equity analyses), as well as household- and person-level outputs. These are aggregated and combined with outputs for the other auxiliary model components prior to the assignment step, which then produces estimates of volumes by vehicle class and transit boardings and alightings by time of day.

3.8 Transit Boardings Estimation and Simulation Tool (TBEST 4.6)

Description: It was primarily designed to accommodate the requirements for Florida transit agencies to include short-term transit ridership estimations within state-mandated Transit Development Plans. The short-term focus of the TBEST software combined with the detailed model input data have made the software/model attractive as not only a supplement to long-range travel demand modeling, but as an everyday service planning and transit analysis tool.

Latest Model Version: TBEST 4.6.

Level of Complexity: Low.

Modeling Area: Zones could be any user input polygon shapefile including local municipalities, census block groups, or any other planning areas.

Software Environment: Stand-alone Microsoft Windows-based software package with ArcGIS required.

Level of Spatial Details: Stop-level ridership model is based on route pattern.

Period of Analysis: A typical weekday and weekend.

Time Periods: Four-time periods for weekdays: AM peak, off-peak, PM peak, and night. Two time periods for weekends: Saturday and Sunday.

Model Structure: Direct demand (Linear regression equation) for each time period. Separate models to estimate direct and transfer boardings.

Modeling Sequence: Simplified modeling sequence, as the model only focuses on transit and assumes that demand from other modes remains the same over the short term.

Main Travel Modes: Transit modes.

Access/Egress Modes: Walk access.

Mode Choice Modeling Methods: No mode choice modeling component is included in this model.

Future Scenarios' Considerations: This model is used for the short-term forecasts, and not for long-term future scenarios.

Input Models & Files: Transit network (GTFS), Census 2010 Block attributes, ACS Block Group demographics, employment (address, LEHD or TAZ), Parcel land use data (optional), land use trip rates per land-use type, route fare, vehicle capacity, special generators, park-n-ride with spaces.

Output Files: Include route service summary report, route socio-economic report, performance reporting, the scenario summary tool, Transit Development Plan reporting, route headway report, and the applied route-level validation factors report. In addition, the tool can be used for market analysis, network accessibility analysis, and Title VI analysis.

3.9 Simplified Trips-on-Project Software (STOPS 1.5)

Description: This model is used for transit ridership estimation for the build and no-build scenarios. The model quantifies the trips-on-project model for all travelers and for transit dependents. The auto VMT can be derived by using locally-derived estimates of vehicle occupancy to convert person miles to vehicle miles. The change in auto VMT under the change of ridership in the two scenarios can also be computed.
Latest Model Version: STOPS 1.5.
Level of Complexity: Medium.
Modeling Area: Zones could be any user input polygon shapefile.
Software Environment: Stand-alone software package with ArcGIS required.
Level of Spatial Details: Maximum number of TAZs/tracts/block groups is 9,000. The maximum number of stations/bus stops is 10,000. The number of new stations/station groups is 250. The number of GTFS file sets for each scenario is 20. The spatial details depend on user input for the zoning system and stations, within the limits allowed by the model.
Period of Analysis: A typical weekday.
Time Periods: Peak and off-peak.
Model Structure: Simplified structure from 4-step model. STOPS includes three parallel groups, which are Highway Supply, Travel Demand, and Transit Supply.
Modeling Sequence:

In parallel:

4 Highway supply (highway travel time and distance)
5 Travel Demand (demographics Census Transportation Planning Products (CTPP) and adaptations; travel flow; and mode choice)
6 Transit supply (FTG network and path; travel time and load)

Outcome:

- Auto VMT
- Travel flow and transit flow summaries

Main Travel Modes: Fixed Guideway only, fixed guideway and bus, and bus only.
Access/Egress Modes: Walk, Kiss-and-ride, Park-and-ride, and combination of them.
Mode Choice Modeling Methods: STOPS employs a conventional nested logit mode-choice model to predict zone-to-zone transit travel based on zone-to-zone travel characteristics of the transit and roadway networks in the study area. Then, STOPS assigns the trips predicted to use fixed guideways onto the various rail and bus-rapid-transit facilities (including the proposed project) in the transit network.
Future Scenarios' Considerations: STOPS will accept any future scenario year for which input data is available.
Input Models & Files:

CTPP, including geographic files of each state. Data from FTA. Transit timetables in GTFS format. Geographic shapefiles from MPO, zone-to-zone estimated highway times and distances. Transit project details, including station locations, station grade level (i.e., at grade or grade-separated), the stations with or without park-and-ride, and operating plan.
Output Files: Summaries of key inputs, existing scenario results, project results, etc.; comparison of existing, no-build, and build station boardings by station mode of access, route mode of access; summary of trips by sub-mode, access mode, auto ownership, and scenario; summary of highway time, distance, and speed; district-to-district analysis of gains and losses between no-build and build; detailed district-to-district linked trips and selected station-station flows; summary of impacts on automobile person miles traveled.

3.10 Regional Dynamic Model (RDM)

Description: This model simulates changes over time in a selected urban area, focusing on transportation, land use, population, employment, etc.
Latest Model Version: RDM was developed by Steer Davies Gleave. It is adjusted/modified before being applied to a certain area.
Level of Complexity: Medium/low.
Modeling Area: Area could be any user input polygon shapefile.
Software Environment: Vensim (Vensim 8.1 is the current version).
Level of Spatial Details: Maximum number of zones is approximately 370. Therefore, the bigger the area is, the less granular the zones are. While there is no hard limit to the number of zones, there is a risk of model failure when the number of zones is too large.
Period of Analysis: N/A.
Time Periods: N/A.
Model Structure: This model includes two main components, namely 'stocks' and 'flows.' In each stock, there is a household 'living' there. At a certain time, some household members may depart (outflow) and some return (inflow). As such, the model can simulate household movement as well as housing, employers, the premises that employers occupy.
Modeling Sequence: The model is built using System Dynamics, a simulation technique designed for modelling how systems behave and for modeling the links between people, employers, transportation, housing and commercial infrastructure as a system. There are three ways to model transportation systems, namely link-based method, generalized time method, and hybrid method. The model can be run as a non-dynamic model (using the land use, employment and sociodemographics as static inputs) or as a dynamic model that simulates the evolution on a 20-year horizon in the region.
Main Travel Modes: car, bus, metro, train, walk/ bike.
Access/Egress Modes: There are no access/egress modes in the model.
Mode Choice Modeling Methods: It uses a hierarchical logit model for both mode choice and route choice.
Future Scenarios' Considerations: This can be handled by changing inputs and model parameters, to forecast future changes over a 20-year horizon in the region.
Input Models & Files: land use data, employment, demographics, growth rate (employers, households), transportation networks, and data for calibrating and validating the models.
Output Files: Number of firms and households, population by zone, age, and type, employment, unemployment, and inactivity, gross value added, floorspace of developments, and private-sector investment, number of new commercial and housing units, transportation flows by modes among zones.

3.11 Conceptual Network Connections Tool (CONNECT)

Description: The CONceptual NEtwork Connections Tool (CONNECT) is a sketch planning tool that is built to estimate the overall performance of high speed and intercity passenger rail (HSIPR) corridors and networks. Some main performance indicators from the model are the order-of-magnitude estimates for ridership, revenue, costs, and public benefits. The indicators provide a basis for relative comparisons between corridors and networks with various configuration and service options.

Latest Model Version: CONNECT was developed by Steer Davies Gleave for FRA. Model documents are not published yet.

Level of Complexity: Low.

Modeling Area: US and parts of Canada and Mexico. The model only includes Core Based Statistical Areas (CBSAs) with at least 10,000 people.

Software Environment: CONNECT consists of two primary files (a Microsoft Excel file and a Microsoft Access database) and a set of support files. CONNECT requires only Microsoft Excel 2010 or later. Microsoft Access is not required to run CONNECT.

Level of Spatial Details: This large-scale low-resolution model includes 973 zones, consisting of 913 zones in the US, 32 in Canada, and 28 in Mexico. Zones with a population of at least 10,000 people are defined in the model. CONNECT can support a maximum of 25 corridors (including the primary corridor) consisting of up to 10 CBSAs per corridor. Very coarse level of spatial aggregation, only useful for long-distance intercity rail.

Period of Analysis: Model operates at daily level.

Time Periods: N/A.

Model Structure: There are four independent demand and binary mode choice models for intercity auto, local air, connect air and bus. The mode choice component computes the mode share for 1) auto and HSR; 2) local air and HSR; 3) connect air and HSR; and 4) bus and HSR.

Modeling Sequence: Three stages: demand models, mode choice models, and induced demand model. Outputs of demand models and mode choice models are used as inputs for the induced demand model for HSR ridership estimation.

Main Travel Modes: HSR, intercity private vehicle travel (business and non-business; en-route captive, destination captive and non-captive); bus (business and non-business); local air travel (business and non-business); and connect air travel (business and non-business).

Access/Egress Modes: There are no access/egress modes. CONNECT uses a default value for access/egress time.

Mode Choice Modeling Methods: Binary logit models.

Future Scenarios' Considerations: The model produces forecast for years 2015, 2035, 2045, or 2055.

Input Models & Files: Basic inputs, which consist of all physical and operational characteristics of the network, include: service tier; frequency of service; markets served; number of stations per segment; airport connections; percentage of existing versus new alignment; percentage on public right-of-way versus new acquisition; general level of investment expected in the corridor; and existing freight density and existing track quality. Advanced inputs include all the other drivers of ridership and cost that are required to run the tool but are not unique to the specific network. These include unit costs for capital and O&M (operation and maintenance) calculations, global service characteristics such as size, run times, and exogenous factors that impact ridership such as projected population growth and fuel prices.

Output Files: CONNECT generates output data to measure the operational and financial performance of a proposed high speed and intercity passenger rail network. CONNECT estimates ridership, revenue, and costs (O&M and capital) in three different contexts, which are standalone context, full network context, and infrastructure corridor context.

3.12 Summary Tables

Table 3.1, Table 3.2, and Table 3.3 show the summary of current statewide, MPO, and transit-oriented models, respectively.

Table 3.1 Summary features of existing models (*statewide models*).

Criteria	CSTDM 3.0	CHSR-BPM V3-2016	New Statewide Rail Model*
Coverage of Link21 megaregion	Statewide level (58 counties), including the entire Link21 megaregion	Statewide level (58 counties), including the entire Link21 megaregion; focus on California HSR.	Statewide level (58 counties), including the entire Link21 megaregion; focus on intercity state rail, HSR, airline, etc. Focus on travel > 40–50 miles
Number of TAZs	5,454 (for internal travel), plus 53 external zones to represent entry/exit points on the state border.	4,683	Approx. 1,200 (estimate)
Spatial Resolution (average TAZ size)	Coarse (38.35 sq. miles)	Coarse (44.67 sq. miles)	Coarse (174 sq. miles)
Complexity	Rather high (activity-based model with limited spatial resolution and level of details)	Medium (Primarily long-distance model using static trip tables as input for short-distance travel)	Medium/Low (Simplified 4-step model for long-distance travel)
Software environment	Cube (modules in Cube Voyager 6.4.4, plus functions activated in Python and Java).	Cube	EMME
Period of Analysis	A typical weekday in fall/spring	A typical weekday in fall/spring	Unknown (to date)

Criteria	CSTDM 3.0	CHSR-BPM V3-2016	New Statewide Rail Model*
Time Periods	6 AM–10 AM 10 AM–3 PM 3 PM–7 PM 7 PM–12 AM and 12 AM–6 AM	6 AM–10 AM 10 AM–3 PM 3 PM–7 PM 7 PM–12 AM and 12 AM–6 AM	Unknown (to date)
Main Travel Modes	**Long Distance Personal Travel Model** Auto Rail Air **Short Distance Personal Travel Model** Auto (SOV, HOV2, & HOV3+) School bus Walk Bicycle Walk to rail-based transit (light rail, heavy rail) Auto to rail-based transit (light rail, heavy rail) Local transit (bus)	**Long Distance** Auto High speed rail Conventional Rail Air **Intraregional** †Auto (SOV, HOV2, HOV3+) Transit Walk Bicycle	Auto High speed rail Conventional rail Intercity bus (Megabus, FlixBus, Greyhound) Air
Access/ Egress Modes	**LDPTM:** If main mode is not auto: drive and park/passenger/transit/taxi/walk) **SDPTM:** Walk to rail-based transit (light rail, heavy rail) Auto to rail-based transit (light rail, heavy rail) Bus access to rail-based transit	Drive-park Rental car Serve passenger (escort) Taxi Public transit Walk	Express bus (explicit access/egress mode for main modes) For other access/egress modes, default parameters for access/egress time to centroid connectors.

* Limited documentation available to date on this model. Model is still under development.

† Autos (drive alone, shared-ride 2, shared-ride 3+) and transit are classified as "motorized modes" in this model. Transit includes local bus; express bus; light rail; bus rapid transit (BRT); and ferry; other transit (e.g., fixed guideway, "Transitway Bus," for SCAG, none for MTC); urban rail (e.g., BART, Metrorail); Commuter rail (e.g., Caltrain, ACE, Metrolink, Pacific Surfliner); and HSR.

Table 3.2 Summary table of existing models (*MPO models*).

Criteria	TM 1.5	TM 2.1	SACSIM19	3-county travel demand model*	SFCTA 2002
Coverage of Link21 megaregion	9 counties in Bay Area/MTC region	9 counties in Bay Area/ MTC region	6 counties in SACOG region	3 Northern counties in San Joaquin Central Valley	9 counties in Bay Area/MTC region
Number of TAZs	1,454	4,700; containing 40K nested MAZs	1,502; 30 gateway[†] TAZs	6,600 TAZs; 100 gateway[†] TAZs	~40,000 MAZs 2245 TAZs
Spatial resolution (average TAZ size)	Fine (6.53 sq. miles)	Fine (2.02 sq. miles); [MAZ: 0.24 sq. miles]	Fine (5.70 sq. miles)	Fine (0.45 sq. miles)	Fine (5.46 sq. miles
Complexity	High (activity-based model)	High (activity-based model)	High (activity-based model)	Medium (Simplified 4-step model, though newer activity-based model might be available)	High (activity-based model)
Software environment	Cube (modules in Cube Voyager, plus others activated in Java, CT-RAMP, GAWK, Microsoft Excel, Python 2.7)	Cube plus EMME for transit crowding and capacity module. Future versions will transition entirely to EMME and will replace CT-RAMP with ActivitySim.	Cube (modules in Cube Voyager, DaySim; for maintenance of model, PopGen v1.1, SOL Server, Python are used)	Cube and ArcGIS	DaySim, Cube, Python
Period of Analysis	A typical weekday	A typical weekday	Average mid-weekday (Tuesday to Thursday) during Spring or early Fall	A typical weekday	A typical weekday

Criteria	TM 1.5	TM 2.1	SACSIM19	3-county travel demand model*	SFCTA 2002
Time Periods	**1) Travel network‡:** Early AM (3 AM to 6 AM) AM Peak (6 AM to 10 AM) Midday (10 AM to 3 PM) PM Peak (3 PM to 7 PM) Evening (7 PM to 3 AM). **2) Traveler's decisions:** one-hour intervals.	Same as TM 1.5	**Demand time periods** AM 3-hour (7-10 AM) Midday 5-hour (10 AM -3 PM) PM 3-hour (3 – 6 PM) Evening 13-hour (6 PM – 7 AM) **Trip assignment to highway networks:** 7 AM–8 AM 8 AM–9 AM 9 AM–10 AM 10 AM –3 PM 3 PM–4 PM 4 PM–5 PM 5 PM–6 PM 6 PM–8 PM 8 PM –7 AM **Transit assignment:** Start of service–10 AM 10 AM–3 PM 3 PM–6 PM 6 PM–8 PM 8 PM to end of service	**Travel demand** AM peak three-hour period PM peak three-hour period Mid-day peak four-hour period Off-peak **Network Assignment** **Auto:** Three-hour peak periods Mid-day peak four hours Off-peak Remaining hours aggregated to daily total volume **Transit:** Peak (3-hour AM and 3-hour PM periods) Off-peak (all other 18 hours)	**Travel demand and network assignment** Early (3-6 AM) AM peak (6-9 AM) Midday (9 AM – 3:30 PM) PM peak (3:30 – 6:30 PM) Evening (6:30 PM – 3 AM)

Criteria	TM 1.5	TM 2.1	SACSIM19	3-county travel demand model*	SFCTA 2002
Main Travel Modes	Drive (alone, shared 2, shared 3+) Taxi TNC Shared TNC 2 Shared TNC 3+ Walk Bicycle Local bus Express bus Ferry Light rail (e.g., Muni) Heavy rail (BART) Commuter rail (e.g., SMART, Amtrak) **Model updates being made to include:** AV Shared AV 2 Shared AV 3+	Same as TM 1.5	**Short-distance modes considered in DaySim:** Walk Bike Drive (alone, shared 2, shared 3+) Walk-to-transit Drive-to-transit School bus **External Travel Model:** Drive (alone, shared 2, shared 3+) **Airport Passenger Ground Access Model:** Auto drop-off Drive-and-park at the airport Return rental car at the airport Taxi Van Transit walk access Transit drive access Transit drop-off access	Drive (alone, shared ride 2, shared ride 3+) Local bus Regional bus Bus rapid transit (BRT)	Drive alone (free) Drive alone (toll) Shared ride 2 (free) Shared ride 2 (toll) Shared ride 3+ (free) Shared ride 3+ (toll) TNC AV Walk Bicycle Local bus Light rail Express bus / Caltrain Ferry BART
Access/ Egress Modes	Walk Drive (include park-and-ride, kiss-and-ride).	Same as TM 1.5	**DaySim:** Walk access Drive access **Airport passenger ground access model:** Transit walk access Transit drive access Transit drop-off access	Walk Drive	Walk Drive

*Some information might be obsolete, due to limited documentation on the model.

[†] Gateway TAZs represent entry/exit points on the region boundary.

[‡] The travel network (road network and transit service frequency) in one period is assumed to be constant and the amount of congestion is also constant.

Table 3.3 Summary table of existing models (*transit-oriented models*).

Criteria	TBEST 4.6	STOPS 1.5	RDM	CONNECT
Coverage of Link21 megaregion	Zones could be any user input polygon shapefile (including local municipalities, census block groups, or other planning areas). The stop-level ridership model is based on a route pattern.	Zones could be any user input polygon shapefile. The number of new stations/station groups is 250. The number of GTFS file sets for each scenario is 20.	Zones could be any user input polygon shapefile. The maximum number of zones is approximately 370. While there is no hard limit to the number of zones, there is a risk of model failure when the number of zones is too large.	Rail ridership model designed for intercity travel. It allows maximum 25 corridors (including the primary corridor) consisting of up to 10 CBSAs per corridor.
Number of TAZs or other zones		Maximum number of TAZs/tracts/block groups is 9,000; maximum number of stations/bus stops is 10,000; the number of new stations/station groups is 250.	The maximum number of zones is approximately 370. While there is not hard limit to the number of zones, there is a risk of model failure when the number of zones is too large.	973 zones (913 in the US, 32 in Canada, and 28 in Mexico), with maximum 25 corridors (including the primary corridor) consisting of up to 10 CBSAs per corridor. Zones with at least 10,000 people are defined in the model.
Spatial resolution			The larger the area of study, the larger the zones need to be due to max number of zones.	Very coarse level of spatial aggregation, only useful for long-distance intercity rail.
Complexity	Low	Medium	Medium/Low	Low

Criteria	TBEST 4.6	STOPS 1.5	RDM	CONNECT
Software environment	Stand-alone Microsoft Windows-based software package with ArcGIS required	Stand-alone software package with ArcGIS required	Vensim	Microsoft Excel and Microsoft Access
Period of Analysis	A typical weekday and weekend	A typical weekday	N/A	Daily level
Time Periods	**Four-time periods for weekdays:** AM Peak Off-Peak PM Peak Night **Two time periods for weekends:** Saturday Sunday	Peak and off-peak	No	No
Main Travel Modes	Transit modes	Fixed Guideway only Fixed guideway and bus Bus only	Car Bus Metro Train Walk/ bike	Auto Bus Local air Connect air Rail
Access/ Egress Modes	Walk	Walk Kiss-and-ride Park-and-ride Combination of above	No	No, a default value for access/egress time

3.13 Section Summary

In this section, we reviewed several available models at regional and statewide levels. At a regional level, while all models have a detailed representation of travel patterns, those models only cover a part of the 21 counties in the Link21 study area. They are usually not able to model internal-external demand that extends beyond their region boundaries or long-distance demand for intercity rail or HSR (though in some cases they use long-distance travel and/or HSR forecasts as external inputs). The future version of the MTC travel model (version 2.1), which is expected to be released by April 2022, will include some important updates that are of interest for improving the ability to model public transportation. These additional features include accounting for transit capacity and crowding, transit station parking capacity, and ridehailing. The newer version of this model also includes an experimental approach to account for the impacts of connected and automated vehicles. MTC also plans to transition to full use of the EMME platform and then move from CT-RAMP to ActivitySim. Meanwhile, the SF-CHAMP, SACSIM, and TCM models use DaySim and Cube Voyager and cover a wider area than the MTC model. This means that these models share similar assumptions, structure of the network systems, zone definitions, etc. which could be used for a larger area. However, even if sharing multiple features, those models are not always consistent in their modeling approaches.

The statewide models cover the entire Link21 study area, which provides consistent assumptions, networks, TAZs, etc. for the entire region of interest for the Link21 program. However, the CSTDM has several disadvantages, such as the limited details on how transit trips are generated, the coarser level of spatial details and information on transit access and egress, and the lack of a complete transit assignment process. In addition, the non-rail transit mode is modeled with a simplified approach that, while appropriate for a statewide model, is not ideal to study the impacts of the upgrade of transit infrastructure and services as part of the Link21 program. The model includes both short- vs. long-distance model components, though the threshold to distinguish between short-distance and long-distance trips, set at 100 miles, is not consistent with other modeling approaches and creates a major discontinuity among trips that are still internal to the Link21 megaregion. On the other hand, the California High-Speed Rail Model (CHSR) model was developed and calibrated based on stated-preference survey data specifically to forecast demand for rail services, which increases its potential to be used to inform new public transit usage behavior. The CHSR model, however, has many disadvantages, such as using a static trip table for short-distance trips inside a region as input in the model, not including many transbay trips, having inconsistent representation of short- and long-distance trips, and limited details for transit forecasting. At the statewide level, Caltrans is also building a new statewide model to support the State Rail Plan update. While the model is designed to model longer-distance (>40-50 mi.) demand for intercity rail services in the state, its simpler 4-step modeling approach and rather coarse level of spatial details does not make it suitable for modeling demand for transit vs. other modes at the regional and local levels, which represent an important component of the expected travel demand for the Link21 program.

Finally, the simplified transit models present some interesting characteristics and modeling features that would make them attractive as easier-to-setup short-term models to forecast demand for transit services. However, they are in no way suitable to serve as long-term modeling tools to forecast demand for various travel modes in future scenarios for the megaregion and cannot meet the Link21 modeling needs.

The summary of the pros and cons of each model is shown in Table 3.4.

Table 3.4 Summary of pros and cons of the current travel demand models.

Agency	Pros	Cons
California Statewide Transportation demand model (CSTDM V3.0)	- Covers study area of Link21 program (21 counties). - Consistent assumptions, TAZs, networks, etc. for modeling of all 21 counties. - Rail options are explicitly coded as individual lines in the rail network. - HSR component is included and can be turned on/off.	- Not designed for modeling local travel demand inside a metro region (e.g., BART vs. auto trips in the Bay Area). - Non-rail transit is modeled with a simplified approach. - It has limited details on how transit trips are generated, and for transit access/egress, transit forecasting and assignment. - Threshold for short- vs. long-distance trips set at 100 miles is not optimal for the Link21 megaregion.
California High Speed Rail Model (CHSR)	- Was developed based on behavioral (stated preference) survey data collected from California with the aim of forecasting HSR and long-distance rail usage. - Covers study area of Link21 program (21 counties).	- Does not include local travel (including transbay trips). - Inconsistent representation of short- and long-distance trips, using static trip tables from MTC and SCAG as input. - Limited details for local transit forecasting.
New Statewide Rail Model	- Covers study area of Link21 program (21 counties). - The model is under development so there is a potential for Link21 to discuss/collaborate with the model development team to develop a model that serves both statewide and Link21 purposes.	- Local travel is not well represented in the model. - The model focuses on intercity state rail, HSR, airline, etc. with a focus on travel over 40-50 miles. - Limited details for local transit forecasting.
Metropolitan Transportation Commission (MTC)	- Detailed representation of travel patterns in the 9 MTC counties, which are the core of the Link21 megaregion. - Travel model 2.1 is under development and it will be able to address transit capacity and crowding, and transit station parking capacity. TM 2.1 is expected to be released in April 2022. - The transition to the EMME modeling software will better accommodate public transit modeling components. - The model has new modules to account for emerging mobility, including ridehailing and an experimental approach to account for connected and automated vehicles.	- The model only partially covers the study area of the Link21 program. - Does not include long-distance travel. - Does not include HSR.

Agency	**Pros**	**Cons**
Sacramento Area Council of Governments (SACOG)	- Together, these three models provide a detailed representation of travel patterns in 18 counties among the 21 of the Link21 megaregion. - The models share a similar modeling approach, using DaySim and Cube Voyager.	- Even if sharing multiple features, the models are not always consistent in their modeling approaches. - Partially cover the study area of the Link21 program. - The models do not explicitly model long-distance travel. - The models do not include HSR. - The Cube modeling software is more limiting for modeling public transportation.
San Joaquin Council of Governments		
San Francisco Chained Activity Modeling Process (SF-CHAMP)		
Transit Boardings Estimation and Simulation Tool (TBEST)	- Simple and easy to implement. - Can cover the entire study area of Link21 program (21 counties).	- Not able to reflect the impacts of auto congestion. - Not a multimodal model, so it assumes that demand for other modes remains the same over the short term.
Simplified Trips-on-Project Software (STOPS)	- Data-driven adaptation of the conventional trip-based model. - Can cover the entire study area of Link21 program (21 counties). - Representation of the transit shares stratified by access mode (walk, kiss-and-ride, and park-and-ride) and sub-mode (fixed guideway-only, fixed guideway and bus, and bus-only). - Calibrated with national information on project ridership. - Adjusted to match local conditions using actual ridership experience. - Simple and easy to implement.	- Routine weekday travel by residents, not special markets (college students, air passengers, etc.). - Models transit demand but does not recognize transit capacity limitations and their impacts on transit ridership. - Improved representation of work-trip markets, less certain for others. - Translation of trip patterns over time based on population and employment, not accessibility. - Recognition of future roadway congestion, but somewhat aggregates impact on buses.
Regional Dynamic Model (RDM)	- Can cover the entire study area of Link21 program (21 counties). - Able to capture the impacts of auto congestion. - Relatively simple and easy to implement. - Land use function can be turned on/off.	- Calibration may take time. - Limited visualization resolution and details. - The level of spatial details and maximum number of zones strongly limits any applications for a detailed model that forecasts travel demand in the megaregion.

Agency	**Pros**	**Cons**
CONceptual NEtwork Connections Tool (CONNECT)	- Cover study area of Link21 program (21 counties).	- Uses generalized calculations that do not account for the specific and unique characteristics of a given corridor or network. - Mainly used for estimating the overall performance of high speed and intercity passenger rail (HSIPR) corridors and networks. - Does not account for critical components of ridership and cost, such as specific station locations, alignment alternatives, and short distance trips (intercity trips less than 50 miles and commuter trips).

4 Expert Interviews

4.1 Overview of the Approach

The use of expert interviews is one of the approaches used to gather information and build rationale to inform the selection of the modeling solutions for the Link21 program. Expert interviews are a qualitative approach that allows collecting information through semi-structured interviews with knowledgeable experts in a particular field[3]. The advantages of this approach are that experts not only provide detailed answers to predetermined questions but can also provide additional information during the interview process on topics not covered through the initial set of questions. Furthermore, talking directly to the experts allows one to ask follow-up questions in real time to obtain additional in-depth details on specific topics. For these advantages, this approach was used to inform this project.

4.1.1 Preparation of the interview process

Based on the scope of work of this project and our discussion with the funding agency, we designed an initial list of questions. Those questions ask information about the expected timeline, ballpark budget and potential issues for model development, model components, model integration, and model calibration and validation—for various modeling approaches that could be used for this project. We discussed the draft questions with the funding agency to obtain additional comments and suggestions before implementation. The details of the six questions that were used to guide the expert interviews are presented in the next section, with the summary of the results from the expert interviews.

One of the preliminary tasks in this process was the selection of the experts to interview. To do this, we first screened potential interview participants who have expert knowledge on travel demand modeling and experience in various sectors including academia, regional, state, and federal transportation agencies, and US Department of Energy national labs. We made sure to include experts from agencies in California, but also from other states and regions. We also included consultants that are part of the Link21 Program Management Team in the interview process, as well as current contractors that are involved in existing statewide travel demand modeling efforts in California, to obtain updated information on these modeling efforts.

Interviewees included experts who have experience developing travel demand models focused on car/highway travel and those who have experience in transit and/or freight modeling. A few experts have experience in multiple domains. Selected decisionmakers who are not model developers

---

[3] Bogner, A., Littig, B., & Menz, W. (2009). Introduction: Expert Interviews - An Introduction to a New Methodological Debate (pp. 1–13). https://doi.org/10.1057/9780230244276_1

themselves but have considerable experience at using the model outputs in their decision-making processes were also invited to participate in the interviews.

4.1.2 Expert recruitment

We worked in close collaboration with the funding agency to expand and converge on a final list of experts that included individuals from academia and the public sector, including metropolitan planning organizations (MPOs), state agencies (California State Transportation Agency [CalSTA] and California Department of Transportation [Caltrans]), one national lab, the Federal Highway Administration (FHWA), the Federal Transit Administration (FTA) and the Federal Railroad Administration (FRA). Many of the included experts are already very familiar with the study area (and the proposed infrastructure projects and modeling challenges), as they have extensive experience working for California states agencies and major regional planning agencies in the state, including the San Francisco Bay Area Metropolitan Transportation Commission (MTC), the Sacramento Area Council of Governments (SACOG), the San Diego Association of Governments (SANDAG), the Southern California Association of Governments (SCAG), the San Francisco County Transportation Authority (SFCTA), and the Los Angeles County Metropolitan Transportation Authority (LACMTA).

We first contacted experts by email to ask for their interest in participating in the interview and provided material on the background of the project, study area, modelling challenges, the questions that would be asked as part of the interview, and supplemental information on available travel demand models that are potentially useful for the purposes of this project. The shared material helped the experts familiarize themselves with the topics to be discussed during the interview.

By the end of the process, we completed interviews with 26 experts affiliated with 19 organizations. These included seven experts from five organizations (listed in Table 4.1) who were interviewed as part of broader general interviews to gather additional information on current on-going model development projects being developed at the statewide level and their application for planning purposes in the California Statewide Rail Plan. The remaining 19 experts from 14 organizations (listed in Table 4.2) were interviewed using the list of semi-structured questions to gather information on specific aspects of travel demand modeling of interest for the Link21 program.

Table 4.1 Experts who were interviewed for general information on current on-going modeling programs in California

Expert	Affiliation
Consultants	
Stefan Reul	DB Engineering & Consulting (California High Speed Rail)
Andrew Desautels	Steer (California High Speed Rail)
Mark Mukherji	Steer (California High Speed Rail)
Public sector	
Chad Edison and Alan Miller	CalSTA / Caltrans (State Rail Plan)
Lyle Leitelt and Peter Schwartz	Federal Railroad Administration (FRA)

Table 4.2 List of experts who were interviewed for the Link21 model development

Expert	Affiliation
Academia	
Ram Pendyala	Arizona State University
Miguel Jaller	University of California, Davis
Chandra Bhat	University of Texas at Austin
Consultants	
Masroor Hasan	Steer
Public sector	
Shengyi Gao	Sacramento Area Council of Governments (SACOG)
Wu Sun	San Diego Association of Governments (SANDAG)
Dan Tischler, Joe Castiglione, Drew Cooper, Bhargava Sana	San Francisco County Transportation Authority (SFCTA)
Bill Davidson	San Francisco Metropolitan Transportation Commission (MTC)
Hsi-Hwa Hu	Southern California Association of Governments (SCAG)
Monique Stinson	Argonne National Laboratory
Guy Rousseau	Atlanta Regional Commission (ARC)
Jeremy Raw	Federal Highway Administration (FHWA)
Jim Ryan, Ken Cervenka, Jeff Roux	Federal Transit Authority (FTA)
Vladimir Livshits	Maricopa Association of Governments (MAG)

4.1.3 Execution of the interviews

All interviews were conducted on the Zoom platform from May to September 2020. The host began each interview by introducing a brief overview of the project and asking if the expert had any questions before the interview. With the experts' permission, all interviews were recorded for internal purposes of notetaking. Information from the interviews were extracted after the interviews and after the experts' insights and opinions were confirmed through a comparison of notes taken by two members of the research team vs. the recording of the interview. The interviews lasted 70 minutes, on average, with the shortest interview duration being approximately 40 minutes, and the longest 120 minutes.

The interviews centered around the following general questions:

1. Would it be feasible to develop a brand new "blue sky" modeling system in one year, assuming no budget constraints, to properly model future travel demand (including, and in particular, for public transit) in the Northern California megaregion? What would be the ballpark budget required?
2. What minimum characteristics should be included in a modeling system that can be realistically developed in up to one year? What would be the ballpark budget required?
3. What should be expected of the modeling approaches and requirements to account for the impacts of the new transportation technologies and emerging mobility services?
4. Should land use and economic development explicitly be considered in these models?
5. How could the model(s) be calibrated/validated considering that data for new technologies (e.g., CAV) are not available yet?
6. Do you have any additional recommendations for the development of this work?

The content of each interview was summarized in main points by combining the notes taken during the interviews. Additional details from the discussion in the interviews are available from the research team and in Appendix A. In the next section, we summarize the responses from all experts in an aggregated format for each question. As agreed with the experts, results are compiled and summarized in the aggregate and no verbatim citations of any specific expert are reported in this document.

4.2 Summary of Expert Opinions

In this section, we summarize the main findings from the experts' interviews, grouped by topic following the list of questions that were used.

Question 1: Would it be feasible to develop a brand new "blue sky" modeling system in one year, assuming no budget constraints, to properly model future travel demand (including, and in particular, for public transit) in the Northern California megaregion? What would be the ballpark budget required?

About 90% of the experts say that creating a brand new "blue sky" model that is optimized for the Northern California megaregion would be valuable but would take longer than the available time to develop. The suggested time for creating this new model is 1–3 years, which would likely exceed the estimated 18-month timeline that the Link21 program has established. The estimation of the time needed is based on the knowledge that creating the new model would involve multiple tasks, including: the conceptualization of the model, identification of the model components, data collection (including travel surveys/travel diaries as well as the use of location-based passively-collected data sources), data processing, integration and manipulation, creation of the land use inputs, the zonal system, road and public transportation networks, estimation of the parameters in the various sub-models, model calibration, and model validation for such a large region (21 counties). Moreover, cross meetings with stakeholders are also time consuming. Given the likely need for more time than realistically available to properly create a brand new model, this approach might return results that are below expectations and would prove to be less reliable (and less performing) than some of the alternative approaches to fulfill the Link21 modeling needs (such as building more extensively on, and leveraging, the modeling features from the existing regional travel demand forecasting models). Furthermore, there are some sources of uncertainty (e.g., the role teleworking in the post-pandemic society, the share/adoption of connected and automated vehicles, the role of micromobility in the future years) that add up to other modeling difficulties and further complicate the development of a new model. As mentioned by some experts, all these factors will influence the model development time. One expert also mentioned that the selection of the platform(s) to implement this model is another key aspect that will finally influence the performance of the model.

The estimated budget varied from a low estimate of approximately $500,000 for a rather aggregate and simplified model to a higher estimate of $2 million for more complete and detailed models. Most budget estimates were in the range of $1–1.5 million. Several experts commented that, beyond a certain level, larger budgets would not help the model development, because there is a limit to the number of tasks that can be carried out in parallel, and the tight timeline will be a more limiting constraint than the budget on the scope and level of details of the model development. Overall, much of the budget and timeline will depend on specifics, especially the targeted range of applications, envisioned lifetime of the modeling system, horizon years, selected platforms and vendors, and in-kind support from the agencies.

Question 2: What minimum characteristics should be included in a modeling system that can be realistically developed in up to one year? What would be the ballpark budget required?

Regarding the recommended strategy to pursue (developing the model system based on a single existing model, or eventually stitching together multiple models), around 60% of the experts recommended developing the model for this project by building upon an existing model. They mentioned the difficulties when stitching together multiple models since different models cover different areas (e.g., the California Statewide Travel Demand Model covers the whole state of California but with lower resolution and fewer details in particular for local public transit, whereas the MTC model only includes the nine counties of the Bay Area but not the rest of the Link21 megaregion), have various complex components that are often based on different modeling approaches, and are often not consistent with each other (e.g., thresholds of long distance vs. short distance trips, and different definitions of activity patterns and trip purposes, among others). Therefore, while it might be desirable for some purposes—covering the 21-county megaregion through merging two model areas, or modeling both long-distance intercity rail as well as local transit with models designed to operate at different levels of geographic resolution—the stitching process will take much longer than expected or could even result in a dead-end approach that cannot be implemented properly. In addition, many experts stated the need for more time to calibrate and validate a combination of two models. Moreover, one expert pointed to the difficulty in combining data from various sources to validate the model. Different models have various data sources, even for the same model components (e.g., trip generation). In sum, building on, and expanding from, one existing model should work better than combining multiple models in terms of project timeline and final output. One expert suggested we should treat the Link21 program and its geographic context as a megaregion model, namely the Northern California megaregion, as a component within the California Statewide Travel Demand Model, encompassing MTC and other surrounding MPO models.

Regarding what components should be included in the model, the experts recommended that the model should definitely include the fundamental modeling features of an activity-based model that is designed for forecasting travel demand and the choice among various modes of travel, including public transportation, while also including TNC, HSR, freight (also considering that freight companies own the right-of-way on which the Capitol Corridor, ACE, San Joaquin and part of Caltrain operate), CAVs, and the ability to account for travel involving internal and external areas (with the necessary inputs in terms of road network, housing, economic development for those areas). However, some of these components pose important challenges and might not be included in the final model due to practical considerations. The experts believe the above components play essential roles in affecting travel demand. For example, it is expected that the growth in e-shopping will continue to cause increasing demand for goods delivery, which will eventually increase traffic congestion, especially in urban areas. Accordingly, one expert expressed concern for the congestion impacts of online shopping and the need to account for its interactions with passenger travel. Among all these components, HSR was emphasized the most. The experts suggested that it be included in the future travel demand model since it is relevant to the Link21 program.

Estimates for the needed budget covered a rather broad range from $250,000 to $2.5 million, with an average estimate of around $1.5 million. The lowest estimates did not include funds for data collection and validation and were largely based on minor adaptation of an existing model to a broader region. It should be also noted that several experts preferred not to provide a budget estimate because they think any estimate would need to be model-based and model-specific. Accordingly, they would need more information on the details of the final model scope to provide a cost estimate. Further, the experts highlighted how the budget estimate for *stitching* two models together would actually be higher than the estimate for building a brand-new model, due to the previously mentioned difficulties associated with such an approach.

Question 3: What should be expected of the modeling approaches and requirements to account for the impacts of the new transportation technologies and emerging mobility services?

Question 3a: Ridehailing (e.g., Uber/Lyft):

Approximately 90% of the experts agreed that ridehailing should be explicitly accounted for in the model. Considering a 12- to 18-month range for model estimation, the experts suggested starting with including ridehailing in mode choices. They mentioned that ridehailing is needed to capture some specific travel options, including airport access/egress, long(er)-distance ridehailing use (which might compete with rail services for regional travel), and first/last-mile access to public transit stations, because ridehailing services may substitute or complement public transportation, including the railway services on the proposed second railway crossing to be evaluated for the Link21 program.

The challenges of building the ridehailing components are the estimation and calibration due to limited data available on ridehailing. Further, ridehailing plays different roles in different areas (e.g., San Francisco vs. Sacramento) and limited information can be transferred across different regions. Nevertheless, the recent regionwide 2019 TNC survey data could help address these challenges by revealing patterns and trends of ridehailing use at various times and places. Furthermore, Chicago and New York City have provided TNC origin-destination (OD) trip data for calibration, which can serve as good reference sources for this project. Meanwhile, one expert raised a concern that we should make sure the use of ridehailing is not "covered by the noise" in the model, which means the model should be sensitive enough to ridehailing service attributes, and not confound their impacts among other unknown confounding factors. Notably, a large model may have limited sensitivity due the relatively small average proportions of ridehailing trips.

One opposing opinion, indicating that ridehailing was not important, was supported by the evidence that ridehailing makes up a small proportion of all trips, and few people would complete longer trans-bay trips by ridehailing, thus limiting the importance for the inclusion of this type of mobility services in the scope of this project. This expert suggested that while ridehailing would be important for shorter-distance trips, for a larger-scale project in the Northern California megaregion, modelers could conduct a sensitivity analysis to determine the rate at which people might switch to ridehailing from other travel modes, instead of building an explicit component for ridehailing. Moreover, the current ridehailing share can also be estimated from the market analysis instead of being dynamically modeled in the main mode choice set or as an access/egress mode for public transportation.

Question 3b: Pooled ridehailing (e.g., UberPOOL/Lyft Share):

Differently from the previous question, most experts did not recommend the explicit inclusion of the pooled ridehailing option in the modeling framework. Among the rest, only three experts held a neutral attitude on the topic, and two did not answer this question explicitly due to time constraints in the interview.

The main reason for not including this means of travel explicitly in the modeling framework is that the mode share of pooled ridehailing is rather limited (i.e., too small to be relevant) and varies depending on the area of service. The budget and time required for building this component are additional considerations. One expert mentioned that this component should be included if there was interest in simulating a specific scenario related to pooled ridehailing, e.g., a scenario with incentives for sharing. Some other experts provided alternative approaches, e.g., adjust factors for the outputs (based on the general ridehailing mode share), or expansion factors for travel distance and post-model sensitivity analysis.

Those experts who had a neutral opinion thought that this travel option might be associated with larger impacts on society in the longer term (20 years or longer) and is highly dependent on policies that will be implemented in the future.

Question 3c: Connected and Automated Vehicles (CAVs):

Connected and Automated Vehicles are posited to become a very attractive mode of travel in the future, probably with large impacts on car ownership, total travel demand (including trans-bay railway demand), demand for parking, vehicle deadheading, roadway capacity, residential location choices, work location choices, transit station design, etc. To implement this component in travel demand models, experts suggest three main modifications might be needed: 1) auto ownership enhancements: including autonomous vehicles into vehicle ownership models; 2) AVs tour availability: including AVs into activity-based tours; and 3) vehicle deadheading model: considering the deadheading of both fleet vehicles (taxis and TNCs) and privately-owned AVs. Regarding diverse types of models, including this component in a four-step model should be easier than adding it in an activity-based model. In the four-step model, the main challenge will be how to conduct traffic assignment, especially in the mixed traffic environment of human-controlled vehicles (HCVs) and CAVs sharing the same infrastructure. In addition, some experts also mentioned that the model should be tested with different scenarios to analyze the impact of CAVs on travel demand, e.g., with different penetration rates of CAVs, users' age restrictions, etc. Approximately 80% of the experts recommend that some CAV-related components should be included in the model.

Those who think there is no need to consider CAVs explicitly in the model cite the long time before CAVs will become part of our lives, and the fact that it is impossible to model real travel behavior changes brought by CAVs with confidence (and therefore the exact ways to model their impacts). Therefore, it is likely too early and not necessary to consider CAVs in this travel demand model.

Question 3d: Micromobility (e.g., bikesharing, e-scooter sharing, etc.):

About 60% of the experts recommend explicitly adding micromobility options in the model framework. The reason for including this mode is the nature of this project: micromobility can improve access/egress to/from transit stations even though this project considers both long-distance and medium-distance trips. Notably, however, one expert raised a concern that there is a lot of uncertainty related to micromobility, and this mode is overly sensitive to policy. Another expert highlighted the need to redesign transit station catchment areas to fit shared micromobility services. However, we still face some challenges when modeling micromobility. The main reason is that the proportion of trips made with this mode is rather limited, and its inclusion might not be justified by the scope of the project. To solve these challenges, the change in travel behaviors caused by micromobility may be simulated by scenario testing.

Additionally, more data are needed to understand how people access/egress transit stations in the 21 counties using micromobility services. The volume, patterns, and profile of users, trip purposes, etc., in the 2019 TNC survey may reveal important insights that certainly could help create access/egress mode choice components for this project. In any case, micromobility options can be aggregated into a single mode choice option, without the need to break down these services into multiple separate modes (e.g., shared e-scooters vs. shared bikes or e-bikes). One expert also suggested including micromobility in the model through a “super walk” mode and explicitly include it in the lower level of a nested mode choice model or in a post-processing analysis.

Question 3e: Telecommuting (vs. regular commute trips):

The trend of telecommuting has boomed recently because of the COVID-19 pandemic. Approximately 80% of the experts think it is relatively easy to model remote work and/or telecommuting by simply adjusting some factors in the current trip generation models. However, modelers need real-world data (whether from a survey or from passive data) in the study area to support a better understanding of these changes. The market analysis should lay a foundation for this study. Then, modelers can change/modify the factors in the model and explore the impact of telecommuting on travel behaviors and patterns. One expert mentioned the option of using North America Industry Classification System (NAICS) code data to develop advanced telecommuting capacities for both activity-based models and four-step models. In addition, one expert pointed out the difference between a work-from-home model (which models the decision of some workers to have a home-based job) and a telecommuting frequency model (i.e., the decision of certain commuters who do not work permanently work from home to eventually telecommute on certain days), which should be considered when dealing with telecommuting.

While several experts believe partial telecommuting might persist in the longer term, after the end of the pandemic, one expert thinks the higher levels of telecommuting caused by COVID19 (which replaced up to 40-60% of total commuting trips in the midst of the pandemic) will not last longer than 2–3 years. After the end of this pandemic, this abnormal trend will halt, and in this view the issue will be of less relevance in longer-term scenarios. Overall, it remains uncertain how many trips will continue to be replaced by working from home solutions in the longer term, or will converge back to normal levels (as before the pandemic). Accordingly, multiple scenarios should be evaluated. A prudent strategy would be to wait 2–3 years after this pandemic to see what the travel patterns will be.

Question 3f: Online shopping (and its impacts on travel):

The opinion of about 40% of the experts is that online shopping will grow in the future and, for this reason, it should be explicitly accounted for in the modeling framework. One expert mentioned that transportation system simulation to explicitly account for e-commerce impacts in the modeling framework has been conducted previously. Even though there is no state-of-the-art approach to deal with this issue, modelers can purchase data and/or collect survey data to develop this component in the model. However, we still face challenges because it is hard to incorporate the influence of more frequent online shopping into the modeling system. Furthermore, many of the current models used in the study area do not have a detailed freight component. Advanced freight models might require substantial, additional funds and require substantial data. In some respects, developing a freight model can be more challenging than developing an advanced passenger model. Therefore, if the impact of e-shopping on freight travel had to be included in the modeling framework, more effort would be needed to build such a component. But the connection between e-shopping and freight travel might be of secondary relevance for this project. Nonetheless, online shopping will reduce personal shopping-related trips. In an activity-based model, including/excluding a shopping trip in a tour does affect the choice of modes for the tour. Therefore, the model could and should be modified (or adjusted) to either consider online shopping as an explicit choice or to reduce the probability of making certain types of shopping trips that are more likely to be replaced by online shopping options. Meanwhile, the redistribution of warehouses and distribution centers will also likely affect vehicle miles traveled (VMT). Only one expert believed that online shopping will not significantly substitute for physical shopping trips and therefore would not be relevant for this project. Another expert also mentioned the consideration of commercial vehicle trips (e.g., Amazon Prime last-mile delivery) in developing the model, which could include: 1) the linkage between shopping trips/shopping activities in activity-based modeling (ABM) and the last-mile delivery; and 2) the routing of last-mile delivery and fleet operation, which has a direct impact on VMT and traffic congestion.

Question 3g: Impacts of extreme events, e.g., COVID-19 pandemic, earthquake, hurricane, storms, etc., on future travel patterns:

Almost all experts suggest running scenarios to simulate the impacts of extreme events on travel behaviors, e.g., to consider potential transit ridership reductions. Additionally, some experts also mention that we need to pay attention to the change of infrastructure caused by extreme events, e.g., changes in transit capacity due to health considerations (as has been the case with social distancing during the COVID-19 pandemic) or the elimination of certain network links after an earthquake or major storm(s).

On the other hand, extreme events may force some people to work from home, and some economic activities may be suppressed, etc. As such, the range and level of effects will differ in both temporal and spatial dimensions, with most impacts likely to have a predominantly temporary nature.

Question 4: Should land use and economic development explicitly be considered in these models?

Regarding land use, several regions in the US have developed land use models that are fully integrated with their travel demand forecasting models. Examples include the UrbanSim model for the MTC region and the PECAS model for the Atlanta Regional Commission (ARC). However, only a few regions have operational land use models after several years of investments in model development and successive stages of model refinement.[4] The prospect of the development of an integrated land use and travel demand model framework is expected to add considerable complexity to the model development process.

Regarding economic development, there are well-established models such as REMI, TREDIS, etc. that can predict economic activity. Many planning organizations are using these models to provide economic input for future scenarios in their travel demand forecasting models.

In sum, a full integration with land use and economic development models is ideal for modeling how transportation and access to it will evolve in future years, and how they would affect land use and economic development. Such modeling would consider a wide range of land use, employment, and socio-demographic policies and strategies. Meanwhile, with BART extensions and the introduction of new stations, development patterns around the stations will have a measurable impact on ridership and travel patterns. There may also be cascading effects of intensified development around and near stations, and more development will likely happen in areas that enjoy better transportation services and faster access to jobs and other destinations/amenities.

---

[4] Most notably, the development of PECAS models was initiated in California at the statewide level and the regional level in selected MPOs (e.g., in the SACOG region), but the process was interrupted due to modeling difficulties and the costs of development that turned out to be higher than initially estimated.

However, a full integration is not feasible in the desired timeline for the ridership forecasts and the evaluation of other transportation and environmental impacts of the new transportation infrastructure in this project. Therefore, land use and economic activity assumptions can be introduced as exogenous inputs in various scenarios of future development for the Northern California megaregion and tested against alternative scenarios in the travel demand modeling framework, as suggested by about 70% of the experts. There is no realistic expectation that land use impacts of transportation changes can be dynamically modeled in this modeling framework.

Question 5: How could the model(s) be calibrated/validated considering that data for new technologies (e.g., CAV) are not available yet?

Without appropriate data, modelers cannot calibrate/validate a model. However, they can refer to the literature to develop a modeling approach and compare results. The most often mentioned approach is running multiple scenarios as part of a sensitivity analysis, based on documented evidence, mainly derived from stated preference surveys of the public, expert interviews, or virtual simulation experiments from the literature.

Furthermore, experts also raised a concern that the assumptions included in scenarios have a certain level of uncertainty, while a model might tend to overfit to the existing conditions. Such a problem may be exacerbated when testing the introduction of new transportation technologies, which might take the model outside the boundaries of application of the model (i.e., range of applicability, outside which the modeling assumptions do not necessarily hold).

Question 6: Do you have any additional recommendations for the development of this work?

The experts have the following additional suggestions:

1. Some key questions should be answered: What are the key project markets? Who are the travelers in those markets today and what do they experience? How do those markets change with the introduction of the proposed alternative? For each question, the answers can be quantified in terms of time, cost, characteristics of the riders, user benefits, and the influence of the alternative specific constants.
2. The Link21 program should build on the market analysis to determine what counties should be included in the study area. Counties that have little interactions with the Link21 program could be eliminated from the study area. This would reduce the time and effort required for preparing the transportation network, collecting data, running the model, etc.
3. It is suggested to consider short-term and long-term modeling approaches. Developing/using rail ridership models for the short term and develop a more complex model for long-term use seems an appropriate solution.
4. Freight modeling should be included since it is likely that there will continue to be rail corridors that are shared between passenger and freight trains.

5. Modelers should consider the possibility of including ridehailing (including pooled ridehailing), mainly as an access/egress mode to transit stations.
6. Air quality model components should be linked to/included in the model.
7. A dynamic simulation should be better to address extreme events (e.g., the COVID-19 pandemic) than a static model.
8. Benefits would derive from considering a compatible platform to implement this model, harvesting the multiple-MPO joint efforts and the move to ActivitySim.
9. Modelers should pay proper attention to the running time, which might be significantly increased by adding too many components to the model.
10. There is often a lack of adequate attention to model calibration and validation. Model calibration requires an in-depth analysis of observed and estimated values, and not the simple adjustment of alternative specific constants to match aggregate targets (as it is sometimes done in the modeling practice).
11. It is extremely difficult to evaluate the accuracy and reliability of the forecasts. We need a proper interpretation of the results and insights drawn from the forecasts that would be of value to decision-makers.
12. The proposed schedule does not allow sufficient time for the local agencies, as well as the consultants, to see what emerges as the post-COVID “new normal” for person travel patterns by mode, purpose, and time-of-day. Any forecast-related work performed in this timeframe will eventually need to be “refreshed,” based on 2023 and later observations of passenger travel.
13. It is important to note that if emerging big data was used, it will need to undergo some level of validation checking, using data that was not available to the consultant/vendor that prepared the big data estimates.
14. Proper integration of an advanced ABM with dynamic traffic assignment (DTA) is another dimension and can take up to one million dollars for a large region.
15. The newly developed model should be able to perform equity analysis.

5 Recommendations for Travel Demand Modeling Approach

Given the timeline and requirements of the Link21 program, there are different needs for short-term and long-term modeling purposes. This means that the program will require developing a rail ridership model for the short term, which will need to be set up and be in operation as soon as possible, while a more comprehensive modeling approach is built for long-term uses. As the development of the short-term model is already underway at the time of writing of this report, in the remainder of this section we will mainly focus on the longer-term modeling recommendations. The expectation is that the development of the long-term model should be carried out within 18 months, though an incremental and modular approach could be conceived, meaning that additional improvements and refinements could be added after that initial period. This would follow a customary approach in modeling practice, in which further model developments and updates are implemented in steps, with the release of new versions of the model and other updates that are implemented after the initial version of the model becomes operational.

In this section, we discuss a range of model properties that the long-term modeling approach should feature and incorporate as well as some additional ones that are desired but could be considered optional. The additional features could be implemented in later stages of the model development and improvement program after the initial version is set up and put into operation.

This chapter is structured in the following way: first, we explain the process that led to the conceptualization of the list of criteria for the evaluation of the modeling features as well as the proposed modeling recommendations. We then discuss the details for each modeling feature, including, but not limited to, the spatial considerations and time requirements, the demand modeling structure and characteristics, the way to account for built environment characteristics, the level of service of public transportation, transportation accessibility, and the impacts of new transportation and communication technologies, among others.

We classify each modeling feature as *critical*, *important*, or *optional*. Then, existing models that have been included in the review in the previous Chapter 3 are evaluated based on the proposed modeling features. Finally, we describe four possible modeling approaches that could be undertaken to forecast travel demand in the Northern California megaregion and account for the impacts of the Link21 program. These are:

1) Build on the MTC TM 2.1 without a long-distance component;

2) Build on the MTC TM 2.1 with a long-distance component;

3) Build on the SFCTA model (either with or without a proper long-distance component); and

4) Build on the CHSR or New Rail Statewide model.

We discuss the extent to which each approach meets the proposed critical, important, and optional modeling features. We summarize in a table the way each modeling approach includes (or eventually does not include) these modeling features. Finally, we conclude by discussing the main pros and cons of these four alternative modeling approaches.

5.1 Modeling feature conceptualization

We created a list of criteria to evaluate different modeling approaches that may be used in the Link21 program. To do this, we first considered a list of goals, objectives, and performance metrics that had been established for the Link21 program:[5]

I. Transform the Passenger Experience
  1 Provide better service
    - Network integration
    - Total travel time
    - In-vehicle travel time
    - Availability
    - Frequency
    - Crowding
  2 Improve reliability and system performance
    - On-time performance
    - Ability to maintain existing and new infrastructure
    - Flexibility to meet future growth
    - Viability in emergencies
  3 Build ridership and mode share
    - Ridership
    - Mode share
    - Vehicle miles traveled (VMT) reduction

II. Enhance Community and Livability
  1 Enhance connections between people and places
    - Job accessibility
    - Work/Non-work trips on network
    - Accessibility of transit options
  2 Improve safety, health, and air quality
    - Expected local pollutants
    - Auto-involved crashes

---

[5] Subsequent to the analyses conducted for this report, the Link21 program has made modest revisions to the goals, objectives and performance metrics, producing the revised list that is reported in Appendix B.

    - Active mode access to transit
    - Coverage of areas of health concern
  3 Advance equity
    - Affordable transportation options

III. Support Economic Growth and Global Competitiveness
  1 Improve access to opportunity and employment
    - Number of jobs within walk/bike distance
    - Business access to potential employees
    - Business access to potential markets
  2 Connect major economic, research, and education centers
    - Travel times between major centers,
    - Travel times between major centers and transportation hubs
    - Trips between major centers
  3 Enable transit-supportive land use
    - Local land-use policies consistent with large capital transit investment

IV. Advance Environmental Stewardship and Protection
  1 Increase climate change resilience
    - Viability under different sea-level rise inundation scenarios
  2 Reduce greenhouse gas emissions
    - GHG emissions
  3 Conserve resources
    - Energy consumption for transportation

Consistent with these goals and objectives, the Link21 team identified a first set of criteria with which to evaluate the potential modeling approaches to support the Link21 program. Accordingly, the modeling tool must be able to:

1. Model travel throughout the Northern California megaregion;
2. Effectively model substantial network and service improvements to existing rail services;
3. Effectively model the implementation of new BART and regional rail services;
4. Model the network impacts of other services, particularly other new rail projects such as DTX, Caltrain improvements, HSR, and Dumbarton Rail;
5. Model competitiveness between auto and rail. This may include considerations of tolls, parking, and congestion among other factors;
6. Model constraints on rail capacity, both on the transit system itself and at park-and-ride facilities;
7. Model land-use impacts of new and improved rail services;
8. Model the impacts of new technologies and travel behavior (*e.g.*, teleworking);
9. Model congestion pricing;
10. Model peak and off-peak ridership;
11. Model VMT by mode;

12. Model travel time savings for trips served by new/improved services;
13. Compute a metric reflecting the level of accessibility of equity groups to new/improved services;
14. Compute a metric reflecting the level of accessibility to businesses.

As part of this project, the research team cross-tabulated the overall Link21 goals and initial proposed criteria list, expanding the list through incorporating modeling features that emerged as relevant based on the review of previous modeling studies, interviews with the experts, meetings with the agency staff, and our understanding of the modeling needs of a project such as Link21.

Accordingly, a proposed revised list of modeling features that should be considered was created, including the following major items, which are selectively subdivided in sub-features, as discussed in later sections of this chapter:

1. Timeline and running time
2. Geographical considerations
3. Rail services modeling
4. Service integration modeling
5. Travel time
6. Travel cost
7. Hours of operation
8. Service frequency
9. Crowding and capacity constraints
10. Reliability
11. Future land use
12. Transit ridership
13. Mode choice modeling
14. VMT estimation
15. Job accessibility
16. Transit options accessibility by different groups
17. Access and egress modes
18. Impacts of new communication technologies
19. Impacts of new transportations options
20. Freight transportation effects

5.2 Main modeling features

In this section, we present the main modeling features that were investigated and considered important in the preparation of the modeling recommendations for the Link21 program. These modeling features are further divided and categorized in section 5.3. The items involve different areas, such as the different scales that the model needs to account for, the need for the model to handle multiple travel modes, level of service attributes, and the impacts of modern communication and transportation technologies, among others. To the extent possible, we also discuss the practical implications that these modeling features involve.

5.2.1 Timeline and running time

Given the existing timeframe for the Link21 program, the core travel demand model must be developed within an estimated 18-month timeline. In addition, the model could incorporate additional modules at a later stage. This means that the proposed solution should be flexible enough, and modular in its nature, to provide valuable insights during its first phase of operation, while also being able to evolve according to the agency's future needs.

In terms of running time, it is not only important that the model's computation time is fast enough to complete the needed scenario runs, but also that the time to prepare the data and input for each scenario should keep the project manageable and allow the agency to design and run the scenarios within the proposed timeline. This is important as the Link21 program will require the evaluation of multiple scenarios over a large geographical area (see the following modeling feature, described below), with complex land use patterns and transportation networks in the Northern California megaregion. While recent hardware and software enhancements and multi-core parallel processing allow for faster running time, still this requirement will likely represent a major area of tradeoff between the need to have a satisfactory level of geographic resolution and ability to model activity and travel patterns with sufficient details and rich behavioral realism, and the need for relatively fast creation and modeling of scenarios.

Running time is also an important factor to consider when choosing the software platform and modeling approach. This is because different modeling approaches and software platforms can handle different model details and scenario input complexity and operate at different computational speeds. Further, the eventual inclusion of additional modules in the overall modeling framework should be evaluated from the perspective of the time required to develop the modules, the running time of the model and its ability to handle complexity. Additional model components, including those that could be added in later phases of the model development, could add significant complexity to the modeling framework and increase the overall running time for the model.

5.2.2 Geographical considerations

The model should model travel by various travel modes through the entire Northern California megaregion. That is, it should be able to operate at and handle multiple *scales* and travel purposes in the 21-county megaregion at the same time, including, to the extent possible, longer-distance travel components (including medium-distance and long-distance trips for work-related and non-work-related purposes made by intercity rail, private cars, or other modes) and shorter-distance travel (including trips made at the regional and local level for various work/commuting and non-work/non-commuting and discretionary travel purposes).

In San Francisco (Figure 5.1) as well as in the entire Northern California megaregion (Figure 5.2), short-distance travel includes trips made by various means of travel, including car, local transit, BART, regional rail, but also ridehailing/TNCs, taxis, active modes of travel as well as other local options including ferries. These are usually modeled in activity-based travel demand models through the simulation of the activity participation and resulting travel of all individuals and households that reside in the region of interest (e.g., forecasted as members of a synthetic population in the model) for the average weekday in spring or fall, where schools are in session and time off from work (and related vacation travel) is usually low.

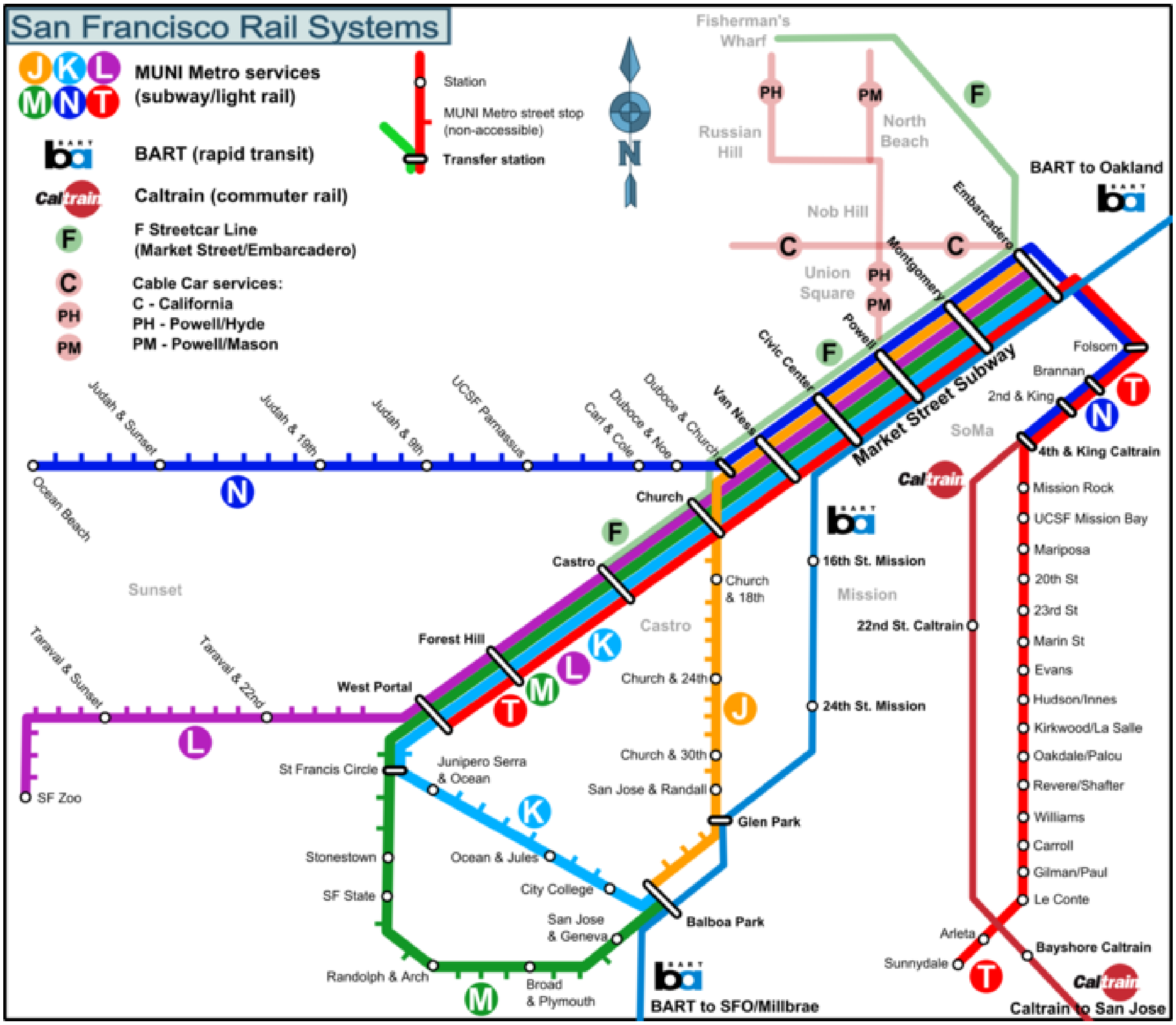


Figure 5.1 San Francisco Rail System Map (Reused under creative commons licenses. Source: https://commons.wikimedia.org/wiki/File:Sanfrancisco_railsystem_printmap.png)

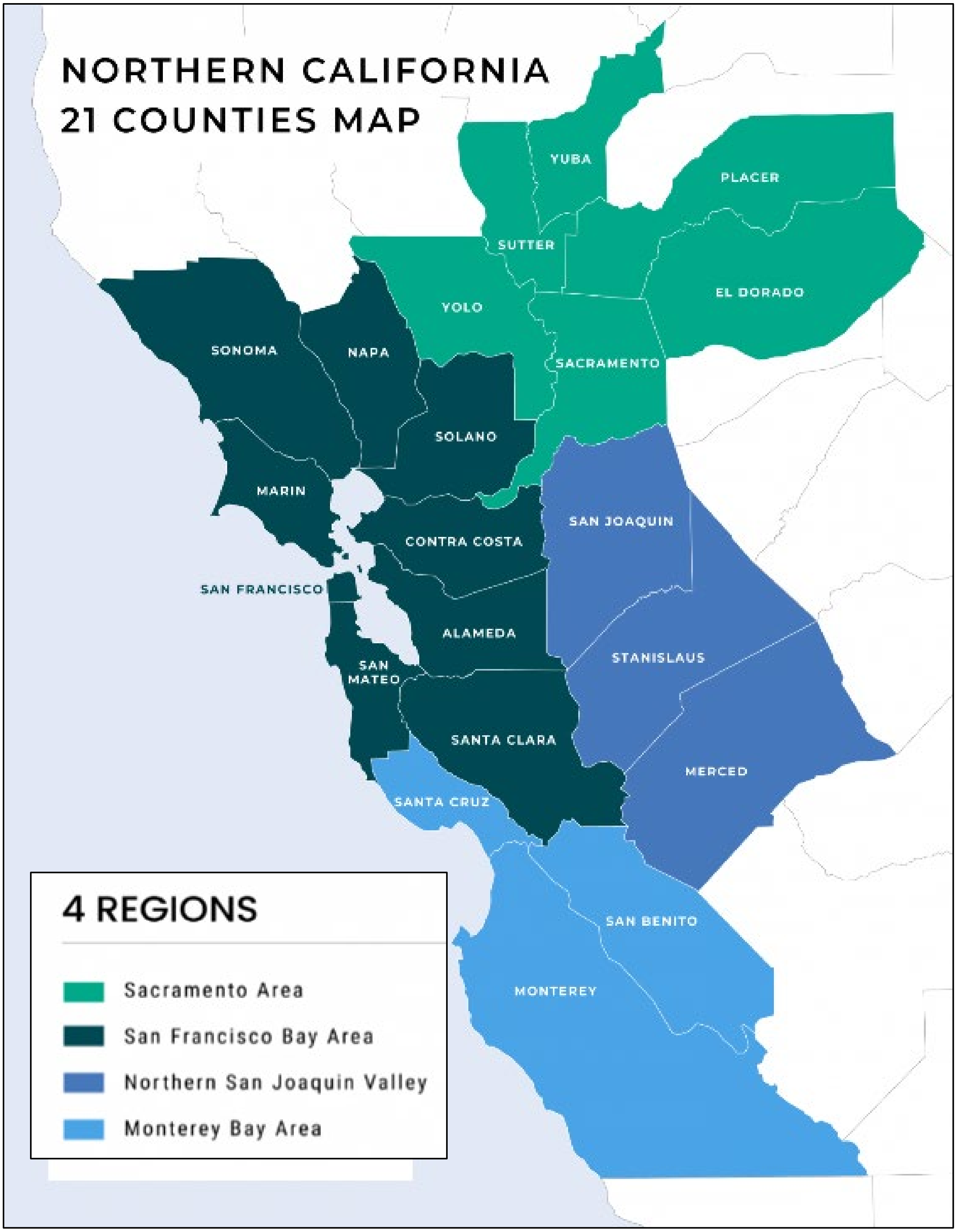


Figure 5.2 Northern California 21 Counties (Source: Link21 program website, https://link21program.org/en/about/northern-california-megaregion)

Longer-distance travel includes travel over medium distances inside the megaregion (e.g., trips made by private cars, regional rail, and intercity buses along the I-80 corridor between the Bay Area and the Sacramento region, and trips to/from the northern portion of the California Central Valley), as well as longer-distance travel to/from the megaregion (i.e., that have the other end of the trip in other parts of the state, or even outside of California) that might be relevant for the flows that cross the Link21 section and might involve the rail system in the region. These components of travel are often modeled in regional models as external travel that crosses the boundaries of the model region. In statewide and larger-scale travel demand models, they are often modeled through the integration of a proper long-distance travel component for either business or leisure/personal purposes.

Being able to address these various components of travel demand is an extremely desirable requirement as many of the potential benefits of the Link21 program will be distributed across different geographic scales, and might come from the interaction between longer-distance and regional/local transportation. Thus, modeling the two in the same modeling framework, and not under two separate modeling systems, if possible, would be preferable.

In addition, the model needs to account for a sufficient level of spatial detail so it can handle multiscale and multimodal travel, including a proper representation of access/egress trips to and from rail stations. It should have a fine level of simulation of activities/travel patterns that generate the use of travel modes for different travel purposes at the various scales, in particular for the subregions that are most relevant for the Link21 movements and travel corridors. To do this, the model needs, among other features, to have a zoning (e.g., through the definition of its transportation analysis zones, or TAZ) system that is detailed enough for these purposes, so it can analyze, for example, the impact of different locations of railway stations, new line alignments, and a new Transbay rail crossing (either a tunnel or bridge).

In addition, the way the model codes the transit network should be easy to understand and easy to manipulate regarding new infrastructure and service improvement. For example, some models use a simplified network for larger scale and long-term planning, which offers a compromise to simplify the model coding, but that approach would not be well suited to study the impacts of public transportation network changes in the Link21 program.

5.2.3 Rail services modeling

The model must have the ability to model the improvements in individual rail services, such as BART, commuter rail, streetcars. It needs an explicit representation of the transit rail network and the entire range of the services provided. To do so, the transit rail network operation, capacity constraints, station location, schedules, frequency of services, and travel times need to be explicitly coded in the modeling framework.

In the case of high-frequency services, such as BART, the model system will likely rely on using a scheduled operation, with the caveat of considering random arrivals at the stations and reflecting headway variability when modeling irregular services. Infrequent and long-distance train or intercity bus services should be modeled through departure times, assuming that travelers will arrive at the station to catch a specific train according to the posted timetable. This criterion is extremely important as transit ridership and mode share forecasts are crucial factors to consider in planning for new public transportation infrastructure.

One of the most important aspects of this project is the potential shift from private cars to public transit. Thus, transit needs to be well modeled, and the model needs to realistically replicate mode choice processes, including the ability to produce realistic estimates of the impacts of new infrastructure and services on the utility (and resulting probability of choice) of the mode to use (and other related travel choice components). This is not possible if transit, and the rail network, is modeled exogenously, e.g., using equations that extract information from the travel demand forecasting model for automobiles.

5.2.4 Service integration modeling

The model should include longer-distance and regional trips, and be able to model intermodal trips connecting across different services. Thus, it is important to consider multiple transit modes, including bus, metro, railway (and potential high-speed rail services that will be deployed in California). For example, railway-metro trips might be a relevant alternative to those commuting by car to downtown San Francisco on the Bay Bridge corridor, a very important market for the Link21 program. To account for these, transfers between different modes need to be accurately modeled, and the model needs to be able to capture travel behaviors and be sensitive to the penalties that travelers associate with transfers across modes. The model should also capture the detailed configurations and possible impendence functions for transfer stations. For example, the model should distinguish between, and capture the impacts on travelers' utility and choices of, a seamless cross-platform transfer versus one that requires a long walk and/or wait. This modeling goes beyond typical transit integration, as in bus and metro, but also needs to consider integration with active travel modes, new mobility services and park-and-ride facilities.

The service integration is a critical feature the model should have as the Link21 program blurs the distinction between BART and regional rail, and future scenarios might involve a new crossing and expansion of the rail network and services involving either or both types of rail systems. Such integration is relevant to better capture the reality of transfers across multiple transit systems, as it is important to consider connectivity when improving the network performance, and the ability of the various rail improvements to eventually attract travelers from other modes such as private vehicles.

5.2.5 Travel time

The model must consider the impacts of travel time on the various travel behavior choices. Accordingly, travel time should be included in the utility functions in different steps of the demand modeling (and not only in the mode choice component). Further, the various components of travel time (e.g., in-vehicle travel time vs. out-of-vehicle travel and waiting time) need to be accounted for separately, as they have been shown to have different impacts on the utility that passengers associate with certain travel modes, in particular for public transportation options. In addition, the different characteristics of services—e.g., the speed of different types of services and modes—should be differentiated, for example for intercity express service vs. all-stop BART service, leading to more accurate quantification of travel time and disutility coefficients.

The model needs to capture realistic elasticities of the travel demand for different modes with regard to the various components of travel time. That is, the model should accurately capture the extent to which transportation demand changes when travel times change, for both current rail services and future network changes. The model should also create a range of realistic forecasts for future years that allow comparisons of different investments (e.g., decisions to increase frequency, and therefore reduce waiting time, or to improve coverage and/or speed, and therefore reduce in-vehicle travel time). Otherwise, there is a risk of misestimating the current and future demand of the proposed project. The model needs to be estimated and calibrated in a way where changes in various components of travel times are effectively reflected in appropriate and realistic changes in travel demand.

Similarly, the model needs to have enough spatial resolution to properly account for and capture the effects of travel times between various combinations of origins and destinations. Not only should the model be able to account for travel times (and changes in travel time) between major centers, or stations, it should also be sensitive to travel time changes between origins/ destinations and various transportation hubs where travelers can access/egress various transportation options. This way, it can be used to assess the impact of various public transportation investment options. Further, it needs to properly account for the travel times needed to access/egress stations by various modes (whether this happens at the intra-zonal level, or between different zones).

5.2.6 Travel cost

The model must account for the different impacts of travel costs on mode choice and other components of the travel demand, for transit and other modes (e.g., cars). Beyond accounting for traditional costs—such as transit fare, gasoline, and parking—the model needs to have a specification that accounts for new policies that could be implemented in the megaregion, including road pricing and congestion pricing. These policies have been gaining popularity in recent years and could be implemented in the region in future years. To account for such policy changes, travel costs should be included in the utility functions in the different steps of the travel demand modeling.

In addition, the model needs to capture realistic elasticities of the travel demand for different travel modes with regard to travel costs (both direct and cross elasticities). That is, the model should accurately capture the extent to which transportation demand changes when travel costs for various means of travel change, for both current services and future proposed changes, and this needs to be appropriately reflected in the range of forecasts for future years.

The ability of the model to properly handle travel times and travel costs for various modes should result in reasonable estimates of travelers' willingness to pay to shorten travel time, and/or the value of travel time. These measures are usually found in the literature to vary by trip purpose (for example, travelers that are traveling for work/business purposes usually exhibit a higher willingness to pay to reduce their travel time), travel mode, and income category. Similarly, willingness to pay to shorten travel time has been shown to differ for (less frequent) long-distance travel vs. short-distance travel.

Accordingly, the model should account for different utility functions for distinct types of travelers and different components of travel. This is usually achieved through considering different utility functions and parameters for different tour and trip purposes, and for individuals belonging to different groups. The adoption of an activity-based modeling approach with a population synthesizer allows the model to distinguish and simulate different activity patterns and travel choices for individuals. Otherwise, there is a risk of misestimating the current and future travel demand for the proposed projects. Ultimately, the model needs to be estimated and calibrated in a way where changes in travel cost reflect changes in travel demand effectively.

5.2.7 Hours of operation

The model should be able to estimate the benefit of extending service hours for public transportation, even if this might be difficult to do, in particular for models that operate with the traditional peak/off-peak time-of-day definitions. For example, the cost of a missed return trip because of limited-service hours is high for those living far from the trip origin, when reasonable alternatives might not be available. This situation would increase the mode share for private vehicles for certain trips, especially during certain times of the day. By extending service hours, trips by public transit could be encouraged, which is essential to the Link21 program. However, this would require a change in how maintenance is performed, especially on the BART system, which conducts maintenance during non-revenue service hours. Accordingly, being able to establish the benefits of eventual modifications in the hour of operations for certain services and/or lines would help show the benefits vs. costs for such a modification.

The definition of hours of operation is typically part of an operational model and not usually included in a large-scale travel demand model. The limitations in this case are mainly on the assumptions included in the supply side of the model, as modern activity-based travel model can account for fine time intervals for the prediction of when trips happen. However, the computation of the attributes of the travel alternatives and travel skims between origin and destinations (for both road travel and public transportation availability) is often done using a separation in rather coarse times of day, e.g., four or five major time-of-day periods, each one spanning several hours of the day, in which the road assignment is carried out and variation of the transportation service *inside* each period is not properly captured. Still, given the characteristics of the Link21 program, the model should make some set of assumptions to be able to evaluate the benefits deriving from changes in hours of operations. For example, finer time intervals could be used in the model, or at least this should be modeled exogenously from previously generated travel demand matrix tables that are sensitive to these different service hours scenarios.

5.2.8 Service frequency

Many of the benefits of several scenarios in the Link21 program come from the improvement in service frequency, especially for regional rail. Thus, the model must be able to account for the benefits that an increase in frequency might have on passenger demand in different scenarios, the extent to which passengers may shift from other travel modes to rail, and the level of induced demand that the project may produce.

In addition, specifically for bus systems, in a high-frequency public transportation context, it is important to consider headway variability (regularity). In the absence of headway control systems—i.e., online management to maintain even headways between consecutive vehicles—the increasing frequency might cause or increase vehicle bunching, which has serious effects both in the expected waiting time and passenger occupancy (crowding) for bus services. However, the headway control for rail systems is usually more robust since trains are closely monitored by control centers and dispatchers.

5.2.9 Crowding and capacity constraints

The model needs to consider the level of crowding in transit services and its effects on travel demand, as well as the capacity constraints in the transit systems. This is important for the BART component of the transit system, as many benefits of several Link21 scenarios come from relieving crowding on transit during peak times. To account for these effects, it would be important to incorporate crowding into travel time valuation and travelers' utility functions. If it is possible for a traveler to miss a transit vehicle (either bus or train) due to crowding, not accounting for in-vehicle capacity would underestimate the waiting time, in addition to ignoring the impacts of crowding on passengers' (dis)comfort and on the decision to switch to other modes during times of high demand and crowded conditions.

The impacts on comfort and (un)pleasantness of a trip would affect the utility of public transportation even if the traveler does not need to wait for the following train. Crowding is less important for longer-distance intercity and commuter rail in the Northern California megaregion, such as the train services provided by the Capitol Corridor Joint Powers Authority (CCJPA) as these types of services usually do not run at capacity and crowding does not usually affect travel feasibility or comfort in a significant way. However, it is worth noting that during pre-pandemic times, Caltrain Baby Bullet express trains often had standing room only and, since Caltrain trains also carried many bicycles, bicyclists sometimes could not board the train because of limited space.

Highway capacity also needs to be properly considered in the model. If highway network capacity (by road type) is not properly considered, the congestion effect is neglected (or not properly captured) as the model would not translate the presence of more vehicles on the road in longer travel time. Thus, travel times (and the resulting generalized travel costs) for the auto mode (and eventually for the bus alternatives, if/when they share the road with private vehicles) would be underestimated. Highway capacity is a rather standard feature of most modern travel demand forecasting models, and therefore highway capacity is more easily accounted for than transit capacity in general.

As an optional added feature, the model might incorporate capacity constraints for park-and-ride facilities. This is a relevant factor affecting the travel choices of those who might consider traveling by rail but do not live near a station. While it is less relevant for central BART stations in San Francisco and other urban areas, which usually do not have parking facilities and rely on other access/egress modes, this is particular important for the access/egress to rail stations in more suburban and less centrally located areas.

5.2.10 Reliability

On-time operation reliability is an important factor for transit use and needs to be accounted for when modeling transit. The negative effect that disruptions and delays have on passengers' perceptions are considerable, as they may cause a negative and unpleasant experience during the trip. Previous negative experience, in turn, might cause disaffection from the service, reducing popularity of transit services, especially among passengers who have access to multiple other travel alternatives) and in locations where transit services are not highly adopted and/or popular among travelers.

As the most negative experiences tend to influence travel choices to a higher degree than average and good experiences, the effect of delays might be underestimated and lead to overestimation of travel demand for public transportation. However, given that reliability is often not well accounted for in large-scale travel demand models, it might need to be evaluated outside the travel model.

5.2.11 Future land use

It is a critical feature that the model considers different scenarios for the future growth of the region of study, in terms of population, employment and jobs, economic activities and land use changes. Land use characteristics can be included as exogenous input in the travel demand model. The model would work with different land-use scenarios, and needs to be able to capture the impacts of land use features. Scenario analysis can consider different assumptions about future development of activities and land use in the region. These land-use scenarios consider, among others, the evaluation of local land-use policies consistent with large capital transit investments – measured by priority development areas (PDAs) and other standards, including zoning and BART station area standards – or the evaluation of the impacts of current and potential future land uses within station catchment areas (*e.g.*, number of residences in priority areas within walk/bike distance thresholds of new or improved service).

However, it might be difficult to estimate the impact of better-designed stations and urban design around the stations using conventional large-scale travel demand models.

Given the limited time to develop the model, it is not feasible to consider a model that accounts for transportation and land use development simultaneously, at least in the first model release. This means that it is not expected that explicit land-use modeling components will be included in the Link21 modeling system. Endogenously accounting for the land-use impacts of new and improved rail services is complex. Thus, it will likely not be part of the Link21 modeling, but can be studied to some extent through various alternative scenarios.

5.2.12 Transit ridership

The model is required to model ridership realistically, as all (or almost all) benefits from public transportation projects are calculated based on the number of passengers traveling under different conditions. The model should ideally operate at a fine enough level of spatial details and explicitly code the various transit lines and services that are operated. This would enable accurate forecasts for station-level ridership, if necessary. It can also allow the postprocessing of the estimated ridership to any desired (coarser) level of aggregation to evaluate the number of trips between major centers, between zones of specific interest, etc.

In addition, the model is expected to output ridership in a detailed enough manner for different time of day periods and to distinguish trip generation for different trip purposes. To do this, the model would need to explicitly forecast public transportation demand and assign transit trips to the transit network by time of day, in a public transportation assignment module.

Most operational models usually model demand on a typical working day during spring or fall, when schools are in session. Accordingly, they do not consider weekend travel, and travel during summer or other holiday seasons. However, an optional desired feature is to consider the usage of additional data, such as passively collected trip tables, to calibrate adjustment factors to model weekends, if this is considered a priority for the planning of certain services.

5.2.13 Mode choice modeling

One of the most important aspects of this project is the evaluation of potential shifts from private cars to transit. To enable that, the model must correctly model mode choice (including the choice of both the main travel mode(s) and any eventual connecting modes). Mode choice (and the resulting mode shares) is an important factor to consider in planning for new infrastructure. This is especially important for the case of auto and rail competitiveness. This is not possible to do if transit, especially the rail network, is modeled exogenously from the rest of the model components for automobiles, or if the model does not properly capture travelers' response to improvements and/or changes in certain travel mode attributes.

There are multiple potential causes for mode choice component to fail to represent the mode shift accurately: 1) it could be caused by the wrong estimation of model parameters in the utility formulation for the mode choice component; 2) It could also suffer from the lack of sufficient details in the measurement of the attributes (which might not allow to properly measure the benefits, for example from changes in access/egress time); 3) It might also be the result of the overfitting of the model through an extensive use of constants, which often improve the ability of the model to replicate the current travel conditions in the base year scenario, but limit the ability of the model to forecast the impact of potential changes to the status quo. If mode choices are inelastic to rail improvements, then most of the expected benefits of the Link21 program might not be captured. On the other extreme, if the model overestimates the responsiveness of travelers to improvements in rail option attributes, it could lead to a substantial overestimation of future demand for transit.

The need for the inclusion of a realistic travel mode choice component automatically limits the ability to use certain types of simplified (e.g., spreadsheet) models that are often used for the estimation of transit ridership but have limited ability to forecast mode shift for the longer-term modeling purposes of this project. Further, the mode choice component of the model should include all means of travel relevant to this project. For transit and other modes, the utility function associated with the use of each available means of travel (or the generalized cost function) should consider factors including access and egress modes (including travel times and costs), in-vehicle travel, number of transfers, and congestion (crowding) effects.

In addition, the model should be able to capture travel shift in time of day. This is related to the potential dynamics in the travel demand generation, traffic control strategy and tolling, and changes in level of service and network capacity during the day. This is also related to the design of time intervals in the model, e.g., morning peak, midday, afternoon peak and after-hours. If the model uses a set of constant travel demand during a day, it might fail to consider, for example, different train fares at different periods, off-peak transit passes, people starting their trips earlier to avoid congestion, and different tolls and congestion pricing at certain times of the day.

The use of an ABM that accounts for the travel impendence in the components of activity generation and daily patterns would help account for modeling mode choice. However, most models consider aggregate measures (e.g., logsums) to feed these activity and travel patterns model components, which might not be very sensitive to minor adjustments that affect, for example, the time of departure for a commuting trip to avoid congestion/crowding.

In addition, the model should consider induced demand implications. This is especially important when evaluating the feasibility of new infrastructure and level of service improvement, as in the Link21 program. Induced demand refers to the increase in demand beyond predicted values because of the decrease in relative costs and or times when increasing supply (see Figure 5.3). In this case, the project will feature increased rail transit capacity and level of service improvements, which will translate in improved travel times and frequency with rail transit and could possibly affect transportation costs. Thus, the model must be sensitive to potential induced demand associated with changes in both travel times and costs, which can be used to test various scenarios and effectively help provide input into the cost-benefit ratio and financial viability. If these aspects were not properly considered, this would lead to an underestimation of travel demand, and it would not properly account for all demand impacts (and congestion impacts).

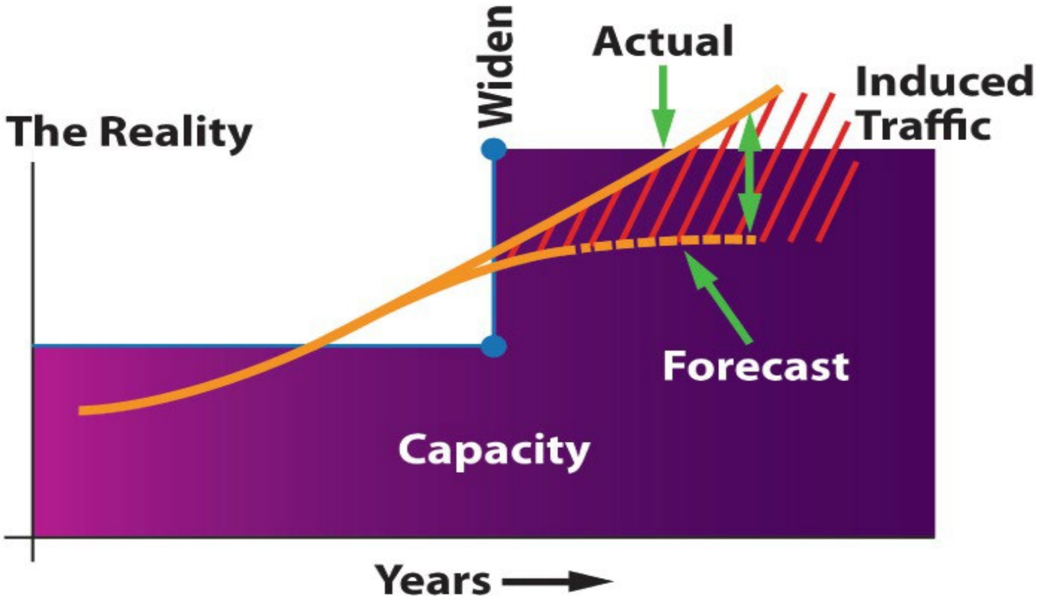


Figure 5.3 Induced Demand Diagram (Source: Speck J. [2018] Understand Induced Demand. In: Walkable City Rules. Island Press, Washington, DC. https://doi.org/10.5822/978-1-61091-899-2_27)

5.2.14 VMT estimation

The model needs to be able to estimate changes in vehicle miles traveled by travel mode and time of day. This is a critical modeling feature as VMT has direct effects on greenhouse gas and other pollutant emissions. Thus, the measure allows the model to account for pollution reduction benefits of rail investments.

To build such estimates, the model should forecast the number of trips and trip distances by mode, time of day, and route. Thus, VMT computation at any desired level is obtained through postprocessing of the generated outputs of the model, e.g., loaded networks and trip tables, at the desired level of spatial aggregation.

5.2.15 Job accessibility

One desired feature of the model is the ability to evaluate job accessibility around stations, especially by walking and bicycle, as well as businesses' access to potential employees and markets. If the model has a good level of spatial details, and the proper land use and socioeconomic data are included and appended to the zonal system characteristics, the accessibility measures could be evaluated outside the travel model using spatial information on job distribution together with the travel demand model outputs.

5.2.16 Transit options accessibility by different groups

Studying the potential effect of transit accessibility is a key feature when evaluating the sensitivity of transit disutility with regard to network and level of service changes. For example, some models use a simplified transit model where the transit attributes and costs are computed for the current services, but the modeling framework is not sensitive enough to extrapolate impacts of new improvements.

The model needs to account for the spatial distribution of sociodemographic characteristics of the affected population groups, as well as distribution of various job types, and other relevant attributes used as inputs in the model in the zonal system. These are usually explicitly included in a population synthesizer process in the first steps of an activity-based model. Accessibility measures for various sub-groups can be computed in postprocessing based on zonal characteristics, sociodemographic information, and the outputs of the travel demand model.

As an optional but desired feature, the model should focus this analysis on individuals with no access to motor vehicles, unbanked individuals, minorities, and individuals with disabilities. These should be all priority groups for analysis in the Link21 program. However, not all of them are easy to consider in standard regional travel demand modeling frameworks.

5.2.17 Access and egress modes

A relevant feature that is expected from the model is to account for auto, walk, bike access/egress to/from transit stations. The model framework also needs to consider connections to other modes such as transit as an access mode to long-distance and intercity rail.

New mobility options, including transportation network companies (TNCs), shared e-scooters, and e-bikes, are becoming increasingly popular but are not often considered in travel demand models. If possible, the model should account for the presence of these new modes because of their increasing relative importance.

When needed, and to the extent possible, alternative simplified approaches could be considered. For example, it is possible to consider travel modes that are considered relevant for the Link21 program as one additional access mode, and account for its effect through potential synthetic measures, e.g., a “super-walker” option with faster walking speed to account for the potential use of micromobility options as an access/egress mode that expands the catchment area at selected stations.

5.2.18 Impacts of new communication technologies

The impacts of new technologies and trends, such as telecommuting and e-shopping, should be considered in the analysis. This is especially important given the potential continuation (at least on a part-time basis) of some telecommuting and/or work from home after the pandemic. This feature should be incorporated directly as a work-from-home activity in the set of activity patterns. Modern activity-based models can account for work-from-home and telecommuting through both the decision of an individual to eventually engage in home-based work arrangement (as a long-term type of employment/work activity) and the decision of eventually telework on a given day, for individuals that do have a workplace distinct from home but might decide on certain days to work remotely for the entirety (or for part) of the day.

At the time of writing, it is still not clear to what level telecommuting will persist over time, after the end of the pandemic, and thus different scenarios should be evaluated (see discussion in the following Chapter 6 on this topic). The model needs to be able to control for different work-from-home penetration levels and the sociodemographics that correlate with this phenomenon. Assuming a flat telecommuting rate evenly distributed over the population would lead to inaccurate transportation demand predictions.

As previously mentioned, work-from-home is a common option included in modern activity-based models. However, re-estimation of these model components and adjustments of existing modeling systems to a new post-pandemic reality might require careful consideration and effort. This is a particularly important feature, considering the huge impact of remote work on commuting trips, and its effects on mode choice and the use of public transportation, especially during peak times of the day.

E-shopping is slightly less relevant than is telecommuting for the Link21 program. E-shopping is considered optional, as it largely generates indirect effects of delivery services on traffic congestion. Its direct effects on passenger travel demand are often considered to be smaller in magnitude, and often associated with a slight modification in trip purpose and/or destination choice (e.g., shopping or entertainment areas).

5.2.19 Impacts of new transportation options

New mobility options, such as shared mobility, micromobility, and, in the near future, CAVs should be considered in the analysis if doing so does not increase the amount of time needed to develop the model. Among these options, shared mobility in the form of regular ridehailing deserves more consideration than carsharing or pooled ridehailing, given the limited relevance of the last two in North America, and the relative urban/local context in which these services are used, i.e., not likely to significantly impact travel flows of interest for the Link21 program.

Certain simplifications could be adopted to reduce the model development and operation efforts. For example, micromobility services could be included in activity-based models with some approximate approach, such as considering expanded catchment areas for transit where micromobility exists, and the use of “super-walker” behaviors. This solution would artificially allow for faster speed of walking access mode to account for the use of shared bikes, e-bikes or e-scooters.

The case of autonomous vehicles or connected and automated vehicles could be largely left out of the first modeling efforts for the Link21 program, as no standard procedures to account for CAVs in travel demand models exist. This is still largely a research topic, though any improvements that are made in the modeling practice in this area could be integrated into the Link21 modeling framework in later model updates.

The following Chapter 6 will discuss these topics in additional details.

5.2.20 Freight transportation effects

To model the impacts of freight travel on passenger travel demand, an activity-based model could account for the impacts on traffic congestion, at least to some extent. While modeling all freight travel components in detail is beyond the purposes of this project, most large-scale travel demand models in operation include a freight component that is run in parallel to the passenger travel demand. At a minimum, the two components of travel demand, for passenger and freight, interact in what is typically the last step of the modeling process. In the trip assignment, the travel demand components for freight and passenger travel that have been modeled separately are assigned to the network simultaneously. In this way, the impacts of freight movements on traffic congestion are captured in the next iteration by the passenger travel demand component.

5.3 Categorization of model features

Following the requirements and timeline of the Link21 program, we categorized these modeling features into three groups of critical, important, and optional:

- *Critical* features are those that a model needs to meet. A modeling approach without them would not fulfil the purposes of the program.
- *Important* features are those that the final model framework should have, but one or more of these expectations could be relaxed if their implementation would cause an excessive delay or excessive difficulties in the model development.
- *Optional* features are desirable in the model but would not cause a meaningful detriment if they were not included (at least for the initial model development). These could be eventually included in future model updates.

The full list of features, its assessment, and comments are presented in Table 5.1.

Table 5.1 Categorization of Proposed Model Features

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Proposed Criteria		Assessment	Comments
1. Timeline and running time	0. Time to develop a core model in 18 months, with possibility to incorporate additional modules later	Critical	
	1. Model running time	Important	Given the considerable number of scenarios to evaluate, the amount of time each scenario takes to run and to prepare is important.
	1a. Data preparation time	Important	
	1b. Scenario running time	Important	
2. Geographical considerations	2. Ability to model travel through the entire Northern California megaregion	Critical	
	2a. Geographical resolution: Model captures route alignments and station locations	Critical	Model should be able to evaluate both long and medium scale trips (e.g., BART and regional rail)
	2b. Level of detail of the zone system	Critical	The model zone system should have a level of detail appropriate to model local characteristics of the urban areas, and access/egress from public transportation stations.

Legend:	🟥 Critical	🟦 Important	☐ Optional

Proposed Criteria		Assessment	Comments
3. Rail services modeling	3. Ability to model improvements in individual rail services (BART, Commuter rail, etc.)	Critical	Need for explicit representation of transit rail network and services provided
4. Service integration modeling	4. Ability to model integration of services (e.g., BART + Capitol Corridor trains, etc.)	Critical	Ability to model both longer-distance and regional trips, including intermodal trips connecting from one service to the other Especially important as project scenarios blur the distinction between BART and regional rail
5. Travel time	5. Ability to model the impacts of travel time	Critical	Travel time should be included in the utility functions for various steps of demand modeling. Model needs to capture realistic elasticities of travel demand (by mode) with respect to travel time and costs.
	5a. Ability to evaluate travel time between major centers	Critical	The model needs enough spatial details to capture this.

Legend:	🟥 Critical	🟦 Important	☐ Optional

Proposed Criteria		Assessment	Comments
	5b. Ability to evaluate travel time between major centers and transportation hubs	Critical	The model needs enough spatial details to capture this.
6. Travel cost	6. Ability to model the impacts of travel cost (including congestion pricing) for transit and auto	Critical	Travel cost should be included in the utility functions for various steps of demand modeling. Model needs to capture realistic elasticities of travel demand (by mode) with respect to travel time and costs, and have realistic values of travel time by group and trip purpose.
7. Hours of operation	7. Account for hours of operations	Important	The model should be able to evaluate the value of extended hours of service (though this is more an item for an operational model, and not for a large-scale demand model). There are ways to estimate the benefit of extending service hours, even if it is difficult to do so in many large-scale travel demand models.
8. Service frequency	8. Account for frequency of service	Critical	Many of the benefits of several scenarios evaluated come from the frequency increase.

Legend:	🟥 Critical	🟦 Important	⬜ Optional

Proposed Criteria		**Assessment**	**Comments**
9. Crowding and capacity constraints	9. Crowding and capacity constraints	Critical	Particularly important for the BART and Caltrain components, less so for longer-distance intercity and other commuter rail services
	9a. For transit itself	Critical	Much of the benefits of several scenarios evaluated come from relieving crowding on transit (during peak time)
	9b. For park-and-ride facilities	Optional	This can be less of a priority in the initial model release (and maybe included in a later stage of modeling). Still, this is being implemented in some existing regional travel demand models from which the Link21 program can benefit.
10. Reliability	10. Reliability (on-time operation)	Optional	Crucial factor for rail transit and regional rail but, given the state of modeling with respect to reliability, might need to evaluate this outside the travel demand model.
11. Future land use	11. Ability to account for impacts of land use scenarios on travel demand	Critical	The model should have the ability to consider different land-use scenarios. Land use characteristics will be modeled as exogenous input in the travel demand model.

Legend:	🟥 Critical	🟦 Important	⬜ Optional

Proposed Criteria		**Assessment**	**Comments**
	11a. Evaluation of local land use policies consistent with large capital transit investments (measured by PDAs and other standards, including zoning and BART station area standards)	Important	
	11b. Evaluation of the impacts of current and potential future land uses within station catchment areas (number of residences in priority areas within walk/bike distance thresholds of new or improved service)	Important	
	11c. Evaluation of the impacts of urban design around stations	Optional	It might be difficult to estimate the impact of better designed stations.
	11d. Ability to model land use impacts of new and improved rail services.	Optional	Given the relatively short time frame to develop the model, we do not expect land-use modeling to be included in the Link21 modeling system. Accounting for land use impacts *endogenously* is complex and will likely not be part of the Link21 modeling (but can be studied through various alternative scenarios).
	12. Ability to model ridership	Critical	Necessary for the project

Legend:	🟥 Critical	🟦 Important	⬜ Optional

Proposed Criteria		**Assessment**	**Comments**
12. Transit ridership	12a. Ability to evaluate trips between major centers	Critical	Important feature from model output (+ postprocessing to aggregate demand from TAZ level to the desired level of aggregation)
	12b. Ridership by time of day and purpose	Important	The model needs to account for a fine-enough level of detail on time of day and distinguish trip generation for different trip purposes.
	12c. Ridership by weekday	Important	Typical output of ridership for most models that forecast demand for a typical working day during spring or fall
	12d. Ridership by weekend	Optional	Not a standard feature of most models, they usually model demand on a typical working day during spring or fall (not weekends, and not summer or holiday season). The modeling program could consider using additional data (e.g., passively collected data) to calibrate adjustment factors to model travel demand during weekends.
13. Mode choice modeling	13. Ability to model mode choice/mode share (including competitiveness between auto and rail)	Critical	Necessary for the project

Legend:	🟥 Critical	🟦 Important	☐ Optional

Proposed Criteria		**Assessment**	**Comments**
14. VMT estimation	14. Ability to estimate VMT impacts (by mode and time of day)	Critical	The model generates forecasts for a number of trips and trip distances, by mode and route, and VMT computation at the desired level can be obtained as postprocessing from those output measures.
15. Job accessibility	15. Job accessibility	Important	Accessibility measures could be evaluated outside the travel model using spatial information on job distribution and the travel demand model outputs.
	15a. Job accessibility by walking/bicycling distance	Important	
	15b. Business access to potential employees	Optional	
	15c. Business access to markets	Optional	
16. Transit options accessibility by different groups	16. Accessibility of transit options by population groups	Important	The model needs to account for spatial distribution of sociodemographics, job types, etc., in the population used as inputs in the model (e.g., through a population synthesizer process in an activity-based model). Accessibility measures for various sub-groups can be computed in postprocessing.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Proposed Criteria		**Assessment**	**Comments**
	16a. Evaluation of equity impacts	Optional	The model needs to account for spatial distribution of sociodemographics—with a focus on individuals with no access to motor vehicles, unbanked individuals, minorities, and individuals with disabilities. While all of these are important analyses, not all of them are easy to consider in standard regional travel demand models. Many measures can be computed as postprocessing of the model output.
17. Access and egress modes	17. Access and egress modes	Important	The model needs to account for auto, walk and bike access to transit. The model needs to consider connecting services to other modes (e.g., transit + long-distance rail). New mobility options are not always easy to consider in travel demand models (TNCs, shared e-scooters or e-bikes).
18. Impacts of new communication technologies	18a. Ability to model the impacts of telecommuting	Critical	It is especially important given the post-pandemic context to account for telecommuting and work from home. Travel demand models can account for work for home (WFH) in the activity patterns.
	18b. Ability to model the impacts of e-shopping	Optional	E-shopping is less relevant for Link21 program, apart from the indirect effects of delivery services on traffic congestion with some limited direct impacts on passenger travel demand, e.g., for shopping trips.

Legend:	🟥 Critical	🟦 Important	☐ Optional

Proposed Criteria		**Assessment**	**Comments**
19. Impacts of new transportations options	19a. Shared mobility (regular ridehailing)	Important	Ridehailing deserves consideration and a TNC mode is getting introduced in ABM approaches.
	19b. Shared mobility (carsharing, pooled ridehailing)	Optional	Carsharing accounts for a limited market in the US. Pooled ridehailing is more common but considered less of a priority than regular ridehailing for inclusion in the model.
	19c. Micromobility	Optional	Eventually, this could be done with some approximate approach, such as expanded catchment areas for transit where micromobility exists, and use of “super-walker” behaviors that artificially allow for faster walking access mode to account for shared bikes, e-bikes and e-scooters.
	19d. CAVs	Optional	Can be left out for now as no standard procedures to account for CAVs in travel demand models exist. It is still a research topic.
20. Freight transportation effects	20. Ability to model the impacts of freight travel on-road passenger travel demand	Optional	An activity-based model would account for freight impacts on traffic congestion, at least to some extent. There is no need for major updates of that component as it is of secondary importance to the Link21 program.

5.4 Evaluation of current operational models with the proposed features

This section discusses how the current models perform based on the proposed modeling features introduced in the previous section. As such, each of the 11 models will first be evaluated following each feature. The evaluations are organized into three sub-tables: one for three statewide models, one for five MPO models, and one for four transit-oriented models. Of the 11 models, the CSTDM 3.0, CHSR-BPM V3-2016, MTC TM 1.5, SACSIM, TCM-2008, and San Francisco Model 2002 are being used in California; the TBEST 4.6, STOPS 1.5, RDM, and CONNECT are being used for different projects/areas; and the New Statewide Rail Model and MTC TM 2.0/2.1 models are currently under development.

5.4.1 Critical modeling features

When focusing on the proposed critical features, all 11 models have the ability to model the integration of services, though some can do this only to a limited extent if they do not have a high level of detail for all public transportation options and/or do not have the ability to properly model transfers between modes; to evaluate impacts of travel time and travel cost; to model scenarios to accommodate future growth in the region; and to evaluate trips between major centers.

All activity-based disaggregate models are able to properly model mode choice by time of day and for various trip purposes, and usually already include a good set of access/egress modes. However, the level of detail with which public transportation is modeled and the ability to capture impacts of crowdedness and transit capacity varies significantly across modeling approaches. While many activity-based models are well suited to model the impacts of new communication technologies and telecommuting, current available models might need substantial modifications to improve this capability. For example, the revised MTC TM 2.1, currently under development, will feature an improved model component to capture modern technology impacts on telecommuting, especially considering the mutated conditions and increased importance that remote work might continue to have in future years, after the recent COVID-19 pandemic.

Models that operate at a statewide level—the CSTDM 3.0, the CHSR-BPM V3-2016, and the new statewide model that is being developed to support statewide rail planning at Caltrans—present many interesting modeling features. They can model demand for various types of rail services, capture mode choice decisions and competition between various modes (in particular between auto modes and rail), include both short-distance and long-distance components of travel, and account for various access/egress modes. They also operate at a large scale that does already include the entire 21-county megaregion as part of their statewide modeling efforts. However, these models tend to operate at a coarse level of spatial detail, are usually designed to capture longer-distance components of trips, and are not well suited to properly capture the nuanced factors affecting local/regional travel decisions that are relevant for the Link21 program. They also are not designed to properly model crowding and capacity constraints of transit and the impacts of new technologies on travel behavior.

The new statewide rail model that is currently under development will share some important features that are desirable for the Link21 program, such as the ability to model demand for rail services and forecast rail ridership and model mode choice, including the eventual availability of longer-distance intercity buses, which are a potential competitor to intercity rail, but are not included in many other models. However, the model is designed to forecast demand for trips over 50 miles, and it should not be used for regional/local travel demand modeling. While many features of this model are still under development, it is likely that, like the other statewide models, it will share the ability to capture the impacts of route alignments and station locations (in particular for longer-distance rail), ability to model the impacts of travel cost for transit and auto (and intercity buses for the new statewide rail model), account for the frequency of service, and to some extent model the impacts of remote work and telecommuting on travel behavior.

Those three statewide models cover all 58 California counties, and therefore, can model travel throughout the entire Northern California megaregion. However, given their current coarse level of spatial details, lack of details for local transportation options, these models are not considered a desirable option to build a future modeling framework for the purposes of the Link21 program. However, they might play an important role to support the modeling of longer-distance components of travel that are relevant to the Link21 program, either by providing exogenous inputs to the Link21 model or directly providing the foundation of a longer-distance travel modeling component that could be integrated in the overall Link21 modeling approach.

On the other hand, four MPO models—i.e., the MTC TM 1.5, SACSIM19, TCM 2008, and the SFCTA model—share many of the critical modeling features for the Link21 program, including the ability to model regional/local travel demand with a high level of detail in an activity-based modeling framework, model the integration of multiple public transportation services, forecast transit ridership and the impacts of future land use with a pretty refined level of spatial details, and include several access/egress modes.

The MTC TM (various versions of the model), SACSIM19, TCM 2008, and SFCTA model cannot model travel through the entire Northern California megaregion, though, and longer-distance components of travel are usually included as external trips crossing the region boundaries. Also, crowding and capacity constraints of transit are usually not well captured, while the impacts of telecommuting on travel behavior are being included in the activity-based travel modeling framework.

The MTC TM 2.1 that is being developed based on the MTC TM 1.5 model will share many of the modeling features of the MTC TM 1.5. However, it will feature an improved ability to model public transportation capacity and transit constraints, and it will also model crowding and capacity constraints for the park-and-ride facilities. All these models already cover a major portion of the study area and collectively cover almost the entirety of the 21-county megaregion, with TAZ resolutions and details in the road and transit networks that are, on average, very high.

The four transit-oriented models—namely TBEST 4.6, STOPS 1.5, RDM, and CONNECT—also feature several (over half of the) critical modeling features, including the ability to model rail services, service integration, impacts of travel time and costs, future land use (to some extent), and model transit ridership. However, these models operate at a level of detail and with simplified modeling approaches that are not well suited for the Link21 priorities. Accordingly, while these models could be suitable (and, to some extent, desirable) for faster, short-term modeling needs of the Link21 program, they are not considered scalable and competitive for the long-term modeling needs of the program.

5.4.2 Important modeling features

Among the proposed important features, current modeling approaches can usually model ridership by time-of-day and purpose and the accessibility of transit options by population groups. More specifically, at a statewide level, the CSTDM 3.0 and the CHSR-BPM V3-2016 can model ridership by time-of-day and purpose, the resulting ridership for an average weekday, and the accessibility of transit options by population groups. Given the focus on larger-scale modeling, these models tend to be better positioned to forecast demand for longer-distance rail services, with worse ability to capture realistic behaviors behind the ridership at regional level and for local non-rail services.

In addition to its coarse level of spatial details, the CSTDM 3.0 has a major limitation as it lacks a proper public transportation assignment module (therefore, OD trip counts are not assigned to specific public transportation services). Further, it only considers bus services through a synthetic (simplified) local transit model system, which means that OD attributes involving local transit are computed through equations estimated using a dataset relating transit trip data from GTFS (General Transit Feed Specification) sources to road network attributes, without the explicit coding of line files for each service in the public transportation module.

The CHSR-BPM V3-2016 also largely focuses on longer-distance travel, while it relies on the MTC model for local/regional travel demand flows. The new statewide model currently under development is optimized to model travel demand for intercity/interregional rail services, and it can model ridership by time-of-day and purpose for these services. It also accounts for major access/egress modes to rail stations and all main alternatives to the use of rail services. It includes main intercity buses among the available modes—an important feature when modeling demand for rail services, in particular as new discount intercity services, such as those provided by MegaBus or FlixBus are likely to represent an important competitor to rail services on intercity routes in the future. However, this model is not intended to forecast demand for trips shorter than 50 miles. Further, many other exact details on the modeling features and the performance of this new model are currently unclear as the model is still under development. Most likely, its development will continue in parallel to the Link21 modeling efforts during the next 18 months.

Among the MPO models, the MTC TM 1.5 (as well as future TM versions starting with TM 2.1) already features many important modeling features. The model, which is based on the CT-RAMP activity-based travel modeling platform and currently runs in the CUBE platform (for TM 1.5), will transition its public transportation components to the Emme software environment starting with version 2.1. This will allow much better modeling of many public transportation features, including the impacts of crowding and capacity constraints for both public transportation lines/vehicles and park-and-ride facilities. The performance of the 2.1 version will remain unknown for a while, and the integration of the CUBE and Emme platform might lead to further complexity in the model structure, which is only partially known, to date, given the on-going work for the model update. The model already features rather high running time for the current CT-ramp and CUBE-based modeling environment, also due to its high level of detail and complexity of the activity-based framework. Future versions of the model, TM 2.2 and TM 2.3, will fully transition to the Emme modeling platform and the new cross-agency collaboratively sourced ActivitySim (instead of CT-ramp) activity-based modeling environment. However, the timeline for the complete conversation of these models to the new modeling software and activity-based platform remain uncertain. The Link21 program could eventually build on some of these efforts, but only at the cost of directly engaging in the development and debut of the ActivitySim platform and thereby potentially becoming the launch user of the new activity-based platform.

The SFCTA and SACSIM19 models share many of the same advantages of the MTC model, as they are based on a comparable and advanced activity-based platform, DaySim, and also run in the CUBE software environment. While these models might not be suited to receive the same upgrades that the MTC model is about to receive for the public transportation model component, they operate at a high level of detail, and also boast the use of an activity-based platform, DaySim, that is reportedly operationally faster than its competitors. The SFCTA also features improved walking features that allow computing improved attributes for walking trips (and walk access to transit station), which are considered particularly important in San Francisco.

Also the TCM 2008 model shares the DaySim activity-based modeling approach and, while the model (to the best knowledge of the authors of this report) has not received the same level of model updates that have been introduced in some of the other larger-MPO models, it can model ridership by the time of day and purposes for an average weekdays, job accessibility by walking/bicycling distance, accessibility of transit options by population groups, and access/egress modes, similar to the other models listed in this section.

In the last group of transit-oriented models, TBEST 4.6 and STOPS 1.5 meet the same six critical modeling features, in that they can account for the hours of operations of transit in their simplified modeling framework, ridership by the time of day and purpose for the average weekday, job accessibility, accessibility of transit options by population groups, and the major access/egress modes for rail stations. By design, however, both models cannot evaluate more sophisticated integration and/or competition of auto vs. train services, the impacts of urban design around stations, and the impacts of new mobility options.

The RDM presents several important modeling features, as it can model (1) ridership by the time of day and purpose, (2) job accessibility by walking/bicycling distance, (3) accessibility of transit options by population groups, (4) ability to account for impacts of land-use scenarios on travel demand, and (5) evaluation of the impacts of urban design around stations. These characteristics are present, according to the model documentation, though the model also operates at a more aggregate level of detail. Finally, CONNECT can account for hours of operation, ridership by the time of day and purpose, accessibility of transit options by population groups, and impacts of land-use scenarios on travel demand. In general, though, and as discussed in the previous section, the level of spatial details and the rather simplified nature of these models do not make them viable options for the development of a long-term modeling approach for the Link21 program.

5.4.3 Optional modeling features

There are several optional modeling features that were identified as of potential interest for the Link21 modeling purposes. While none of the existing modeling approaches fully addresses all these topics, many of the more sophisticated and detailed models—especially the activity-based models operating at the MPO level—present some of these optional features or have undergone development and extensions leading to features that could be of interest for Link21. Accordingly, the Link21 program could harvest some opportunities to include these modeling features, including eventual model components and codes, from these sources. These could be integrated in or used as inspiration for the development of the modeling work for the Link21 program.

The summary of the fitment of current models based on the highlighted modeling features is presented in Table 5.2, Table 5.3, and Table 5.4. The evaluations provide overall insights into the desirable features of these existing models that facilitate the discussion of the alternative model recommendations for the Link21 program in the next sub-section.

Table 5.2 Existing models fit with the proposed features (*statewide models*).

Legend:	🟥 Critical	🟦 Important	⬜ Optional

Modeling Features		CSTDM V3.0 (CSF2TDM)	CHSR-BPM V3-2016	New Statewide Rail Model*
1. Timeline and running time	1a. Data preparation time	Not explicitly included in the model documentation, but expected to be not very high compared to alternative activity-based models, considering the coarser level of spatial details in the model	Not explicitly included in the model documentation, but expected to be not very high compared to alternative activity-based models, considering the coarser level of spatial details in the model	Unclear because the model is being developed—likely not very high compared to alternative models, as the model will operate at a coarser level of detail and has been designed with a simplified approach (instead of a full activity-based model) to reduce complexity and cut modeling time in an intentional tradeoff
	1b. Scenario running time	Runtime for the forecasting scenario: 8-10 hours per iteration with a total of 40-50 hours until convergence (depending on hardware resources)	Not included in the model documents	Unclear because the model is being developed but likely not too high, based on the simplified modeling system that is optimized for faster run time

Legend:	🟥 Critical	🟦 Important	☐ Optional

Modeling Features		**CSTDM V3.0 (CSF2TDM)**	**CHSR-BPM V3-2016**	**New Statewide Rail Model***
2. Geographical considerations	2. Ability to model travel through the entire Northern California megaregion	The model already covers all of California (58 counties)	The model already covers all of California (58 counties)	The model already covers all California (58 counties)
	2.a Geographical resolution: Model has the ability to capture the alignment of routes and locations of stations.	The model has road network covering most important facility types, and it has explicit line coding for rail network representation, but only has approximation for local bus network.	The model has road network covering the most important facility types, and it has explicit line coding for alignment of rail network. For local/regional travel in the bay region, the model relies on MTC model.	Unclear because the model is being developed, but most likely coarse resolution that is optimized to model intercity travel (for distances larger than 50 miles)
	2b Level of detail of the zoning system	Coarse TAZ system with 5454 TAZs covering the entire state (average TAZ size is 38.36 sq. miles)	Coarse TAZ system with 4683 TAZs covering the entire state (the average TAZ size is about 44.67 sq. miles), with reliance on MTC model for regional travel in the bay area	Coarse TAZ system with about 1200 TAZs (average TAZ size is about 174 sq. miles), which is appropriate for the focus on intercity (distance >50 miles) travel components
3. Rail services modeling	3. Ability to model improvements in individual rail services (BART, Commuter rail, etc.)	Yes, by modifying the rail transit network	Yes, especially for the MTC and SCAG intraregional models (building on MTC model, though, and not directly in CHSR model)	Yes, mainly focus on long-distance rail travel; the model is not intended for use for trips shorter than 50 miles

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		**CSTDM V3.0 (CSF2TDM)**	**CHSR-BPM V3-2016**	**New Statewide Rail Model***
4. Service integration modeling	4. Ability to model integration of services (*e.g.*, BART + Capitol Corridor trains, etc.)	To some degree for rail, but it has a simplified model for local bus network.	To some degree; the model focuses on longer-distance main modes (high-speed rail, conventional rail, Air) with access/egress mode (transit)	With main focus on the long-distance rails, as the model is not intended for use for trips shorter than 50 miles.
5. Travel time	5a. Ability to evaluate travel time between major centers 5b. Ability to evaluate travel time between major centers and transportation hubs	Yes, it is possible by deriving from loaded network, with level of detail appropriate for the larger scale of the model. Results might be suboptimal for shorter/regional components of travel.	Yes, it is possible by deriving from loaded network for MTC, SCAG areas, and for long-distance travel component.	Yes, it is possible by deriving from loaded network, but with focus on longer-distance travel, and the model should not be used for local/regional travel components.
6. Travel cost	6. Ability to model the impacts of travel cost (including congestion pricing) for transit and auto	Yes, it is built in the generalized cost function. Tolls can be included in auto operating cost for specific facilities.	Yes, it is built in the generalized cost function. Tolls can be included in auto operating cost or airport access.	Certainly yes, as it is an important feature, though details are missing as the model is being developed.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**CSTDM V3.0 (CSF2TDM)**	**CHSR-BPM V3-2016**	**New Statewide Rail Model***
7. Hours of operation	7. Account for hours of operations	Not well: local transit is not explicitly modeled, and for rail services the model is subject to the use of the major time of day definitions.	Not well: local transit is not always well accounted for, and for rail services the model is subject to the use of the major time of day definitions.	Most likely no, but still unclear because the model is being developed
8. Service frequency	8. Account for frequency of service	Yes, the frequency is included in the generalized travel time cost function. And there can be different coefficients for different times of day. However, the local bus system is not modeled explicitly, only through a simplified local transit model component.	Yes, frequency of bus and rail	Most likely yes, as it is an important feature, though details are missing as the model is being developed
9. Crowding and capacity constraints	9a. For transit itself	No, the model cannot handle capacity constraints and crowding impacts.	No, the model cannot handle capacity constraints and crowding impacts.	Under consideration, but not likely given the simplified structure of the model
	9b. For park-and-ride facilities	No, not included	Yes, for parking at access locations	Unclear because the model is being developed

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		**CSTDM V3.0 (CSF2TDM)**	**CHSR-BPM V3-2016**	**New Statewide Rail Model***
10. Reliability	10. Reliability (on time operation)	To some extent, it can be added into generalized cost, but it is not dynamically modeled	To some extent, it can be added into the generalized cost for high-speed rail, air, and conventional rail, but it is not dynamically modeled.	Under consideration
11. Future land use	11. Ability to account for impacts of land use scenarios on travel demand	Yes, the forecasting year ranges from 2020 up to 2050, and the model uses land use characteristics as an exogenous fixed input at TAZ level.	Yes, the forecasting years currently includes 2029, 2033, and 2040, and the model uses land use characteristics as an exogenous fixed input at TAZ level.	Yes, possible, though with coarser level of spatial details
	11a. Evaluation of local land use policies consistent with large capital transit investments (measured by PDAs and other standards, including zoning and BART station area standards)	To the extent allowed by scale of the model	To the extent allowed by scale of the model	Unclear because the model is being developed

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**CSTDM V3.0 (CSF2TDM)**	**CHSR-BPM V3-2016**	**New Statewide Rail Model***
	11b. Evaluation of the impacts of current and potential future land uses within station catchment areas (number of residences in priority areas within walk/bike distance thresholds of new or improved service)	Not feasible	Not feasible	Unclear because the model is being developed
	11c. Evaluation of the impacts of urban design around stations	In a limited way, due to the coarse scale and limited number of parameters in the model	In a limited way: for example, model coefficients are used to set CBD as a more attractive destination.	Unclear because the model is being developed
	11d. Ability to model land use impacts of new and improved rail services.	No	No	No
12. Transit ridership	12a. Ability to evaluate trips between major centers.	Yes, it can model aggregated transit trips, but not for single transit vehicle (or train).	Yes, results are computed for transit ridership and can be aggregated at the desired level of detail.	Yes, results are computed for transit ridership and can be aggregated at the desired level of detail.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**CSTDM V3.0 (CSF2TDM)**	**CHSR-BPM V3-2016**	**New Statewide Rail Model***
	12b. Ridership by time of day and purpose	Yes, the model generates activity patterns and corresponding tour/trips by purpose and mode. Each trip by rail can be associated with a time-of-day, OD information and trip purpose.	Yes, for the services included in the model	Yes, for the services included in the model
	12c. Ridership by weekday	Yes, travel demand is forecasted for an average weekday.	Yes, travel demand is forecasted for an average weekday.	Unclear because the model is being developed
	12d. Ridership by weekend	No	No	Most likely, no, but unclear because the model is being developed
13. Mode choice modeling	13. Ability to model mode choice/mode share (including competitiveness between auto and rail)	Yes, part of mode choice component, though with discontinuity for short-distance trips and longer-distance trips with threshold of 100 miles to separate the two	Yes, part of mode choice component, but optimized for longer-distance travel, with discontinuity for shorter-distance travel for which the model relies on MTC model	Yes, part of mode choice component, but optimized for intercity travel components (the model is not intended for use for trips shorter than 50 miles)

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**CSTDM V3.0 (CSF2TDM)**	**CHSR-BPM V3-2016**	**New Statewide Rail Model***
14. VMT estimation	14. Ability to estimate VMT impacts (by mode and time of day)	Yes, VMT is one outcome of traffic assignment, but with coarser road network without details on local roads	Yes, VMT is one outcome of traffic assignment, but with coarser road network without details on local roads	Yes; details TBD, but most likely with coarser road network without details on local roads
15. Job accessibility	15a. Job accessibility by walking/bicycling distance	Not explicitly considered in the activity pattern and destination/mode choice. While it could be calculated indirectly, the coarse level of spatial details in the model make it not well suited for good estimation of measures based on walking/bicycling modes.	Similar to CSTDM 3.0, it can only be calculated indirectly.	Unclear because the model is being developed
	15b. Business access to potential employees	Yes, business access can be computed indirectly at the aggregated TAZ level.	Yes, business access can be computed indirectly at the aggregated TAZ level.	Unclear because the model is being developed
	15c. Business access to markets	Yes, at the TAZ level (but with rather coarse details)	Yes, at the TAZ level (but with rather coarse details)	Unclear because the model is being developed
16. Transit options accessibility by different groups	16. Accessibility of transit options by population groups	Yes, it can be calculated at TAZ level.	Yes, it can be calculated at TAZ level.	Unclear because the model is being developed

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**CSTDM V3.0 (CSF2TDM)**	**CHSR-BPM V3-2016**	**New Statewide Rail Model***
	16a. Evaluation of equity impacts	Yes, related to sociodemographics included as model input (e.g., household income, but not race/ethnicity)	Not included in the model documents, but likely possible for to sociodemographics included as model input	Unclear because the model is being developed
17. Access and egress modes	17. Access/egress modes	Yes, it is part of mode choice design for access by walking and car.	Yes, it is part of mode choice design for access by walking and car.	Express bus and default parameter for access/egress time to centroid
18. Impacts of new communication technologies	18. Ability to model the impacts of telecommuting and e-shopping	The model has limited ability to capture the impacts of remote work though it can be to some extent modeled in the daily activity pattern. The impacts of e-shopping are not well captured in the model.	The model has limited ability to capture the impacts of remote work though it can be to some extent modeled in the daily activity pattern. The impacts of e-shopping are not well captured in the model.	Unclear because the model is being developed (but most likely no ability)
19. Impacts of new transportation options	19a. Shared mobility (regular ridehailing)	No, not considered in the activity pattern or mode choice	No, not considered in the activity pattern or mode choice	Under consideration

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**CSTDM V3.0 (CSF2TDM)**	**CHSR-BPM V3-2016**	**New Statewide Rail Model***
	19b. Shared mobility (carsharing, pooled ridehailing)	No	No	No
	19c. Micromobility	No	No	Unclear because the model is being developed (but most likely no ability)
	19d. CAVs	No	No	Unclear because the model is being developed (but most likely no ability)
20. Freight transportation effects	20. Ability to model the impacts of freight travel on road passenger travel demand	Yes, it has a freight forecasting module	No	No

*Limited documentation on this model

Table 5.3 Existing models fit with the proposed features (*MPO models*).

**Some information might be obsolete, with limited documentation on model

***Some information might be based on documentation for older version of the model, updated as possible through conversations with MPO modelers

Legend:	🟥 Critical	🟦 Important	⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
1. Timeline and running time	1a. Data preparation time	Information not available	Information not available	Not included in the model documents	Not included in the model documents	Not included in the model documents
	1b. Scenario running time	1 hour to 1 day depending on the amount of RAM and number of processors allocated	It possibly takes more time to run than TM 1.5, considering the additional model features, and the model splitting tasks between CUBE and Emme	16-24 hours for the base scenario	Not included in the model documents	1 hour for the base scenario, but when using the Transit Access Points (TAPs) resolution, it can go up to around 8 hours.
2. Geographical considerations	2. Ability to model travel through the entire Northern California megaregion	It covers nine counties in the Bay Area/ MTC region.	It covers nine counties in the Bay Area/ MTC region.	It covers six counties in SACOG region.	It covers three Northern counties in SJ Central Valley.	It covers nine counties in the Bay Area/ MTC region.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
	2a Geographical resolution: Model has the ability to capture the alignment of routes and location of stations.	Yes, both alignment routes and station locations	Yes, both alignment routes and station locations	Yes, both alignment routes and station locations	Yes, alignment of routes (accuracy depend on input shapefiles)	Yes, both alignment routes and station locations
	2b Level of detail of the zoning system	1454 TAZs (average TAZ size is 6.53 sq. miles)	40K MAZs, 4700 TAZs (average MAZ size is about 0.24 sq. miles; average TAZ size is about 2.02 sq. miles)	1502 TAZs (average TAZ size is 5.70 sq. miles)	6,600 TAZs (average TAZ size is 0.45 sq. miles)	1739 TAZs (average TAZ size is 5.46 sq. miles). In San Francisco, there are 766 TAZs (nested in 127 MTC TAZs for San Francisco region)
3. Rail services modeling	3. Ability to model improvements in individual rail services (BART, Commuter rail, etc.)	It includes local bus, light rail, heavy rail, and commuter rail through line files in CUBE. Scenarios can be built modifying the transit network.	The model will inherit features from TM 1.5 with additional improvements for public transportation components in the Emme software.	It includes rail options through line files in CUBE. Scenarios can be built modifying the transit network	No, rail mode choice is not included.	It includes rail options through line files in CUBE. Scenarios can be built modifying the transit network.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
4. Service integration modeling	4. Ability to model integration of services (*e.g.*, BART + Capitol Corridor trains, etc.)	It includes local bus, light rail, heavy rail, and commuter rail, but model is not designed to properly study demand for medium-/longer-distance services (e.g., CCJPA).	The model will inherit features from TM 1.5 with additional improvements for public transportation components in the Emme software.	The integration of rail and bus is modeled with transfer location, transfer time, transfer fare, etc., but model is not designed to properly study demand for medium-/longer-distance services (e.g., CCJPA).	For buses only	The integration of rail and bus is modeled with transfer location, transfer time, transfer fare (*e.g.*, MUNI with BART, bus and train), but model is not designed to properly study demand for medium-/longer-distance services (e.g., CCJPA).
5. Travel time	5a. Ability to evaluate travel time between major centers 5b. Ability to evaluate travel time between major centers and transportation hubs	Yes, included in the utility functions and generalized costs, for all model components, updated from loaded network within nine counties	The model will inherit features from TM 1.5, while also improving the ability to handle public transportation travel time and reliability.	Yes, included in the utility functions and generalized costs, for all model components, updated from loaded network within six counties	Yes, included in the utility functions and generalized costs, for all model components, updated from loaded network within three counties	Yes, included in the utility functions and generalized costs, for all model components

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
6. Travel cost	6. Ability to model the impacts of travel cost (including congestion pricing) for transit and auto	Yes, it is built in the generalized cost function.	The model will inherit features from TM 1.5, while also improving the ability to handle public transportation attributes including costs, and fares (individual-level discounts, e.g., for seniors, monthly passes, etc.).	Yes, it is built in the generalized cost function.	Yes, it is built in the generalized cost function.	Yes, it is built in the generalized cost function.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
7. Hours of operation	7. Account for hours of operations	Limited by the use of the times of day in the model: early morning, morning peak, midday, and evening transit. Transit operation is fixed in one period.	The model will inherit features from TM 1.5 and it might also feature improvements in the level of service by time of day.	Limited by the use of the times of day in the model: transit operation is allocated into five periods, namely 5:00–9:00 am; 9:00 am–3:00 pm; 3:00–6:00 pm; 6:00–8:00 pm; 8:00–11:00 pm.	No, that of transit is not explicitly accounted.	Limited by the use of the times of day in the model: transit operation is allocated into Early AM, AM peak, midday, PM peak, and Evening. Behavioral impacts can be considered by creating additional skim matrices.
8. Service frequency	8. Account for frequency of service	Yes, frequencies/ headways are reflected in the transit networks. Additional short-run routes operate during commute hours.	The model will inherit features from TM 1.5 while it might also feature additional improvements to consider different types of service.	Yes, frequencies/ headways by time of day are reflected in the transit networks.	No, not explicit in transit	Yes, frequencies/ headways by time of day are reflected in the transit networks.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		TM 1.5	TM 2.1	SACSIM19	TCM 2008**	SFCTA***
9. Crowding and capacity constraints	9a. For transit itself	No	Yes, incorporation of transit capacity and crowding will happen through the new public transportation modules in Emme, with the inclusion of reliability as well.	No, it is not included	No, it is not included	No. Tested but ultimately not included due to mismatch between model estimation results and survey data—cannot calibrate. Postprocessing process has been more recently added but rather cumbersome and slow to run
	9b. For park-and-ride facilities	No	Yes, transit station parking lot capacity will be included in TM 2.1, with the computation also of the time by when the parking lot gets filled.	Yes, parking capacity is included	No	No

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
10. Reliability	10. Reliability (on time operation)	No	Yes, it will be included in new TM 2.1 model release.	Yes	No	No, it was tested but ultimately not included in operational model.
11. Future land use	11. Ability to account for impacts of land use scenarios on travel demand	Yes, it can simulate until 2050. The model uses land use characteristics as inputs at the TAZ level. Land use and demographic are exogenous inputs imported from UrbanSim (or other sources, as needed).	Yes, it can simulate until 2050. The model uses land use characteristics as inputs at the TAZ level. Land use and demographic are exogenous inputs imported from UrbanSim (or other sources, as needed).	Yes, forecast travel demand until scenario year 2040. The model uses land use characteristics as inputs at the TAZ level, and also creating parcel buffers in DaySim.	Yes, it can forecast until scenario year 2040. The model uses land use characteristics as inputs at the TAZ level.	Yes, multiple scenario years already created. The model uses land use characteristics as inputs at the TAZ level.

Legend: 🟥 Critical ▨ Important ☐ Optional

Modeling Features		TM 1.5	TM 2.1	SACSIM19	TCM 2008**	SFCTA***
	11a. Evaluation of local land use policies consistent with large capital transit investments (measured by PDAs and other standards, Inc. zoning and BART station area standards)	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data
	11b. Evaluation of the impacts of current and potential future land uses within station catchment areas (number of residences in priority areas within walk/bike distance thresholds of new or improved service)	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
	11c. Evaluation of the impacts of urban design around stations	Yes, it is doable to some extent by changing the land use information in the TAZ input file.	Yes, it is doable to some extent by changing the land use information in the TAZ input file.	Yes, it is doable to some extent by changing the land use information in the TAZ input file.	Yes, it is doable to some extent by changing the land use information in the TAZ input file.	Yes, it is doable to some extent by changing the land use information in the TAZ input file.
	11d. Ability to model land use impacts of new and improved rail services	Yes, based upon integration with UrbanSim	Yes, based upon integration with UrbanSim	No	No	No
12. Transit ridership	12a. Ability to evaluate trips between major centers	Yes, transit ridership forecasts can be aggregated to the desired level. It has labeled land use types by regional core/ CBD/urban	The model will inherit the features from TM 1.5.	Yes, transit ridership forecasts can be aggregated to the desired level.	Yes, transit ridership forecasts can be aggregated to the desired level (though the model is not well suited to study transit).	Yes, transit ridership forecasts can be aggregated to the desired level.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
		business/ suburban/urban.				
	12b. Ridership by time of day and purpose	Yes	The model will inherit the features from TM 1.5.	Yes	Yes	Yes
	12c. Ridership by weekday	Yes, typical weekday	Yes, typical weekday	Yes, typical weekday	Yes, typical weekday	Yes, typical weekday
	12d. Ridership by weekend	No	No	No	No	No
13. Mode choice modeling	13. Ability to model mode choice/mode share (including competitiveness between auto and rail)	Yes, part of mode choice component	Yes, with consideration of three types of skim sets – local only, local + premium, and premium only	Yes, part of mode choice component	Yes, part of mode choice component	Yes, part of mode choice component

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
14. VMT estimation	14. Ability to estimate VMT impacts (by mode and time of day)	Yes, it is computed based on trips and modes used. MTC model already generates county level VMT by vehicle types by hour as one of the default outputs	The model will inherit the features from TM 1.5.	Yes, computed based on trips and modes used	Yes, computed based on trips and modes used, for short distance	Yes, computed based on trips and modes used, for short distance
15. Job accessibility	15a. Job accessibility by walking/bicycling distance	Yes, it can be calculated indirectly; jobs access via auto and transit	The model will inherit the features from TM 1.5.	Yes, it can be calculated indirectly; jobs access via auto and transit	Jobs access within 30 mins of transit	Yes, it can be calculated indirectly; jobs access via auto and transit
	15b. Business access to potential employees	Yes, it can be calculated indirectly.	The model will inherit the features from TM 1.5.	Yes, it can be calculated indirectly.	Information is not available.	Yes, it can be calculated indirectly.
	15c. Business access to markets	Yes, it can be calculated indirectly.	The model will inherit the features from TM 1.5.	Yes, it can be calculated indirectly.	Information is not available.	Yes, it can be calculated indirectly.

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		TM 1.5	TM 2.1	SACSIM19	TCM 2008**	SFCTA***
16. Transit options accessibility by different groups	16. Accessibility of transit options by population groups	Yes, it can be calculated at TAZ level.	Yes, in addition to the features from TM 1.5, the model will be better able to measure the impact of accessibility on travel behavior through improved public transportation components.	Yes, it can be calculated at TAZ level.	Yes, it can be calculated at TAZ level (to the level of detail allowed by the model, as this model is not designed to study transit in detail).	Yes, it can be calculated at TAZ level.
	16a. Evaluation of equity impacts	Yes, related to sociodemographics explicitly accounted for in the model	The model will inherit the features from TM 1.5.	Yes, related to sociodemographics explicitly accounted for in the model	Yes, related to sociodemographics explicitly accounted for in the model	Yes, related to sociodemographics explicitly accounted for in the model

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		TM 1.5	TM 2.1	SACSIM19	TCM 2008**	SFCTA***
17. Access and egress modes	17. Access/egress modes	Yes, TM 1.5 considers access to transit, including walk and drive.	The model will inherit the features from TM 1.5, with potential improvements due to the improved public transportation components.	Yes, it is part of mode choice design.	Yes, walk and drive	Yes, walk and drive access and egress to transit, with potential improvements when running the model with transit access point (TAP) feature

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
18. Impacts of new communication technologies	18. Ability to model the impacts of telecommuting and e-shopping	Work from home can be modeled in the daily activity pattern in the activity-based model	Work from home can be modeled in the daily activity pattern in the activity-based model. Improvements in TM 2.1 also include major improvements in the work from home features, for both those that do that on a permanent, frequent, or in-frequent basis.	Work from home can be modeled in the daily activity pattern in the activity-based model.	Work from home can be modeled in the daily activity pattern in the activity-based model.	Work from home can be modeled in the daily activity pattern in the activity-based model.
19. Impacts of new transportations options	19a. Shared mobility (regular ridehailing)	Yes, TNC are included in new module.	Yes, improvements for MaaS (TNCs and taxi modes) have been added in mode choice.	Yes, car rental and taxi	No, it is not considered in activity pattern or mode choice	No, it is not considered in activity pattern or mode choice

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
	19b. Shared mobility (carsharing, pooled ridehailing)	Yes, shared ride (2/3 people) and shared TNC are included.	The model will inherit the features from TM 1.5 with improvements for MaaS module.	No	No	No
	19c. Micromobility	No, the model only includes active travel options (walk and bike).	No, the model only includes active travel options (walk and bike).	No, the model only includes active travel options (walk and bike).	No, the model only includes active travel options (walk and bike).	No, the model only includes active travel options (walk and bike).
	19d. AVs	Only as an experimental attempt, but not in operational model	TM 2.1 includes option for owned or shared AVs, subject to validity of the assumptions.	It will be included in the future version.	No	Only as an experimental attempt, but not in operational model

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TM 1.5**	**TM 2.1**	**SACSIM19**	**TCM 2008****	**SFCTA*****
20. Freight transportation effects	20. Ability to model the impacts of freight travel on road passenger travel demand	The model includes commercial vehicle movements as an external auxiliary model.	The model will inherit the features from TM 1.5.	Yes, the model has a commercial vehicle travel module.	While the model includes truck (small, medium, large) trips, trip generation rates are derived from CSTDM and not endogenously modeled.	This is included through one of the external model components, which models the movements of light-duty commercial (for local deliveries and services) and freight movements and trucks (heavy duty goods movement).

Table 5.4 Existing models fit with the proposed criteria (*transit-oriented models*).

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
1. Timeline and running time	1a. Data preparation time	Information is not available.	Prepare data and run model for current/existing condition: one to two weeks. Developing data for build scenario: one to two weeks	It takes about 5-7 weeks to build the database of current land use, demographics, employment, and transportation modes and networks	Information is not available.
	1b. Scenario running time	It varies with the number of transit routes but could be anywhere from 5 minutes to 24 hours.	It takes about 3-8 hours.	Dynamic (changes in transportation, land-use, population, and employment): 30 mins; non-dynamic: 5 mins	Information is not available.
2. Geographical considerations	2. Ability to model travel through the entire Northern California megaregion	No, it is purely used for transit ridership estimation (no explicit spatial component).	No, it is purely used for transit ridership estimation (no explicit spatial component).	Yes, it can be used for any region but with low spatial resolution.	No, it partly covers Northern California megaregion.
	2.a Geographical resolution: Model has the ability to capture the alignment of routes and location of stations.	The model considers both alignment of routes and station locations. However, the model has no explicit spatial component.	The project corridor is a 25-mile buffer around the set of existing and future stations. The model operates at a low level of spatial resolution.	The model considers alignment of routes (accuracy depend on input shapefiles). The model operates at a low level of spatial resolution.	No - not exact station locations or alignment alternatives are considered (the model focuses on ridership of all CBSA pairs on the network). The model

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
					operates at a low level of spatial resolution.
	2b Level of detail of the zoning system	Zones could be any user input polygon shapefile including local municipalities, Census Block Group, or any other planning areas.	The maximum number of TAZs/tracts/block groups is 9,000. Maximum number of stations/bus stops is 10,000.	The maximum number of zones is 370. Thus, the model operates at a very aggregate level of spatial details.	The model includes 973 zones, consisting of 913 in the US, 32 in Canada, and 28 in Mexico. Each zone has at least 10,000 residents.
3. Rail services modeling	3. Ability to model improvements in individual rail services (BART, Commuter rail, etc.)	Yes, the model forecasts ridership that reflects the service changes from inputs.	Yes, the model forecasts ridership that reflects the service changes from inputs.	Yes, for the train travel option in the model	Yes, for HSR and interregional rail
4. Service integration modeling	4. Ability to model integration of services (*e.g.*, BART + Capitol Corridor trains, etc.)	Yes, the integration of rail and bus is modeled with transfer location, transfer time, transfer fare, etc.	Yes, the integration of rail and bus is modeled with transfer location, transfer time, transfer fare, etc.	Yes, it is possible to model the integration of rail services.	Yes, for intercity rails and airlines

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
5. Travel time	5a. Ability to evaluate travel time between major centers 5b. Ability to evaluate travel time between major centers and transportation hubs	The model only includes transit travel time. Max travel time is 90 mins.	Yes, the transit time follows transit timetables, while that of other modes is adopted from the MPO models.	Yes, it is possible by deriving travel time from the loaded network.	Yes, it is possible by deriving travel time from the loaded network.
6. Travel cost	6. Ability to model the impacts of travel cost (including congestion pricing) for transit and auto	Yes, for transit but limitations when considering competitiveness between auto and transit	Yes, for transit and auto	Yes, it is built in the generalized cost function	Yes, it is built in the generalized cost function
7. Hours of operation	7. Account for hours of operations	Not properly, transit operation is allocated to AM Peak, Off Peak, PM Peak, Night, and Saturday and Sunday.	Not properly, transit operation follows actual timetable, but model cannot dynamically adjust competition with other modes.	Information is not available.	Transit operations are based on fixed times of day, 16 hours/day (bus: 20 hours/days).

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
8. Frequency modeling	8. Account for frequency of service	Yes, it is accounted as actual timetable.	Yes, it is accounted as actual timetable.	Information is not available.	Yes, it is accounted.
9. Crowding and capacity constraints	9a. For transit itself	Yes (default of 60 seats per transit vehicle).	No, it is not accounted for.	Calculations in the link-based method increase the perceived travel times as a result of crowding effects.	The model tracks the maximum seats per train (emerging: 300; regional: 400; core express: 600)
	9b. For park-and-ride facilities	Yes, parking capacity is included.	Yes, parking capacity is included.	Information is not available.	No.
10. Reliability	10. Reliability (on time operation)	The model follows the distribution generated from real data but with limitations in capturing the impacts on demand.	The model follows the distribution generated from real data but with limitations in capturing the impacts on demand.	Information is not available.	The model considers minimum reliability targets.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
11. Future land use	11. Ability to account for impacts of land use scenarios on travel demand	The model is only used for short-term forecasts, applying socio-economic growth parameters.	The model forecasts ridership for opening year, and then 10-year and 20-year forecasts. The model operates with a low level of spatial details.	The model performs a dynamic simulation of how transportation, land use, population and employment interact. When the dynamic component is off, it uses land use information as model inputs. However, the model operates with a low level of spatial details.	Scenarios are created for 2015, 2035, 2045, and 2055. The model operates with a low level of spatial details.
11. Future land use	11a. Evaluation of local land use policies consistent with large capital transit investments (measured by PDAs and other standards, inc. zoning and BART station area standards)	It can be done to the extent allowed by the low level of detail in the model.	It can be done to the extent allowed by the low level of detail in the model.	It can be done to the extent allowed by the low level of detail in the model.	The model performs analyses based on level of capital investment.

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
	11b. Evaluation of the impacts of current and potential future land uses within station catchment areas (number of residences in priority areas within walk/bike distance thresholds of new or improved service)	It can be done with the market analysis module, to the extent allowed by the low level of detail in the model.	Most likely not feasible with this model	It can be done to the extent allowed by the low level of detail in the model.	Most likely not feasible with this model
	11c. Evaluation of the impacts of urban design around stations	Not feasible with this model	Not feasible with this model	It can be done to some extent but with huge limitations due to the low level of detail in the model.	Not feasible with this model
	11d. Ability to model land use impacts of new and improved rail services.	Not feasible with this model	Not feasible with this model	Yes, it can be done if the dynamic simulation is activated.	Not feasible with this model

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
12. Transit ridership	12a. Ability to evaluate trips between major centers	Yes, it can model ridership for single train.	Yes, it can model ridership for single train.	Yes, it can model aggregated transit trips.	Yes, it models ridership for long distance train services (not for trips less than 50 miles and commuter trips).
	12b. Ridership by time of day and purpose	Yes	Yes	Yes	Total ridership (no further separation)
	12c. Ridership by weekday	Yes, typical weekday	Yes, typical weekday	Not clear	Not clear
	12d. Ridership by weekend	Yes (Saturday and Sunday)	No	Information is not available.	Information is not available.
13. Mode choice modeling	13. Ability to model mode choice/mode share (including competitiveness between auto and rail)	No, TBEST does not have this capacity.	The huge limitation is that the model inputs travel time of auto from external model. Bus travel time is averaged from auto travel time.	Yes, in link-based options	Yes, for auto, bus, air, and rail (for emerging, regional, and core express services)

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
14. VMT estimation	14. Ability to estimate VMT impacts (by mode and time of day)	No, TBEST only includes transit VMT	Yes	Yes	Yes
15. Job accessibility	15a. Job accessibility by walking/bicycling distance	Yes, there is a feature to calculate this as well as jobs accessible via transit.	The model can compute the jobs accessible via transit.	The model can compute the jobs accessible by zone.	No, the model does not have this capacity.
	15b. Business access to potential employees	No	Information is not available.	Yes, it can be calculated indirectly.	Information is not available.
	15c. Business access to markets	No	Information is not available.	Yes	Information is not available.
16. Transit options accessibility by different groups	16. Accessibility of transit options by population groups	Yes, it can be calculated indirectly.	Yes, it can be calculated indirectly.	Yes, it can be calculated indirectly.	Yes, it can be calculated indirectly.

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
	16a. Evaluation of equity impacts	Yes, the model provides support for Title VI analyses.	No, it does not have this capacity.	It can be computed indirectly.	No, it does not have this capacity.
17. Access and egress modeling	17. Access/egress modes	Yes, walk	Yes, walk, kiss-and-ride, park-and-ride, and all	No specific access/egress modes	No, access/egress time takes default values.
18. Impacts of new communication technologies	18. Ability to model the impacts of telecommuting and e-shopping	No	No	It is possible to account for the impacts of telecommuting and it has been tested in the UK.	No
19. Impacts of new transportations options	19a. Shared mobility (ridehailing)	No, it is not considered in activity pattern or mode choice.	No, it is not considered in activity pattern or mode choice.	No, it is not considered in activity pattern or mode choice.	No, it is not considered in activity pattern or mode choice.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**TBEST 4.6**	**STOPS 1.5**	**RDM**	**CONNECT**
	19b. Shared mobility (carsharing, pooled ridehailing)	No	No	No	No
	19c. Micromobility	No	No	No	No
	19d. CAVs	No	No	No	No
20. Freight transportation effects	20. Ability to model the impacts of freight travel on road passenger travel demand	No, it does not have this capacity.	No, it does not have this capacity.	No, it does not have this capacity.	No, it does not have this capacity.

5.5 Long-term modeling recommendations

Based on the discussed set of modeling features, four different modeling approaches (i.e., options) are further considered for their potential application to the Link21 program:

1. Build on MTC TM 2.1 regional model (without dedicated long-distance component)
2. Build on MTC TM 2.1 regional model (with dedicated long-distance component)
3. Build on SFCTA regional model (with or without dedicated long-distance component)
4. Build on CHSR or New Statewide Model

In the next subsections, we provide an overall description of each modeling approach and discuss how the set of modeling features could be organized, with their pros and cons. The detailed evaluation of the modeling features for each of these four modeling approaches is presented in Section 5.6.

5.5.1 Build on MTC TM 2.1 regional model (without a dedicated long-distance component)

One option to build the new modeling framework for the Link21 program could be to use the MTC TM 2.1 regional model as the base model, which could be expanded to the larger 21-county region, without a dedicated long-distance component. At the essence of the definition of whether to include or not a long-distance travel component is the decision of whether to (and how to) separate/identify short-distance vs. long-distance trips. Thresholds of long and short-distance travels are set differently in various models that use this distinction, with some models setting the threshold at 50 miles and others at 100 miles, for example. All these distance-based approaches introduce some discontinuity in the modeling system. We will return on this topic in later subsections of this chapter. In this proposed approach, we assume that no specific long-distance component is introduced in the Link21 model that is built starting from the MTC TM 2.1.

The MTC TM 2.1 is currently under development, and it builds on the TM 2.0 version, which focused on Marin County and served as a first trial of the new implementation of the model. TM 2.1 will feature improved public transportation components that have been migrated for this purpose from the CUBE to the Emme modeling software environment. From this point of view, the model presents many important upgrades that will be extremely useful for the Link21 program.

In this proposed approach, we assume that there is no distinct separation based on trip distances. The assumption is that by expanding the CT-ramp activity-based modeling approach to the 21-county megaregion, the model would be able to internalize many of the trips that are currently considered external trips to/from the areas surrounding the MTC region. In this way, these internalized trips can be captured in the “activity patterns” within the activity-based model, e.g., long-distance commute trips to/from the San Joaquin Valley. Capturing these trips as such assumes the modeling framework is modified and calibrated assuming sufficient data are available to inform this model development process. The model re-estimation can also be considered, if time allows.

TM 2.1 is a complex ABM model and thus model development takes significant time. However, the Link21 efforts would capitalize on previous modeling work to build on the existing (and continuing) TM 2.1 work to further develop a new model that fulfills the goals and objectives of the Link21 program. TM 2.1 is expected to become operational in April 2022. TM 2.1 has many critical and important features, such as a detailed zonal system, ability to model improvements in individual rail services as well as integrated services, ability to account for rail transit capacity and crowding, as well as the effects of telecommuting on activity scheduling and trip generation, etc.

If the “expanded TM 2.1” can capture the behaviors behind travel demand in the Northern California megaregion (including flows on I-80, the expanded San Francisco-Sacramento corridor, and the Bay Area to Central Valley dynamics), it would allow for a simpler approach without complications of integrating an explicit long-distance component.

However, if this approach is followed, the Link21 modeling framework would depend on the TM 2.1 development, which could incur in potential delays. For example, significant delays in the TM 2.1 have already incurred due to the addition work required for network coding and socioeconomic data preparation (e.g., employment and workforce levels) as the model inputs. It is expected that the current calibration process will end in April 2022, with an additional month to develop the detailed documentation. Further, the TM 2.1 is still somewhat of a hybrid model, which runs primarily in CUBE, with the public transportation components that have been fully transitioned to EMME. Hence, the Link21 somehow would hybridize a model (in terms of model setups and areas) that is already using a complex setup integrating two modeling platforms and different software packages. Additional levels of complication and complexity (and potential issues) would be expected in the model development and future operations.

In addition, the lack of an explicit long-distance travel component might be a limitation, as the behavioral foundations that explain the generation of travel over longer distances might be different from the predominantly short-distance travel that is modeled in activity-based modeling frameworks. Elasticities for long-distance travel are usually different from short-distance travel decisions. “True” long-distance travel (i.e., to/from areas outside the boundaries of the 21-county megaregion) is not explicitly modeled but could be included as an exogenous trip table from another model. The previous Chapter 2 in this report has discussed the relative magnitude of these travel markets in the Link21 region. Additional efforts should be made to quantify “how small” of a market this type of long-distance travel is and the appropriate level of efforts that should be dedicated to it: the preliminary analyses presented in this report showed that the market is relatively small (compared to the overall volume of trips of interest for the Link21 program) but that this travel market would also represent an important market for the potential mode shift from cars to transit over medium- and long-distances. If the market for these components of travel that are not well captured by the activity-based modeling framework (that focuses on the usual activity/travel patterns carried out in the average weekday in fall or spring) are large enough for the purposes of the Link21 program, this approach would not be recommended. This could be particularly relevant in terms of the potential implications for any investments in conventional standard-gauge intercity rail in the Link21 program. Accordingly, the use of a special travel model component (see the second modeling approach below) would become preferable.

In terms of the proposed list of features, the current TM 2.1 model is under development covering nine counties which can be expanded to cover the 21 counties in the Link21 megaregion. Longer-distance travel inside the 21 counties could be merged into the current short-distance functions in TM 2.1. In addition, the model already has many critical features, such as modeling improvements in rail services, integration of services, modeling the impacts of travel time and cost, accounting for changes in service frequency, and the ability to model ridership for various types of rail services, among others. As it lacks a proper long-distance model, some limitations in modeling at least in part the longer-range services (e.g., the train services provided by CCJPA on the I-80 corridor and/or the travel to/from the northern portion of the San Joaquin Central Valley, in addition to longer-distance conventional and high-speed rail systems in California, and the integration of these services with BART and other public transportation services in the San Francisco Bay Area) might affect the new model.

In terms of future plans, MTC is planning two additional versions of their travel model. TM 2.2 will feature a full conversion from CUBE to EMME, is expected later on during 2022. TM 2.3 will feature the transition from the activity-based CT-Ramp core to ActivitySim, a new open-source activity-based travel behavior model based on best practices from existing models such as CT-Ramp itself and DaySim. Accordingly, a proposed modification of this first modeling approach would be to link the Link21 modeling effort directly to one of the next phases of the MTC model improvement, i.e., either TM 2.2 or TM 2.3.

The advantage of one of these approaches would be to align the Link21 modeling effort to the best modeling practices where other planning agencies are converging, simplify the software environment (abandoning CUBE entirely, in favor of EMME), and replacing the CT-ramp activity-based modeling framework with the improved and more performing ActivitySim. However, this would add considerable uncertainty to this plan, as the Link21 modeling efforts would not build anymore on an operational model from an MPO to build the larger modeling efforts, but would somehow invest in new modeling approaches with very high potential, but with a somewhat uncertain future and performance still to be assessed. Such an approach could be also carried out in the future, though model version updates for the Link21 modeling framework, beyond the initial 18 months. This would be a more conservative/prudent approach, though not very efficient in terms of resource allocation, as many tasks would be repeated/duplicated, but could be considered preferable from the perspective of reducing uncertainty in the model development.

5.5.1.1 Critical features

The MTC TM 2.1 is being developed and is expected to have many of the features listed in this document. In terms of critical features, the current TM 2.1 model already covers nine counties (including the highest-density and most complex counties from the standpoint of land use features and transportation networks and services in the megaregion) and provides a strong modeling basis that can be expanded to cover the 21 counties in the megaregion.

Longer-distance travel inside the 21 counties could be modeled with some extension of the current functions in TM 2.1 (this would cover most trips in the region through the computation of trip tables and travel demand from the regional model functionalities). In addition, trips to/from outside the 21 counties can be obtained from external inputs from other models (e.g., exogenous trip table from CHSR or New Statewide Model) for trips to/from external areas (that likely accounts for a relatively small portion of trips, as already discussed). This would be an approach similar to what the current MTC model does for external travel to/from other external areas. This portion of the modeling framework would not allow for proper endogenous modeling of demand on those corridors/demand components though, but this would be an intentional tradeoff obtained with lower model complexity and no need to integrate multiple (heterogenous) travel demand model components.

The TM 2.1 can capture both route alignment and station locations. To maintain the resolution of the average MAZ and TAZ sizes, the future model for 21 counties should have about 142K MAZs and about 17,000 TAZs, though lower resolution could be likely used for other areas that are farther located from the Link21 proposed Transbay crossing, to reduce the running time. Aggregations of TAZs also in the nine MTC counties could be done without loss of validity for the modeling purposes of Link21. Thus, TAZ and MAZ could be identical in those more external areas saving resources to model the core area of analysis in the Bay Area and corridors that are relevant to study public transportation demand with higher resolution.

The issue of longer-distance travel remains difficult to deal with, although a preliminary assessment shows that this accounts for a relatively small portion of trips in the megaregion (as discussed in Chapter 2 of this report). Therefore, this approach could lead to efficient use of resources in the project, with a relatively limited loss in terms of modeling capabilities. However, questions remain about the ability to model travel inside the 21-county megaregion, for those trip purposes that do not follow the typical travel patterns that are modeled in a regional travel demand model in terms of the activity patterns and related trips for commuting and non-commuting purposes in the average weekday of spring or fall.

Regarding the ability to model improvements in various rail services (BART, regional rail, etc.), TM 2.1 handles this feature satisfactorily for short/medium-distance trips in the region, including access/egress modes. However, a solution that handles this efficiently for longer-distance travel would be key and needs to be accounted for in the new model in particular to study various scenarios involving conventional standard-gauge rail and its integration with mass transit. TM 2.1 can model the integration of services (e.g., BART+CCJPA trains, etc.), including local bus, light rail, and commuter rail options, but it would have problems in modeling behavior for long-distance travel as well as infrequent trips with less common trip purposes. This is the case, for example, of travel for business purposes, personal travel, or vacation travel, which could be relevant for certain type of rail services. TM 2.1 can also consider transit pass ownership and transit subsidies, which could be targeted at the individual level based on individual and household characteristics in the population synthesizer, a feature that is very important for the Link21 objectives.

Similarly, TM 2.1 can model the impacts of travel time and travel costs for short- and medium-distance trips, but if these are perceived in different ways for longer-distance travel it would have limitations since it does not have a special component for long-distance trip modeling. This might cause undesirable outcomes, especially for the Link21 program. As previously mentioned, elasticities to travel time and costs are different for long-distance travel (and inside this market, they differ for business/work-related and personal/vacation trip purposes) and, without properly modeling them, they might not be captured. TM 2.1 can evaluate travel time inside the megaregion between major centers and/or transportation hubs. Moreover, TM 2.1 can model the impacts of travel costs (including congestion pricing) for transit and private vehicles, for short- and medium-distance trips but, similarly to what previously discussed, not for long-distance travel.

In terms of frequency of service, input headway is included in TM 2.1. For example, a value of 15 means a transit vehicle arrives at every point on a certain route every 15 minutes. Additional short-run routes operate during commute peak hours. Commuter rail could be coded by the time of arrival (current standard) or based on headway (frequency) for high-frequency services. On the other hand, TM 2.1 equips modules addressing crowding and capacity constraints for both transit vehicles and park-and-ride facilities. The modules have been only developed for short-distance trips, to date, but the Link21 program could build on this functionality with any necessary modifications to expand them to the entire suite of rail services of relevance to the program.

TM 2.1 can model scenarios to accommodate future growth in the region. As the model was originally developed to model nine counties, the process of model development would require creating all input data, including land use and sociodemographic inputs, and road and public transportation networks for the entire megaregion, and (the eventual re-estimation, in addition to) the calibration and validation of the model. The model can evaluate trips between major centers as well as between any other level of geographies that are compatible with its fine resolution and rich level of spatial details.

Regarding the ability to model mode choice/mode share (including competitiveness between auto and rail), TM 2.1 has this feature for short/medium-distance trips and to the extent the model can be extended to the 21 counties, it would be able to perform proper mode choice forecasts. Under this option, long-distance travel would not be properly modeled so limitations apply if long-distance travel components account for a meaningful portion of the travel markets deemed important for the Link21 program. The VMT impacts by mode and time of day can be computed by post-processing of the model output (for short/medium-distance travel). Moreover, TM 2.1 can model the impacts of new technologies (e.g., telecommuting and e-shopping) on travel behavior. More advanced than other models, the MTC TM 2.1 would allow for a good representation of the TNCs and taxi modes as these are explicitly considered as travel modes in this model.

5.5.1.2 Important features

TM 2.1 has about two-thirds of the important features already. Some features are present directly while others can be carried out through post-processing. For instance, some limitations apply in TM 2.1 in accounting for hours of operations. Transit operations are currently modeled in blocks of time. This could be addressed in the model development through transitioning the transit assignment to shorter periods (*e.g.*, one hour), with potential further improvements needed in the travel demand model component. In addition, ridership in TM 2.1 is modeled by the time of day and trip purpose for the average weekday, but it currently does not model demand during weekends. Both job accessibility by walking/bicycling distance and accessibility of transit options by population groups can be computed indirectly from the outputs of TM 2.1. The model accounts for access to transit, including walk and drive, but does not include solutions for access modes for long-distance travel.

TM 2.1 can account for impacts of land-use scenarios on travel demand using exogenous inputs. It can evaluate the impacts of both current and future land use characteristics within a station catchment area and (to some extent) the impacts that urban design around stations might have by changing the land use information in the TAZ input file. Depending on the extent allowed by the spatial system in the final Link21 model, a travel modeling system building on TM 2.1 could help evaluate local land-use policies consistent with large capital transit investments, measured by PDAs and other standards, including zoning and BART station area standards.

In terms of model running time, TM 1.5 takes between one hour and one day, depending on the complexity of the scenarios and the type of run (with cold or hot start). TM 2.1 will likely take similar times, if not longer, considering the additional features, the larger modeling area, and the expanded transportation networks, though continuous computational improvements can help make the model runs more efficient also through increased adoption of parallel progressing, wherever possible.

5.5.1.3 Optional features

TM 2.1 already boasts most of the optional features that have been discussed to support the Link21 program. For instance, TM 2.1 has modules modeling capacity of transit and reliability (on-time operation). Reliability is somewhat possible for short-distance travel, although this is a complex feature and might need to be handled to the extent possible with some post-processing and might require significant resources to be implemented for other types of rail service.

The business access to potential employees and business access to the market are not built in the model but can be computed indirectly through postprocessing of the rich output of the model. A modeling system building on TM 2.1 could help evaluate equity impacts by income groups and auto sufficiency, as well as other sociodemographic inputs of interest that are used in the model structure and included in the population synthesizer.

TM 2.1 can model the impacts of new transportation options. For example, the model includes shared mobility options in a new experimental module. This module is included in the daily activity model through the nest for *Mobility as a Service modes*, and this could be the embryonal basis on which to further build during the Link21 model development if more features of this type and/or travel services need to be included. The model also includes active transportation modes. Experimentally, TM 2.1 also accounts for privately-owned and shared automated vehicle, though the validity of the assumptions for these modules should be carefully evaluated, and this is still an active research topic.

5.5.2 Build on MTC TM 2.1 regional model (considering a dedicated long-distance component)

As mentioned in subsection 5.5.1, building on the TM 2.1 has many advantages as this model already has most of the desirable modeling features for the Link21 program. The option of building on the MTC TM 2.1 while also including a long-distance component will further enhance its capabilities in terms of dynamically model both shorter and longer distance trips, but at the cost of some additional complexity. TM 2.1 is a complex ABM model, so model development and creation of inputs and networks takes time that can challenge the 18-month requirement to develop the core model. The Link21 efforts would build on existing modeling work, in particular with the TM 2.1, and if justified by the travel flows in the megaregion, a long-distance component could be added. This would require additional time and effort, and the final product, while conceptually superior and preferable, could incur in limitations in particular for the discontinuity in the modeling of trips for the shorter-distance and more regular trip purposes vs. longer-distance and infrequent trip purposes.

This approach would include two passenger components in the model, one for short-distance travel based on TM 2.1 and one for long-distance travel, similar to what has been done in many statewide models that need to operate at different geographic scales of travel. The two components can run on the same software platform and be integrated using the same inputs.

An important decision would relate to the identification of the distance threshold separating the two model components and/or the trip purposes/components of travel modeled in the two systems. One potential solution, which would avoid the creation of undesirable discontinuities in the modeling process, would be to separate the components of travel by trip purpose instead of by travel distance. Accordingly, in this modeling approach, one portion of the passenger model would follow the traditional activity-based formulation for all travel happening in the 21-county megaregion in the average weekday for commuting and non-commuting purposes. This would be based on the CT-ramp (for a modeling framework building on MT 2.1/2.2) or ActivitySim (in future developments of the Link21 modeling framework). Another special assessment travel model component would account for less frequent trips made for non-usual trip purposes, such as business, personal or vacation travel. This model component could be derived from the CHSR model or the long-distance passenger travel demand model component from the CSTDM, in the first release of the Link21 model, and eventually be substituted in future model updates by the new model component that is being developed by Caltrans to support the new statewide rail plan. The two model components would run in parallel in the CUBE platform, and trip tables merged so that travel assignment is run for all trips and the two components interact with each other through their impacts on the travel skims at each round of iteration in the model run.

This approach would allow the model to account for the different behavioral foundations and elasticities that are associated with short-distance commuting and non-commuting trips vs. the less frequent longer-distance travel for either work/business or personal/leisure purposes. The model could also model “true” long-distance travel (i.e., trips to/from areas outside the boundaries of the 21-county megaregion), though this is not a very large market, and therefore it does not justify allocating a large volume of resources to it.

In terms of modeling capabilities, some components might be required to be imported from other models. If that is the case, the merging process must be successful in such a way that, for example, it is possible to model the integration of different services (e.g., BART + CCJPA), also when they tender to potentially different components of travel demand, e.g., short-distance regional travel and intercity/longer-distance travel. The two components would be hosted as part of the same modeling platform, to create synergies between the processes and easier handling of inputs and outputs, and trip table from the short-distance and long-distance components merged before the assignment step in the model, so all trips are assigned together and the feedback loops from the model fed into all steps of the modeling framework.

5.5.2.1 Critical features

This option shares all the qualifications of the previous option (presented in the sub-section 5.5.1) in terms of having/not having the proposed critical modeling features. Additionally, modeling longer-distance travel would require a modeling component designed to forecast passenger travel movements on a larger scale (*e.g.*, medium-/long-distance travel inside the megaregion to/from areas outside the 21-county megaregion).

The long-distance travel component could be built importing a model component from another model (*e.g.*, CHSR or New Statewide Model), with the necessary modifications, though identifying the way the two components interact and are merged might present some difficulties. The long-distance component could model the longer-distance components of passenger travel, but some discontinuity would exist at the merger of the two components with risks of additional complexity in trying to make the two model components work well together to model the integration of services and the impacts of travel times and costs for the available travel options, including intermodal trips featuring transfers across various means of travel.

5.5.2.2 Important features

This option shares all the qualifications of option 1 (presented in the sub-section 5.5.1) in terms of having/not having the proposed important features. Moreover, the integration with the long-distance travel component might make the model more complex resulting in longer runtimes and more difficult calibration and validation, but it will likely allow better ability to model the various components of travel demand and the realistic behavioral changes that are associated with trips made for different travel purposes and over different distances.

5.5.2.3 Optional features

This option shares all the qualifications of option 1 (presented in the sub-section 5.5.1) in terms of having/not having many of the proposed optional modeling features.

5.5.3 Build on SFCTA model (with or without a dedicated long-distance component)

The third option consists of building on the SFCTA, a rather complex activity-based model, which in general terms has already most of the relevant features. The current model covers nine counties, and it could be expanded to cover the 21 counties (though with some limitations compared to the TM model) in similar terms building at least on part on land use information, TAZs, and network inputs from both the SACSIM and Three County Central Valley Travel Demand Models, which are also based on the DaySim platform and share many similarities with the SFCTA model. The model provides a fine level of spatial resolution. There are a total of 1739 TAZs with an average size of 5.46 sq. miles. Similar to other models, SFCTA only models travel for typical weekdays.

Similar to the MTC travel model, SFCTA is also part of the consortium of Metropolitan Planning Organizations and Department of Transportations, which are involved in the ActivitySim development and migration, so future model versions (from which Link21 could also benefit) would likely converge towards the same modeling platform.

5.5.3.1 Critical features

For the case of short-distance trips, the model has most of the features already, such as the ability to model individual rail improvements and the interactions between different services, forecasting transit ridership, and accounting for the impacts of frequency and other travel attributes, among many others. However, it would have problems in modeling behavior for long-distance travel and would be subject to the issue of assuming correct elasticities for this type of trips, unless a proper long-distance model component is also included. These components of travel include trips going into, going out of, and coming through the 9-county bay area, as well as the longer-distance trips inside the megaregion that might not follow the typical behavioral patterns of regional travel. The trips inside San Francisco are modeled through the San Francisco activity-based model whereas Baycast, the MTC legacy trip-based model, is used to model trips originated in the other 8 counties of the region. Then, a solution that handles this issue efficiently for long-distance travel would be key, as this might need to rely on an extension of the Baycast model area (similar to what suggested in option 1) or on the inclusion of a long-distance module (similar to what suggested in option 2), which adds the additional issue of having three different models simultaneously.

One benefit is that the model provides a reasonably good level of detail and is already operational. Further, DaySim is a rather efficient, user-friendly and fast platform. The transit network is explicitly coded, and this allows for modifications to consider the improvement of the service and network expansion. Transit operation is allocated to 5 time-of-day periods: early morning (before 6 AM), AM peak (between 6 and 9 AM), mid/day (until 3:30 PM), PM peak (between 3:30 and 6:30 PM), and evening (after 6:30 PM and until 3 AM). Frequencies by time of day are included in the transit network modeling, thus adjustments in the frequency of the transit service can be accounted for. Similarly, the ridership by time and purpose can be modeled due to the fine resolution of the transit network.

The travel cost and mode choice are captured through the generalized utility component, and the model has been already used successfully to evaluate the impacts of congestion pricing. Therefore, potential impacts from transit service improvement might be captured by adjusting the characteristics of the transit service in the mode choice model as well as other model components. Carpooling and active transport are included as travel modes, in addition to solo-driving and transit (Muni Metro, BART, and others such as Caltrain, ferries, express buses). More complicated services such as ridehailing and CAVs are not considered in the current version of the model.

One of the major limitations of this model is that this model does not account for transit vehicle capacity and thus passenger crowding is neglected from the analysis, at least in its current version (but this feature has been tested for an upcoming new version). There exists a current implementation to address transit capacity, however, it adds a substantial amount of time to each modeling iteration. This considers a dynamic access module, which evaluates whether each service is available given the number of people travelling inside, and a dynamic dwell time module, which calculates the additional stop time given the number of onboards and alights. Given the additional computational burden, it is hard to consider this feature to be readily available in its current version. This is a critical feature if we consider the focus of the Link21 program on transit service, and thus, this alternative would be inferior to the modeling approaches based on the MTC TM 2.1 model.

Park and ride facilities capacity restriction are absent as well, as these have not been considered as a central feature in San Francisco (the planning area of main interest for SFCTA). On the other hand, this approach would build on a reliable, operational, and rather fast model with limited "surprise" and almost zero uncertainties in the process. Also, the process of creation of the additional inputs, including road and public transportation network input files, could be performed more easily exploiting certain commonalities with the SACSIM and three-county model, which are also based on the DaySim activity-based modeling platform.

Some other considerations include that only the nine counties in the Bay area are included in the SFCTA model, with high-level of detail in particular for the San Francisco area, so future expansion of the model would require extensive work to gather the information for the other parts of the region. Most of the model components are estimated from household survey results for San Francisco residents only.

The SFCTA model is used to forecast trips in San Francisco while the remaining eight counties in the Bay Area are forecasted using Baycast. Thus, the entire model has three components: 1) San Francisco model; 2) region model (non-San Francisco trips), and 3) external models. The external models forecast travel for the interregional travelers (workers and other travelers entering or leaving the Bay Area), visitors (tourism, i.e., travel from people staying in hotels), light-duty commercial (for local deliveries and services), and freight and trucks (heavy-duty goods movements). This model structure poses a challenge to adjust and expand to the entire 21-region, though other models based on a similar model interface and modeling system (for the SACOG region and the northern portion of the San Joaquin Central Valley) also are available and would be handy to create inputs for the model and the expansion of the modeling framework to the entire megaregion. As the main focus of the original model is on the nine counties in the MTC region, this might not be entirely problematic as it is possible to incorporate large portions of the additional counties with a lower level of detail.

5.5.3.2 Important features

Significant data preparation time is required since existing models only include the information for nine counties out of a total of 21 counties. As a complex activity-based model, SFCTA based model would take a relatively long time to run. The current model uses five transit networks for five time periods (Early AM, AM Peak, Midday, PM Peak, Evening). Accounting for the hours of operation would require transit assignment happening on shorter periods (e.g., 1 hour), with potential further improvements needed in the travel demand model component. This can be directly done in the current version by developing additional skim matrices and modifying the roster input file, which indicates which skim matrixes are associated to each time of the day.

Walking and driving are considered two options for access/egress mode to transit. This treatment is similar to other major activity-based models.

The impacts of land-use scenarios on travel demand can be modeled using exogeneous changes of the inputs. Similar to options 1 and 2, access to business and jobs can be computed indirectly based on the land-use information and network performance metrics from the model.

5.5.3.3 Optional features

The model includes modules related to carpooling and active transportation. However, similarly to many other currently available activity-based models, the SFCTA model cannot directly evaluate the impacts of new mobility options, including ridehailing, other forms of sharing mobility, and CAVs. Similar to the recommendations for option 1 and option 2, a modeling approach building on the SFCTA model can be expanded with or without a long-distance component to serve the Link21 program needs.

5.5.4 Build on CHSR or New Statewide model

Finally, it is possible to build on the California High-Speed Rail model (CHSR). As the most direct benefit, this option includes long-distance travel but then it relies on MTC model for intraregional travel components. However, the model has been designed to operate at a large scale of operation and is mainly designed to model long-distance travel. As such, it lacks the level of detail and modeling capabilities required to properly model local travel demand at the regional level, which is an important component of travel for the Link21 infrastructure and proposed service upgrades. Accordingly, we are including this option mainly for comparison, as it is not considered a viable option to build on for the purposes of the Link21 priorities. It would require significant modifications while likely returning results that do not meet expectations for the modeling framework. The original model was developed based on behavioral (stated preference) survey data collected from California that is potentially used to inform new long-distance rail usage. While these features are all desirable, the CHSR model (or the new statewide rail model) could serve as the model component for longer-distance travel in conjunction with one of the previous modeling options, building on one of the regional travel demand models, rather than the basis for the development of the entire Link21 model system.

All statewide models cover the study area of the Link21 program but with low ability to forecast local and regional model. For example, the CHSR model includes two modules: Long-Distance Model and Short-Distance Intraregional Models, with the latter that relies on static trip tables which comes from local transportation models, such as MTC TM for the San Francisco Bay Area.

To address the limitations in the resolution needed to model local trips and public transportation networks and services, one possibility is to incorporate a more carefully designed, possibly more sophisticated, short-distance model focused in the area of main interest for the study.

For example, by including MTC TM as the short-distance model component, this modeling option could converge to something similar to option 2 but in the opposite sense (by including a short-distance model into a long-distance one instead of the other way around). However, the main difference would come from the distinctive differences between the core models. Long distance models rely on Cube, which has basic modeling features, and low capabilities for further enrichment in particular for modeling public transportation ridership. Any activity-based model has already much better ability to forecast realistic regional travel behaviors, and the MTC TM 2.1 public transportation component relies on EMME2, which has significant advantages in terms of transit modeling and crowding analysis. Thus, option 2 (or option 1) is still preferable even after considering the potential similarities between these different approaches.

5.5.4.1 Critical features

As statewide models, the CHSR or New Statewide models cover the entirety of California with all 58 counties included. This helps capture the potential long-distance travel and inter-regional travel. The average TAZ size of the CHSR and New Statewide models are 44.67 and 174 sq. miles, respectively, leading to a less desirable granularity of the statewide modeling framework. As a result, this level of detail might not be able to capture all the travel-related impacts at the local level. Extra effort is needed to develop a more detailed TAZ system and make improvements in the modeling components to model local/regional travel. This task might be very demanding and might not result in a successful approach to model local travel.

The models have a detailed representation of the long-distance transit rail network, with stations and routes explicitly captured as input. A direct benefit of the network coding is that the travel time between major centers can be derived from a loaded network as one of the modeling results. Similarly, VMT impacts by mode and time of day can also be indirectly obtained from the outputs. Detailed transit network representation allows the inclusion of the potential rail service improvement into the modeling system.

However, the hours of operation of transit services are not explicitly accounted for. Also, the model has limited potential in terms of the level of detail needed for local transit forecasting (except for the MTC intraregional model component, but this is also included as a static trip table input in the CHSR, thus making it less desirable than a purposely designed modeling system, such as those presented in the previous options).

The model has a poor ability to capture details of transit networks and access/egress to stations, as well as to model short-distance travel choices. Crowding and capacity constraints cannot be directly estimated. The updates would require substantial efforts that might not be possible to be introduced efficiently in the model framework. On the other hand, the light weight of the model would lead to shorter model runtimes, compared to other options.

Travel cost is modeled in a generalized utility function, where different scenarios can also include tolling and congestion pricing scenarios. Similarly, for transit systems, the frequency of bus and rail is accounted in the generalized travel cost function within the transit components. The competition between auto and transit is captured through a mode choice component, meaning the model might be able to capture the modal shift after the improvement of rail service, depending on the sensitivity of the mode choice model. Access/egress models are included in the mode choice design. The accessibility of transit options by different population groups can be indirectly estimated at the TAZ level. Also, the availability of parking and park-and-ride facilities can also be modeled for access and egress processes.

One of the major limitations of the CHSR and New Statewide models is their incompetency in modeling short-distance trips, which would jeopardize the capability to model the improvement of transit service and integration of services at the local level.

5.5.4.2 Important features

Considerable time might be required for data preparation for the fine-resolution analysis, especially when those details are not included in the original model development. The currently forecasting years include 2029, 2033, and 2040, leaving the ability to accommodate for future growth of social demographics, travel demand, transportation networks, and many other aspects. Similar to the other models mentioned above, both the CHSR and the new statewide rail model focus on travel in a typical weekday, and thus do not explicitly consider travel demand for transit and other modes during the weekend.

Similar to many of the existing models, the two models are not capable of implicitly modeling the impacts on land use, and this is treated as an exogenous input. Further, local land-use modifications cannot be always directly studied due to the granularity of the TAZ system. Job and business accessibility can be calculated indirectly, to the extent possible by the information available at the TAZ level.

Overall, the inclusion of more details and the upgrade of the modeling approach of a large-scale model to meet the needs of the Link21 program is not an easy task and thus this approach might have too many limitations in its ability to satisfy the modeling needs of the program.

5.5.4.3 Optional features

Access to potential employees and other markets cannot be directly estimated due to the limited level of detail. For similar reasons, the evaluation of equity impacts cannot be achieved especially at a fine level of spatial detail. Finally, at least in the current model specifications, those models are not able to capture the impacts of shared mobility, CAVs, or micromobility.

5.6 Evaluation of each modeling approach based on proposed modeling features.

Table 5.5 Model evaluations

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
1. Timeline and Running Time	1. Time to develop a core model in 18 months. Possibility to incorporate additional modules later.	This is a rather complex ABM model, so model development takes time, but the Link21 efforts would build on existing modeling work, in particular with the TM 2.1.	This is a rather complex ABM model, so model development takes time, but the Link21 efforts would build on existing modeling work, in particular with the TM 2.1. The long-distance component would require additional time and efforts.	This is a rather complex ABM model, so model development takes time, but the Link21 efforts would build on existing modeling work.	Work could build on the existing CHSR or New Statewide Model, but considerable time and efforts would be required to add the needed level of detail without satisfactory results (this approach might not be feasible/recommended).
	1a. Data preparation time	It will take considerable time for data preparation, especially for the data outside of the current 9 counties that the TM 2.1 covers.	It will take considerable time for data preparation, especially for the data outside of the current 9 counties that the TM 2.1 covers.	It will take considerable time for data preparation, especially for the data outside of the current 9 counties that the TM 2.1 covers.	It will take considerable time for data preparation, especially to reach a fine level of resolutions for the study area.

Legend: 🟥 Critical 🟩 Important ☐ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
	1b. Scenario running time.	TM 1.5 takes between one hour and one day. TM 2.1 likely takes longer.	TM 1.5 takes between one hour and one day. TM 2.1 likely takes longer. Besides, the integration with the LD component might make the model heavier and take longer to run.	This model is complex and takes a long time to run.	This model might take less time for running as it is not a complex model compared to the models presented in options 1-3.

Legend: 🟥 Critical 🟩 Important ☐ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
2. Geographical considerations	2. Ability to model travel through the entire Northern California megaregion	The current TM 2.1 model is under development covering 9 counties which can be expanded to cover 21 counties. Longer-distance travel inside the 21 counties could be modeled with some extension of the current functions in TM 2.1 (this might cover the large majority of trips in the region - need to evaluate from trip tables and market demand study) + potentially external inputs from other models (*e.g.*, exogenous static trip table from CHSR or New Statewide Model) for trips to/from external areas (this might account for small portion of trips).	The current TM 2.1 model is under development covering 9 counties which can be utilized to expand to cover 21 counties. Need to build additional module for long-distance travel to be dynamically modeled together with the regional trips in the same model platform.	The current model covering 9 counties can be expanded to cover 21 counties (though with some limitations compared to MT model), but it would build on similarities with land use, TAZ and network inputs from both SACSIM and the Three County Travel Demand Model.	The current model covers all of California (58 counties), but with low resolution in the current version, so considerable efforts would be required to add details and modeling capabilities that are not included in the current model. This can be a very problematic task.

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
2. Geographical considerations	2a. Geographical resolution: Model captures route alignment and station locations.	Satisfied (both route alignment and station locations)	Satisfied (both route alignment and station locations)	Satisfied (both route alignment and station locations)	Poor ability to capture details of transit network, and access/egress to stations, as well as to model short-distance travel choices. The updates would require substantial efforts that might not be possible to introduce efficiently in the model framework.
	2b. Level of detail of the zoning system	To maintain the resolution of the average MAZ and TAZ sizes, the future model for 21 counties should have about 142K MAZs and about 17,000 TAZs, though lower resolution could be used for other areas that are less relevant to study major transportation corridors. The issue of longer-distance travel remains not easy to deal with	To maintain the resolution of the average MAZ and TAZ sizes, the future model for 21 counties should have about 142K MAZs and about 17,000 TAZs, though lower resolution could be used for other areas that are less relevant to study major transportation corridors. Modeling longer-distance travel would require a spatial framework to study travel	To maintain the resolution of the average TAZ size, the future model for 21 counties should have about 6250 TAZs, but lower resolution could be applied for other areas that are less relevant to study major transportation corridors. Questions remain on how to model long-distance travel in a model that was not built	To maintain the resolution of the average TAZ size, the future model for 21 counties should have about 760 TAZs. But that solution would not be adequate to model detailed short-distance travel. Hence, big improvements would be needed.

Legend: 🟥 Critical 🟩 Important ☐ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
		though it likely accounts for a small portion of trips in the megaregion.	on larger scale (*e.g.*, coarser TAZs to study long-distance travel to/from areas outside the 21-county megaregion).	to do that. Some difficulties overlap with option 1 and option 2.	
3. Rail services modeling	3. Ability to model improvements in individual rail services (BART, Commuter rail, etc.)	TM 2.1 satisfies this criterion for short distance trips. But a solution that handles this efficiently for longer-distance travel would be needed.	TM 2.1 satisfies this criterion for short distance trips. Long-distance travel would require importing a model component from another model (*e.g.*, CHSR or New Statewide Model) and merging the two and making sure they work well in coordination might be the difficult task.	The model satisfies this criterion for short distance trips. But a solution that handles this efficiently for longer-distance travel would be needed.	CHSR somewhat satisfies this criterion, with imported information for MTC and SCAG intraregional models. But none of these models were designed to study short-distance travel and the model would require considerable upgrades.

Legend: 🟥 Critical 🟩 Important ☐ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
4. Service integration modeling	4. Ability to model integration of services (*e.g.*, BART + Capitol Corridor trains, etc.)	The model can integrate local bus, light rail, and commuter rail BUT would have problems in modeling behavior for long-distance travel.	It can integrate local bus, light rail, and commuter rail (for short-distance trips). The long-distance component could model long-distance travel, but some discontinuity would exist at the merger of the two components, depending on the way this is handled, with risk of additional complexity in trying to make the two model components work well together.	The model can integrate local bus, light rail, and commuter rail (for short-distance travel). Similar issues to those discussed for option 1 and option 2 would apply for the long-distance services, depending on the way the long-distance travel is handled.	The integration is in theory modeled between main long-distance modes (high-speed rail, conventional rail, air) and access/egress mode (transit). The models of this type lack good short-distance components at the moment, so that weaker part would require considerable upgrades to fulfill the Link21 needs.

Legend: 🟥 Critical 🟩 Important ☐ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
5. Travel time	5. Ability to model the impacts of travel time	TM 2.1 is already well positioned to capture the impacts of travel time and travel costs for short-distance trips, but not for long-distance travel. The problem is that elasticities to travel time and costs are different for long-distance travel and without properly modeling them, they might not be well captured.	TM 2.1 is already well positioned to capture the impacts of travel time and travel costs for short-distance trips. The long-distance model component would supposedly fulfill the requirement for longer-distance travel, but the discontinuity at the merger of the two model components, whatever way it is handled, can be a problem.	The model is already well positioned to capture the impacts of travel time and travel costs for short-distance trips. Similar issues to those discussed for option 1 and option 2 would apply for the long-distance services, depending on the way the long-distance travel is handled.	The model is well suited to fulfill this for intercity travel, but would require significant efforts for model properly the impacts of changes in the attributes of local/regional travel (*e.g.*, inside the Bay Area on BART).
	5a. Ability to evaluate travel time between major centers	The model would satisfy the feature well inside the megaregion.	The model would satisfy the feature well inside the megaregion.	The model would satisfy the feature well inside the megaregion.	The model is well suited to fulfill this for intercity travel, but would require significant efforts to model local/regional travel (*e.g.*, inside the Bay Area on BART) properly.

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		Option 1: Build on MTC TM 2.1 model (W/O LD)	Option 2: Build on MTC TM 2.1 model (W/ LD)	Option 3: Build on SFCTA model	Option 4: Build on CHSR or New Statewide Model
	5b. Ability to evaluate travel time between major centers and transportation hubs	The model would satisfy the feature well inside the megaregion.	The model would satisfy the feature well inside the megaregion.	The model would satisfy the feature well inside the megaregion.	The model is well suited to fulfill this for intercity travel, but would require significant efforts to model local/regional travel (*e.g.*, inside the Bay Area on BART) properly.
6. Travel cost	6. Ability to model the impacts of travel cost (including congestion pricing) for transit and auto	TM 2.1 is already well positioned to capture the impacts of travel time and travel costs for short-distance trips, but not for long-distance travel. As elasticities might be different for long-distance travel, this would require careful evaluation for that component of trips.	TM 2.1 is already well positioned to capture the impacts of travel time and travel costs for short-distance trips, but not for long-distance travel. The inclusion of a long-distance component would supposedly solve this problem for long-distance travel. However, some discontinuity might exist at the merger of the two model components, requiring careful consideration.	The model is already well positioned to capture the impacts of travel time and travel costs for short-distance trips. Similar issues to those discussed for option 1 and option 2 would apply for the long-distance services, depending on the way the long-distance travel is handled.	This model satisfies this criterion (toll is included in auto operating cost or airport access) for intercity travel, but the model is not able to model this well for shorter/ regional trips, unless big improvements are introduced.

Legend: 🟥 Critical 🟩 Important ☐ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
7. Hours of operation	7. Account for hours of operations	Transit operations are currently modeled in blocks of times. The model is being improved with new public transportation modeling features. Hours of operation could be considered in model development with transit assignment happening on shorter time periods (*e.g.*, 1 hour), with potential further improvements needed in the travel demand model components.	Transit operations are currently modeled in blocks of times. The model is being improved with new public transportation modeling features. Hours of operation could be considered in model development with transit assignment happening on shorter time periods (*e.g.*, 1 hour), with potential further improvements needed in the travel demand model components.	The current model uses five transit networks for five time periods (Early AM, AM Peak, Midday, PM Peak, Evening). Accounting for the hours of operation would require transit assignment happening on shorter time periods (*e.g.*, 1 hour), with potential further improvements needed in travel demand model components.	To date, the model can handle it for intercity bus and rail, but the model currently has big limitations in dealing with short-distance travel that would take a large amount of resources to overcome.

	Legend:	🟥 Critical	🟩 Important	☐ Optional

Modeling Features		Option 1: Build on MTC TM 2.1 model (W/O LD)	Option 2: Build on MTC TM 2.1 model (W/ LD)	Option 3: Build on SFCTA model	Option 4: Build on CHSR or New Statewide Model
8. Frequency modeling	8. Account for frequency of service	The model uses input headway information, *e.g.*, a value of 15 means a transit vehicle arrives at every point on its route every 15 minutes. Additional short-run routes operate during commute peak hours. Commuter rail could be coded by time of arrival (current standard) or based on headway (frequency) for more frequent services.	The model uses input headway information, *e.g.*, a value of 15 means a transit vehicle arrives at every point on its route every 15 minutes. Additional short-run routes operate during commute peak hours. Commuter rail could be coded by time of arrival (current standard) or based on headway (frequency) for more frequent services.	The model uses input headway information (e.g., within 15-, 30-, and 45-minute time intervals). The use of headway coding accounts for a transit vehicle arriving every certain number of minutes on a route. Commuter rail could be coded by time of arrival (current standard) or based on headway (frequency) for more frequent services.	This model satisfies this criterion for intercity bus and rail but has big limitations in dealing with short-distance travel, to date.
9. Crowding and capacity constraints	9. Crowding and capacity constraints	TM 2.1 has introduced important modifications to model public transportation and now satisfies this criterion for short distance trips.	TM 2.1 has introduced important modifications to model public transportation and now satisfies this criterion for short distance trips. A similar approach could be developed for long-distance travel if considered a priority.	The feature was tested but ultimately not included, due to mismatches between model estimation results and survey data. The model could not be calibrated.	Not something that can be easily implemented in this type of model.

Legend: 🟥 Critical 🟩 Important ⬜ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
	9a. For transit itself	Satisfied	Satisfied	Tested but ultimately not included	Not satisfied.
	9b. For park-and-ride facilities	Satisfied	Satisfied	The SF-CHAMP / DaySim model includes park-and-ride parking capacity constraints.	Partially satisfied for parking at access locations for long-distance travel options only
10. Reliability	10. Reliability (on time operation)	MTC is developing a transit reliability module for inclusion in TM 2.1. The Link21 modeling efforts will benefit from this on-going model development process.	MTC is developing a transit reliability module for inclusion in TM 2.1. The Link21 modeling efforts will benefit from this on-going model development process.	Tested but ultimately not included.	On-time performance is modeled through scenarios for high-speed rail, conventional rail, and air. The model is not designed to properly model short-distance travel.

Legend: 🟥 Critical 🟩 Important ⬜ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
11. Future land use	11. Ability to account for impacts of land use scenarios on travel demand	The model uses land-use characteristics as exogeneous inputs.	The model uses land-use characteristics as exogeneous inputs.	The model uses land-use characteristics as exogeneous inputs.	The model uses land-use characteristics as exogeneous inputs (but with limited spatial resolution in current model).
	11a. Evaluation of local land use policies consistent with large capital transit investments (measured by PDAs and other standards, inc. zoning and BART station area standards)	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data.	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data.	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data.	The low spatial resolution limits this evaluation in particular for short-distance travel.
	11b. Evaluation of the impacts of current and potential future land uses within station catchment areas (number of residences in priority areas within walk/bike distance thresholds of new or improved service)	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data.	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data.	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data.	The low spatial resolution limits the evaluation of this topic.

Legend: 🟥 Critical 🟩 Important ⬜ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
	11c. Evaluation of the impacts of urban design around stations	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data.	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data.	Yes, by varying exogenous inputs, to the extent allowed by the spatial level of detail and input data.	The low spatial resolution limits the evaluation of this topic.
	11d. Ability to model land use impacts of new and improved rail services.	The model is designed to work in integration with UrbanSim, but modeling land use and transportation interactions in an endogenous way will likely not be feasible as part of this model development, due to the limited timeline.	The model is designed to work in integration with UrbanSim, but modeling land use and transportation interactions in an endogenous way will likely not be feasible as part of this model development, due to the limited timeline.	Not feasible to achieve in an endogenous way as part of this model development.	Not feasible to achieve in an endogenous way as part of this model development.
12. Transit ridership	12. Ability to model ridership	TM 2.1 satisfies this criterion for short-distance trips.	TM 2.1 satisfies this criterion for short-distance trips. Assuming a long-	The model satisfies this criterion for short-distance trips.	This is satisfied for the type of services the model is able to consider.

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
			distance travel component is implemented, that would address that too, but with some potential issues associated with the discontinuity at the merger of the model components.		Limitations apply to the modeling of short-distance travel options.
	12a. Ability to evaluate trips between major centers	Satisfied for the type of services and trips that the model considers	Satisfied for the type of services and trips that the model considers	Satisfied for the type of services and trips that the model considers	Satisfied for the type of services and trips that the model considers
	12b. Ridership by time of day and purpose	Satisfied, based on time-of-day periods in the model	Satisfied, based on time-of-day periods in the model	Satisfied, based on time-of-day periods in the model	Satisfied, based on time-of-day periods in the model
	12c. Ridership by weekday	Satisfied	Satisfied	Satisfied	Satisfied
	12d. Ridership by weekend	Not satisfied	Not satisfied	Not satisfied	Not satisfied

Legend: 🟥 Critical 🟩 Important ☐ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
13. Mode choice modeling	13. Ability to model mode choice/mode share (including competitiveness between auto and rail)	TM 2.1 satisfies this criterion for short distance trips. Under this option, long-distance travel might not be properly modeled so limitations might apply for that component of travel.	TM 2.1 satisfies this criterion for short distance trips. Assuming a long-distance travel component is implemented, that would address that too, but with some risk with discontinuity at the merger of the model components.	The model satisfies this criterion for short-distance travel and the services that are modeled. Similar issues to those discussed for option 1 and option 2 would apply for the long-distance services, depending on the way the long-distance travel is handled.	Satisfied for the type of services that the model is able to consider. Limitations apply to the modeling of short-distance travel options.
14. VMT estimation	14. Ability to estimate VMT impacts (by mode and time of day)	By post processing, for short distance	By post processing, for short distance, and for long distance too, assuming a good integration of the two components	Satisfied for short-distance travel	By post processing, only for the travel modes and demand components that the model is able to consider
15. Job accessibility	15a. Job accessibility by walking/bicycling distance	It can be computed indirectly.	It can be computed indirectly.	It can be computed indirectly.	This is difficult to achieve unless the level of spatial resolution and modeling approach are dramatically improved.

Legend: 🟥 Critical 🟦 Important ☐ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
	15b. Business access to potential employees	Not built in the model but it could be computed indirectly.	Not built in the model but it could be computed indirectly.	Not built in the model but it could be computed indirectly.	This is difficult to achieve unless the level of spatial resolution and modeling approach are dramatically improved.
	15c. Business access to markets	It can be computed indirectly.	It can be computed indirectly.	It can be computed indirectly.	This is difficult to achieve unless the level of spatial resolution and modeling approach are dramatically improved.
16. Transit options accessibility by different groups	16. Accessibility of transit options by population groups	It can be computed indirectly.	It can be computed indirectly.	It can be computed indirectly.	This is difficult to achieve unless the level of spatial resolution and modeling approach are dramatically improved.

Legend: 🟥 Critical 🟩 Important ⬜ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
	16a. Evaluation of equity impacts	Satisfied, by income groups and auto sufficiency	Satisfied, by income groups and auto sufficiency	Satisfied, by income groups and auto sufficiency	This is difficult to achieve unless the level of spatial resolution and modeling approach are dramatically improved.
17. Access and egress modes	17. Access/egress modes	The model accounts for access to transit, including walk and drive. No solution for long-distance travel is currently included.	The model accounts for access to transit, including walk and drive. A similar approach could be implemented for long-distance travel.	The SF-CHAMP / DaySim model considers both walk and drive access and egress to transit. Similar issues to those discussed for option 1 and option 2 would apply for the long-distance services, depending on the way the long-distance travel is handled.	It is part of mode choice design for the long-distance travel modes included in the model. The model currently has big limitations in dealing with short-distance travel that would take a large amount of resources to overcome.

Legend: 🟥 Critical 🟩 Important ⬜ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
18. Impacts of new communication technologies	18. Ability to model the impacts of telecommuting and e-shopping	Work from home can be modeled in the daily activity pattern in the activity-based model, but model improvements might be needed, in particular to adjust to the mutated conditions after the pandemic.	Work from home can be modeled in the daily activity pattern in the activity-based model, but model improvements might be needed, in particular to adjust to the mutated conditions after the pandemic.	Work from home can be modeled in the daily activity pattern in the activity-based model, but model improvements might be needed, in particular to adjust to the mutated conditions after the pandemic.	Work from home can be modeled to some extent in the daily activity pattern in the activity-based model. Model improvements might be needed, in particular to adjust to the mutated conditions after the pandemic.
19. Impacts of new transportations options	19a. Shared mobility (regular ridehailing)	Yes, for TNCs and taxi modes	Yes, for TNCs and taxi modes	Not included in the model	Not included in the model
	19b. Shared mobility (carsharing, pooled ridehailing)	The model includes shared pooled options in the new experimental module.	The model includes shared pooled options in the new experimental module.	Not included in the model	Not included in the model
	19c. Micromobility	No	No	No	No

Legend: 🟥 Critical 🟦 Important ⬜ Optional

Modeling Features		**Option 1: Build on MTC TM 2.1 model (W/O LD)**	**Option 2: Build on MTC TM 2.1 model (W/ LD)**	**Option 3: Build on SFCTA model**	**Option 4: Build on CHSR or New Statewide Model**
	19d. CAVs	In an experimental way, TM 2.1 accounts for privately-owned and shared automated vehicle options.	In an experimental way, TM 2.1 accounts for privately-owned and shared automated vehicle options.	Not included in the model	Not included in the model
20. Freight transportation effects	20. Ability to model the impacts of freight travel on road passenger travel demand	To some extent	To some extent	To some extent	To some extent

5.7 Discussions and recommendations

This section provided guidelines for the future travel demand model development that address the goals and objectives as well as meet the required timelines of the Link21 program. After discussing the critical, important and optional modeling features for the Link21 modeling framework, we presented four modeling options that could be considered for the Link21 program. Each of the four options has its pros and cons. Therefore, building the Link21 travel demand model from any of these options would require careful considerations and evaluation of many details for the appropriate implementation of one of these approaches.

In particular, Option 1 may suffer from some limitations in modeling travel components that are not easily captured by an activity-based modeling formulation that models the "average travel on a weekday" – for example, infrequent trips that often happen over longer-distances for business, personal or vacation purposes, and that are usually modeled in long-distance models. Option 2 could address that but would demand earnest effort to build a separate auxiliary module for modeling this type of long(er)-distance travel. The module for long-distance travel can be adapted from one of the statewide models, such as from CSTDM or CHSR and, in future Link21 model updates, it could integrate the new Statewide Rail Model that is being built by Caltrans.

The eventual preference for the option 1 vs. option 2 largely depends on the relative importance of the long-distance travel market. The larger the size of this market for the purposes of the Link21 program, the more benefits would derive from adding a dedicated long-distance model component with the additional complexity this approach would entail (and the higher amount of resources required for its development and implementation). Further, another important assessment should be made on the ability of option 1 to appropriately model medium-distance trips inside the 21-county megaregion. If the activity-based modeling core of this approach is not only able to realistically represent short-distance travel with local/regional transportation options but also model trips that happen for commuting and non-commuting purposes along longer travel corridors that span beyond the core MTC region (e.g., I-80 / Capitol Corridor between Sacramento and the San Francisco Bay Area), the remaining long-distance travel components to/from the megaregion would account for a relatively small portion of total trips. Under such a scenario, option 1 could prove to be the preferable resource-efficient approach. However, the activity-based modeling core might eventually prove to be not well suited to properly model some of these components of travel. Under those circumstances, the inclusion of a proper long-distance travel model, as proposed in option 2, might be useful, in particular if this model component can realistically model not only real long-distance travel (e.g., to/from outside the megaregion) but also an important portion of travel demand on the medium-distance corridors for the I-80 / Capitol Corridor or from the northern portion of the Central San Joaquin Valley to the San Francisco Bay Area, which might be explained more properly in terms of infrequent trips for business/work or personal/vacation trips, rather than routine trips modeled for the "average weekday in Fall or Spring" (as it would be done in a typical regional ABM).

Meanwhile, Option 3 comprises challenges of both options 1 and 2, depending on whether an explicit long-distance component is included or not. It is a lower-risk option, as it builds on a model that is already in operation, and it is not subject to the MTC model improvement schedule, performance evaluation and potential delays. However, it relies on the current SFCTA model that is lacking some important modeling features, such as the ability to account for crowding and rail transit capacity. Option 4 has limited capacity to model local travel and transit forecasting, and it appears to be an inferior modeling approach compared to the others discussed in this section. However, the larger-scale models that are discussed as the basis for this option might somehow constitute the embryonal concept for the long-distance travel component to be included in Option 2 or Option 3 if such an approach with long-distance component is chosen.

The following table presents a summary of the pros and cons of the four suggested options for travel demand modeling for the Link21 program.

Table 5.6 Pros and cons of the four suggested options

Option 1: Build on MTC TM 2.1 regional model (without a dedicated long-distance component)
Pros • This approach saves model development time because the TM 2.1 model is being developed for nine counties in the MTC core region inside the megaregion. • TM 2.1 has many critical and important features, such as detailed zonal system, ability to model improvements in individual rail services/integrated services, rail transit capacity and crowding, effects of telecommuting on activity scheduling and trip generation, etc. • If the "expanded TM 2.1" is able to capture the behavioral choices behind travel demand in the Northern California megaregion (including flows on I-80, the expanded San Francisco-Sacramento corridor, and the Bay Area to Central Valley dynamics), it would allow for a simpler approach without complications of integrating an explicit long-distance component. • The TM 2.1 will feature great improvements in the public transportation components of the model, thanks to the inclusion of capacity constraints and reliability, among other features, with the transition from the CUBE modeling software to EMME. • Some of the limitations with the use of the TM 2.1 could be further addressed by directly linking the Link21 model development to the on-going development of TM 2.2 (which will run entirely in EMME) or the future TM 2.3 (replacing CT-ramp with the newer ActivitySim).

Cons

- Link21 would depend on TM 2.1 development (with potential delays).
- TM 2.1 is a hybrid model featuring new EMME components for public transportation that run in a larger modeling environment based on the legacy CUBE model from TM 1.5. This could cause further complexity for the model development for Link21, linking the development of this modeling framework to a “placeholder” TM 2.1 model from MTC, which will be soon replaced by further improved model features in the following model releases TM 2.2 and TM 2.3.
- If linked directly to the on-going model development of TM 2.2 or the future development of TM 2.3, further uncertainties about the timeline of the MTC modeling program and the novelty of the new modeling framework could affect the Link21 program, likely causing the Link21 model development process to fall behind schedule.
- The lack of an explicit long-distance travel component might be a limitation, as the behavioral foundations that explain the generation of travel on longer distances might be different.
- Elasticities for long-distance travel are usually different from short-distance travel decisions. Where do intercity services such as CCJPA or trains from San Joaquin Valley fit on that scale (closer to short-distance transit, or long-distance rail)?
- “True” long-distance travel (i.e., to/from areas outside the boundaries of the 21-county megaregion) is not explicitly modeled but would be included as an exogenous trip table from another model. It would be important to quantify “how small” of a market this type of travel is.

Option 2: Build on MTC TM 2.1 regional model (considering a dedicated long-distance component)

Pros

- This approach saves model development time because the TM 2.1 model is being developed for nine counties in the MTC core region inside the megaregion.
- TM 2.1 has many critical and important features, such as detailed zonal system, ability to model improvements in individual rail services/integrated services, rail transit capacity and crowding, effects of telecommuting on activity scheduling and trip generation, etc.
- The TM 2.1 will feature great improvements in the public transportation components of the model, thanks to the inclusion of capacity constraints and reliability, among other features, with the transition from the CUBE modeling software to EMME.
- Some of the limitations with the use of the TM 2.1 could be further addressed by directly linking the Link21 model development to the on-going development of TM 2.2

(which will run entirely in EMME) or the future TM 2.3 (replacing CT-ramp with the newer ActivitySim).

- This approach would include two passenger components in the model, one for short-distance travel based on TM 2.1 and one for long-distance travel, which would allow modeling in the same platforms the various components of travel involving the 21-county megaregion.
- The model would be able to account for the different behavioral foundations and elasticities that are associated with short-distance commuting and non-commuting trips, and less frequent longer-distance travel for either work/business or personal/leisure purposes.
- The model could also model "true" long-distance travel (i.e., to/from areas outside the boundaries of the 21-county megaregion). It would be important to quantify "how big" of a market this type of travel is.
- The model could integrate an existing long-distance travel model component from the CHSR model (or the new statewide rail model, in future Link21 model updates), saving important time and resources and aligning this project with other modeling efforts carried out in California to support the evaluation of rail investments.

Cons

- Link21 would depend on TM 2.1 development (with potential delays).
- TM 2.1 is a hybrid model featuring new EMME components for public transportation that run in a larger modeling environment based on the legacy CUBE model from TM 1.5. This could cause further complexity for the model development for Link21, linking the development of this modeling framework to a "placeholder" TM 2.1 model from MTC, which will be soon replaced by further improved model features in the following model releases TM 2.2 and TM 2.3.
- If linked directly to the on-going model development of TM 2.2 or the future development of TM 2.3, further uncertainties about the timeline of the MTC modeling program and the novelty of the new modeling framework could affect the Link21 program, likely causing the Link21 model development process to fall behind schedule.
- TM 2.1 is not well-positioned to model long-distance travel so this would need to come from a longer-distance module that is merged and the way the two models interact (in a kind of model "grafting"/integration) in the system.
- The model would be able to account for the different behavioral foundations and elasticities that are associated with short-distance commuting and non-commuting trips, and less frequent longer-distance travel for either work/business or personal/leisure purposes, but the coexistence of the two components might lead to some discontinuity and inconsistencies at the merger of the two.

- The two model “cores” need to work well together (*e.g.*, to model intermodal trips from long-distance rail + transit, which can compete with autos and other travel modes). This can be rather effort-intensive and require time to develop and implement.
- The separation of the two model components based on a distance threshold has proved to be problematic in some modeling frameworks. A potential separation for the two model components could be based on trip purpose, rather than distance. While this approach seems appealing, the data available to estimate this model component might be limited.

Option 3: Build on SFCTA regional model (with or without a dedicated long-distance component)

Pros

- SFCTA alights with SACSIM19 and TCM 2008, which can allow for faster development of model components, networks and data inputs for 18 counties within the study area.
- SFCTA has a similar modeling approach (DaySim and Cube Voyager) with SACSIM19 and TCM 2008, which cumulatively cover 18 counties within the study area.
- The approach would build on an already operational model, which uses the reliable and rather fast DaySim platform.
- The model has a module dedicated exclusively to model visitors (tourism), and also trips from California to outside.
- This is a low-risk/low-uncertainty option.

Cons

- The SFCTA model has several limitations compared to the more advanced MTC TM 2.1 model, such as the inability to address transit vehicle crowding or reliability, which might make this option less desirable for the Link21 purposes.
- In the longer-term, SFCTA will not further invest in this model development, but is preparing for a transition to the new ActivitySim activity-based modeling framework and the EMME software (hence, future model updates would somewhat converge with Option 1 or Option 2, in the longer-run).
- Long-distance travel poses the same difficulties identified in Option 1 and Option 2.

Option 4: Build on CHSR or New Statewide Model
Pros - This modeling approach would build on a system that already includes long-distance travel and intraregional (MTC area only) components. - The model was developed based on behavioral (stated preference) survey data collected from California useful to inform new long-distance rail usage. - The existing model (already in operation) covers the entire study area of the Link21 program, i.e., 21 counties, even if with rather low level of spatial details.
Cons - The model is not well suited to study local travel (including Transbay trips). - Limited details for local/regional transit forecasting exist in the model (except for the MTC intraregional model component, which is currently used as a static input in the larger model). - A huge amount of resources should be invested to upgrade the model, improve the level of detail, and enrich it with additional model components. - The inclusion of more details and the upgrade of the modeling approach of a large-scale model is not an easy task. This approach might prove rather inefficient. - The approach might have too many limitations in its ability to satisfy the needs of the Link21. Overall, it might fail to meet the Link21 needs.

To sum up, option 2 appears to be a solid option with multiple desirable features, though its main limitations relate to depending on the MTC TM 2.1 model development (and any delays in the development of that model) and the difficulties associated with the integration of two model components for the local/regional travel and longer-distance travel. Further, both Options 1 and 2 benefit from the current and ongoing effort of the development of the MTC TM 2.1, but that model development could also be a source of risk of delay to the Link21 program. MTC TM 2.1 is also itself a hybrid model with some components running in EMME and the rest of the model in the legacy CUBE environment from the previous MTC TM 1.5. The development of the extended network to represent the Link21 megaregion will take considerable time before a model can be run. That could give additional time for the completion of the MTC TM 2.1.

Option 3 is, theoretically, less preferable since the SFCTA modeling system does not have some of the new modeling features, in particular for public transportation modeling, of the MTC TM 2.1 model. Given that the focus of Link21 program will be on future scenarios involving a second rail crossing, the absence of the ability to represent rail transit capacity and crowding as well as station capacity restraint is a critically important topic. But the SFCTA model is already operational, and uses the rather reliable, efficient, and faster DaySim activity-based modeling core. Option 3 is therefore an alternative reduces uncertainty.

The least preferable option is certainly Option 4, which would build a new travel demand model for the Link21 program based on the CSHR or the new Statewide Rail Model. This approach would be limited by the poor resolution and long-distance focus of these large-scale models. Therefore, considerable efforts would be required to add details and modeling capabilities that are not included in the current model, with results that will likely not meet the expectations for the Link21 program.

Finally, these modeling approaches should not be evaluated as closed silos, but further hybridization could be possible, as well as additional model development that eventually depart from one or more of these approaches, and/or build on modeling features already introduced in some of the mentioned models (or in other models). Considering the limited timeline of the project, additional improvements on the model could be possible but these could be limited by the available data, as new data collections would be difficult to be carried out in the available timeline for the Link21 program. The use of data driven approaches and use of passively collected data could complement, when needed, the availability (or lack, eventually) of the desired survey data to re-estimate or calibrate some of the new modeling system components. They could also provide the basis for the expansion of certain model components to include additional details and/or further subdivide time periods, e.g., to assign traffic flows to shorter time periods, or to develop additional modules for travel during weekends (if considered desirable for the Link21 purposes).

6 Sources of Uncertainties

Several major sources of uncertainties affect future travel demand forecasts for the Link21 program. Among these, new transportation technologies and services (including technology-enabled transportation and shared-mobility services), the deployment and adoption of electric and other alternative-fuel vehicles, and increased connectivity and automation, are quickly transforming transportation demand and supply in many ways. These disruptive trends sum up to (and are often confounded with) other factors that affect travel patterns, such as changing economic activities and lifestyles among certain population groups. This second group of factors includes sociodemographic changes, behavioral differences across generations, changes in household compositions and lifestyles (e.g., associated with the reduction in birth rate and postponement of childbearing), the reorganization of economic activities (with the emergence of flexible forms of employment, adoption of collaborative workspaces, etc.), and shifts in the urban form of cities. While many of these factors can be controlled in traditional travel demand modeling frameworks, especially activity-based travel demand models, through the estimation of model parameters and modifications in exogenous inputs (e.g., sociodemographic and land use data), others require careful consideration to account for their impacts in travel demand models.

In addition to these topics, and especially relevant to the Link21 program, starting in early 2020 the COVID-19 pandemic has disrupted society in many ways, significantly changing the ways individuals live, work, study, shop, socialize and travel. While the impacts of the COVID-19 pandemic are not fully understood yet, there is potential that the temporary shifts in activities and travel observed during the peak of the pandemic might extend over time and turn, at least in part, into longer-term impacts. These impacts might sum up to, and are often difficult to separate from, other on-going societal shifts including the adoption of technological innovations, and might potentially alter future travel demand patterns in ways that are not fully accounted for in existing travel behavior studies and travel demand modeling frameworks.

The remainder of this section presents some sources of uncertainties that might affect future travel demand in the Link21 regions, with a brief discussion of some of their potential impacts, and the degree to which these might be accounted for in a travel demand forecasting framework. The sources of uncertainties that are discussed include the impacts of the COVID-19 pandemic and the changing work patterns (including the adoption of telework and various forms of work from home); the introduction of shared mobility services, in particular ridehailing services, micromobility; the potential deployment of MaaS solutions; and the forthcoming deployment of CAVs.

6.1 Impacts of the COVID-19 pandemic on transportation

6.1.1 Observed affects March 2020 to Early 2022

Starting in early 2020, the COVID-19 pandemic has caused huge disruption to society, including transportation. While this project started before the beginning of the pandemic, and by the time of writing of this report, its impacts on activities and travel are still not fully understood, there is evidence that travel patterns have been severely impacted during the various stages of the pandemic. Some of these changes might well extend into the future, with longer-term consequences on travel demand that might affect society well after the end of the current pandemic.

The COVID-19 pandemic has disrupted many aspects of life as we know it. Shelter-in-place orders and social distancing policies issued during the early stages of the pandemic largely affected the way that individuals worked, studied, socialized, and attended to necessities like grocery shopping and other essential services. Travel behavior associated with these activities changed in response to these pressures.

While essential workers were still required to do their jobs in-person, starting in Spring 2020, in most regions of the country, including the Northern California megaregion, travel demand changed as an important portion of the workforce moved to forms of remote work and the demand for non-essential activities performed outside of home dropped. Essential workers who had to continue to physically report to work during the pandemic tended to have lower incomes and be people of color[6]. In numerous sectors, many activities moved to online/remote formats with an uptick in the adoption of telecommuting, online schooling, telehealth, and online shopping. Gig-economy services like DoorDash, Uber Eats, and Instacart allowed many to not travel at all to receive food and grocery items that they needed[7]. These services increased in popularity, especially in urban areas and among more technologically savvy individuals, at a time when demand for on-demand passenger services dropped. More traditional forms of internet-based shopping (including those with relatively fast one-day or two-day deliveries) increased in

---

[6] Matson, Grant, Sean McElroy, Giovanni Circella, and Yongsung Lee. "Telecommuting Rates During the Pandemic Differ by Job Type, Income, and Gender." Transportation Research Record, forthcoming.

[7] Beck, Matthew J., and David A. Hensher. "Insights into the impact of COVID-19 on household travel and activities in Australia–The early days under restrictions." Transport Policy 96 (2020): 76-93.

Contreras, Francoise, Elif Baykal, and Ghulam Abid. "E-leadership and teleworking in times of COVID-19 and beyond: what we know and where do we go." Frontiers in Psychology (2020): 3484.

Conway III, Lucian Gideon, Shailee R. Woodard, and Alivia Zubrod. "Social psychological measurements of COVID-19: Coronavirus perceived threat, government response, impacts, and experiences questionnaires." (2020). Available at https://psyarxiv.com/z2x9a/ Last accessed March 10, 2022.

their popularity, with their user base expanding beyond traditional early adopters of e-shopping. Larger groups of individuals, including older individuals and residents of less urban areas, adopted internet-based forms of e-shopping[8]. As more individuals started to shop online, the likelihood increased that at least some of them would continue to do so in the future. From this point of view, the pandemic largely accelerated an already pre-existing trend with the growing penetration of internet shopping in society that was already observed over the previous few years.

During the pandemic, patterns of telecommuting and engaging in at-home activities evolved rapidly. In a study conducted via an online panel as part of the American Trends Panel, the Pew Research surveyed a representative sample of working adults throughout the US with at least one primary job. As of December 2020, 71% of those who said that their job duties could be performed from home were currently telecommuting, while only 20% of them had been telecommuting before the pandemic. Those who reported they did not or could not telecommute during the pandemic were more likely to be Hispanic or Black, low- to middle-income, and to not have a college degree. Conversely, those who identified as Asian were the most likely to report having a job wherein some or all duties could be performed from home.[9] Similar patterns have been recorded in several other survey-based travel behavior studies that analyzed the impacts of the pandemic on mobility. For example, in a survey-based study from the Chicago region, the percentage of employees who telecommute full time (5 days a week) increased considerably from 15% in 2019 to above 55% in 2020[10]. Similar increases were recorded in other nationwide studies carried out by university research centers based at the University of California, Davis (UC Davis) and Arizona State University, as well as the RSG Inc. consulting firm, among others. During the COVID-19 pandemic, people have experienced reductions in their physical commutes to work, other work-related travel and many out-of-home activities. Recent studies found that work-from-home would likely persist, at least partially, after the restrictions due to the pandemic eased. For example, De Hass et al. (2020) shows that 27% of work-from-home workers would also expect to work more from home in the future even after COVID period.[11]

---

[8] Young, Mischa, Jaime Soza‐Parra, and Giovanni Circella. "The increase in online shopping during COVID‐19: Who is responsible, will it last, and what does it mean for cities?." Regional Science Policy & Practice (2022).

[9] Parker, Kim, J. Menasce Horowitz, and Anna Brown. "About half of lower-income Americans report household job or wage loss due to COVID-19." Pew Research Center 21 (2020).

[10] Shamshiripour, Ali, Ehsan Rahimi, Ramin Shabanpour, and Abolfazl Kouros Mohammadian. "How is COVID-19 reshaping activity-travel behavior? Evidence from a comprehensive survey in Chicago." Transportation Research Interdisciplinary Perspectives 7 (2020): 100216.

[11] de Haas, Mathijs, Roel Faber, and Marije Hamersma. "How COVID-19 and the Dutch 'intelligent lockdown' change activities, work and travel behaviour: Evidence from longitudinal data in the Netherlands." Transportation Research Interdisciplinary Perspectives 6 (2020): 100150.

Results from a behavioral study based on multiple waves of surveys administered at the University of California, Davis showed that workers who transitioned to working from home full-time in the early stages of the pandemic continued to do so, even if with lower frequency, when they started to return to work on certain days of the week. By 2021, many individuals were found to often engage in hybrid forms of work, combining remote and in-person work on different days of the week, and sometimes also on the same workday (e.g., working from home in the early part of the morning and postponing the commuting trip to work to avoid peak hour traffic). While the percentage of individuals who expect to physically commute to work in the future at least on certain days of the week is found to be similar to pre-pandemic numbers, many workers expect to continue to work with a hybrid schedule in the future, suggesting that the number of total commuting trips (and their spatial and temporal patterns) might remain different in the future (Circella et al., forthcoming).

Vehicle miles traveled (VMT) in California underwent a sharp decline at the beginning of the pandemic, when shelter-in-place orders rolled out in mid-March 2020. With telecommuting still in place for many employees, VMT began to rebound within 80-100% of the pre-pandemic baseline in the summer of 2020, and then back to as low as 60% of the VMT baseline toward December 2020, as a new pandemic wave disrupted the country.[12] However, as the pandemic receded and individuals started to increase their activity participation (including travel), total VMT increased significantly during 2021, in many locations exceeding pre-pandemic levels. This is noteworthy considering that many workers were still engaging in at least partial remote work. While the total VMT has rebounded to levels that are similar to the pre-pandemic level, trip mode choice and the spatiotemporal distribution of where trips happen substantially differ from the pre-pandemic travel conditions. This includes lower travel volumes during the AM peak towards job attractors, with a related peak flattening and increased levels of car travel during non-peak times also due to forms of home-based trips, which often involve the use of private vehicles. The changes in activity participation are also affecting demand for public transportation, in particular as public transportation systems in major US cities are largely designed to serve peak demand on major corridors used for commuting trips, with only a limited number of complementary lines serving other lower-demand and/or non-work/non-central trip attractors. The use of rail-based and local (mostly bus) services has also changed with the pandemic, and use of the former has declined more and been slower to recover than the latter. These differences in the magnitude of decline and recovery rate are probably due to a difference in the type of users of these forms of public transportation. Users of rail-based services are more likely than users of local transit to have access to other transportation options and to have jobs that can be done remotely. Demand for many of the rail-based services has continued to stagnate during various stages of the pandemic. Instead, demand for many bus transportation services, which is more often composed of

---

[12] Parker, Kim, J. Menasce Horowitz, and Anna Brown. "About half of lower-income Americans report household job or wage loss due to COVID-19." Pew Research Center 21 (2020)

passengers who have limited alternatives to the use of public transportation, individuals that are more likely to be considered essential workers, members of lower-income communities, and people of color, has started to rebound at a faster rate.[13]

As more people stayed at home, their engagement in recreational activities also changed. For instance, highly-educated individuals who telecommuted during the COVID-19 pandemic often engaged in more social activities, as well as more long-distance travel for recreational purposes.[14] A sizable portion of these trips relied on car travel. The pandemic has also brought a major shift in mode choice. More personal, isolated modes like walking, bicycling, and the use of personal vehicles became (at least temporarily) more popular, at the expenses of more public and shared modes of transportation like public transit and ridehailing. This is due in part to the perception that these shared, public modes posed higher risk of transmission.[15] Even as overall VMT recovered during the summer months of 2020, public transit saw a much slower recovery period, and continued to remain significantly below its pre-pandemic levels for longer.[16]

6.1.2 Modeling post-pandemic transportation demand

While many of the above described patterns can be accounted for rather well in activity-based travel demand models, assuming that the models contain the appropriate model components and enough data are available to estimate the impacts of the pandemic on all these travel components, several sources of uncertainty will continue to affect future studies of travel demand in the post-pandemic society. One major risk for mid-term and long-term planning is associated with the possible discrepancy between stated-preference surveys used to build travel demand forecasting model and the continuously changing travel behavior in the COVID-19 and post-COVID-19 era. Current surveys are continuing to study an evolving topic, which is still far

---

[13] Soza-Parra, J., G. Circella and D. Sperling (forthcoming) “Changes in Activity Organization and Travel Behavior Choices in the United States”, book chapter in "Transportation Amid COVID-19 and Pandemics: Practices and Policies" (editors: Hayashi Y. and J. Zhang), Elsevier.

[14] Molloy, Joseph, Thomas Schatzmann, Beaumont Schoeman, Christopher Tchervenkov, Beat Hintermann, and Kay W. Axhausen. "Observed impacts of the Covid-19 first wave on travel behaviour in Switzerland based on a large GPS panel." Transport Policy 104 (2021): 43-51.

[15] Shamshiripour, Ali, Ehsan Rahimi, Ramin Shabanpour, and Abolfazl Kouros Mohammadian. "How is COVID-19 reshaping activity-travel behavior? Evidence from a comprehensive survey in Chicago." Transportation Research Interdisciplinary Perspectives 7 (2020): 100216.

Barbieri, Diego Maria, Baowen Lou, Marco Passavanti, Cang Hui, Inge Hoff, Daniela Antunes Lessa, Gaurav Sikka et al. "Impact of COVID-19 pandemic on mobility in ten countries and associated perceived risk for all transport modes." PloS one 16, no. 2 (2021): e0245886.

[16] Brough, Rebecca, Matthew Freedman, and David C. Phillips. "Understanding socioeconomic disparities in travel behavior during the COVID‐19 pandemic." Journal of Regional Science 61, no. 4 (2021): 753-774.

from post-pandemic stability, and respondents might often report unrealistic expectations about post-pandemic work environments or travel preferences. These issues could lead to underestimation of trip generation rates in the post-pandemic scenarios and forecasts for less travel by public transit in modeling and planning studies. On the other hand, modeling exercises based on surveys conducted before the COVID-19 pandemic might likely lead to other types of errors in forecasting travel demand. One possibility is using a combination of survey data from before and during the COVID-19 pandemic to account for the range of travelers' preferences and impacts on travel, while using a large range of scenario analyses. Such an approach could be used to study, for example, potential impacts of eventual persistence of hybrid forms of work among certain groups, changes in preferences for various travel modes, changes in residential location, and persistence of e-shopping and on-demand delivery of goods and services.

However, more research is needed to fully understand how travel behavior would change in the post-pandemic era. It is possible that strong heterogeneity in the adoption of work from home choice might persist based on occupation, working status, income, age, and many other factors. This is a direct concern for regions with large percentages of commuting trips, as in the case of the Link21 megaregion. Possible reductions in transit trips due to lower levels of commuting to work would bring uncertainties in both planning and operation decisions for transit operators, including the need to adjust transit fares, including monthly passes, to make them appetible to travelers. In parallel to the travel demand modeling framework development, more research will be needed to inform this work and improve the understanding of 1) the long-term impacts of the COVID-19 pandemic on travel demand and activity patterns; and 2) the best way to incorporate these changes in the travel demand forecasting framework.

6.2 Ridehailing

Ridehailing services, such as those provided by Uber and Lyft, have been one of the major elements of novelty in the transportation landscape in recent years. However, their availability and the impacts of their use on other components of travel demand are rarely explicitly included in travel demand forecasting models. The adoption of ridehailing and its impact on passenger mobility has been an important topic in transportation research.

Several studies, to date, have focused on the relationships between the adoption of ridehailing and both car ownership and travel behavior. For example, Alemi et al. (2018) found that individuals with stronger pro-environmental, technology-embracing, and variety-seeking attitudes are more inclined to use ridehailing.[17] In one line of investigation, researchers have studied the

---

[17] Alemi, Farzad, Giovanni Circella, Susan Handy, and Patricia Mokhtarian. "What influences travelers to use Uber? Exploring the factors affecting the adoption of on-demand ride services in California." Travel Behaviour and Society 13 (2018): 88-104.

impacts of the emergence of ridehailing services on auto ownership (including buying or selling privately owned vehicles when starting to use ridehailing services). Many studies have shown ridehailing services could possibly reduce auto ownership, though evidence for this type of relationship is usually weak. For example, Li et al. (2017) studied ridehailing services and traffic congestion based on the data from Uber and Urban Mobility Report.[18] They applied a difference-in-difference estimator approach to the data that had an 11-year span on 87 urban areas. They concluded that ridehailing has the potential to reduce private vehicle ownership in the cities where it operates by providing a feasible alternative to other transportation modes. Ward et al., (2019) used a similar approach using TNC data from 2005 to 2015.[19] The results showed that the entry of TNCs caused registrations to decline by 3%. Sabouri et al. (2020) also found a negative relationship between the usage of ridehailing services and vehicle ownership in the long run, based on the NHTS 2017 data.

However, the results from studies based on travel survey data highlights how the majority of people have not yet shown a decrease in vehicle ownership after the adoption of ridehailing services. For example, Rayle et al. (2016) collected survey data in the San Francisco bay area and found that 90% of the respondents had not changed their car ownership since they began to use ridehailing.[20] Comparable results were found by Clewlow and Mishra (2017), who found that ridehailing had no impact on vehicle ownership among 91% of the respondents.[21] While this result might appear rather remarkable, issues with the sampling of respondents for this study, as well the impact of other confounding factors, might partially explain the reduction. Hampshire et al. (2017) investigated the impact of an unanticipated disruption of ridehailing service in Austin from May 2016 and found out that 8.9% of the respondents reported they had to buy a new vehicle after the restrictions imposed on TNCs.[22] Other survey-based studies even showed an increase in car ownership after the introduction of ridehailing services. For example, Gehrke et al.

---

[18] Li, Ziru, Yili Hong, and Zhongju Zhang. "An empirical analysis of on-demand ride sharing and traffic congestion." In Proc. International Conference on Information Systems. 2016.

[19] Ward, Jacob W., Jeremy J. Michalek, Inês L. Azevedo, Constantine Samaras, and Pedro Ferreira. "Effects of on-demand ridesourcing on vehicle ownership, fuel consumption, vehicle miles traveled, and emissions per capita in US States." Transportation Research Part C: Emerging Technologies 108 (2019): 289-301.

[20] Rayle, Lisa, Danielle Dai, Nelson Chan, Robert Cervero, and Susan Shaheen. "Just a better taxi? A survey-based comparison of taxis, transit, and ridesourcing services in San Francisco." Transport Policy 45 (2016): 168-178.

[21] Clewlow, Regina R., and Gouri S. Mishra. "Disruptive transportation: The adoption, utilization, and impacts of ride-hailing in the United States." (2017).

[22] Hampshire, Robert, Chris Simek, Tayo Fabusuyi, Xuan Di, and Xi Chen. "Measuring the impact of an unanticipated disruption of Uber/Lyft in Austin, TX." Lyft in Austin, TX (May 31, 2017) (2017).

(2019) investigated the results of a survey administered in the great Boston region in 2017.[23] The results showed that 59% of ridehailing trips were associated with an increase in the number of vehicles on the road. This result is in line with the finding that many people buy additional cars to become ridehailing drivers.[24]

One of the major impacts of ridehailing adoption is in mode substitution. Table 6.1 summarizes the survey results from several sources in the literature. The table highlights important substitution patterns with ridehailing, with the users of these services often replacing taxis but also public transportation with Uber or Lyft. For example, several studies suggested that public transit would have been the most popular mode of transport if ridehailing was unavailable.[25] Lavieri and Bhat (2019) used a trip-level ridehailing attributes multivariate model for the mode substitution by sociodemographic characteristics using data from Dallas-Fort Worth Metropolitan Area.[26] The results showed that women were more likely to replace transit trips with ridehailing. Non-Hispanic Whites, individuals with a graduate degree, students, part-time employees, and medium and high-income households have a higher probability of substituting ridehailing trips for taxi trips, whereas millennials and self-employed individuals are least likely to switch to ridehailing trips from taxi trips. Similar results were found in a study from California.[27] Note that Table 6.1 only represents the survey results in terms of mode shifts. However, it is not possible to directly compare the results among different studies and areas. Tirachini (2020) pointed out two

---

[23] Gehrke, Steven R., Alison Felix, and Timothy G. Reardon. "Substitution of ride-hailing services for more sustainable travel options in the greater Boston region." Transportation Research Record 2673, no. 1 (2019): 438-446.

[24] Parrott, James A., and Michael Reich. "An earnings standard for New York City’s app-based drivers." New York: The New School: Center for New York City Affairs (2018).

Wells, K. J., K. Attoh, and D. Cullen. "The Uber Workplace in Washington." DC Report, Kalmanovitz Initiative for Labor and the Working Poor, Georgetown University (2018).

[25] Gehrke, Steven R., Alison Felix, and Timothy G. Reardon. "Substitution of ride-hailing services for more sustainable travel options in the greater Boston region." Transportation Research Record 2673, no. 1 (2019): 438-446.

Henao, Alejandro, and Wesley E. Marshall. "The impact of ride-hailing on vehicle miles traveled." Transportation 46, no. 6 (2019): 2173-2194.

[26] Lavieri, Patrícia S., and Chandra R. Bhat. "Investigating objective and subjective factors influencing the adoption, frequency, and characteristics of ride-hailing trips." Transportation Research Part C: Emerging Technologies 105 (2019): 100-125.

[27] Alemi, Farzad, Giovanni Circella, Susan Handy, and Patricia Mokhtarian. "What influences travelers to use Uber? Exploring the factors affecting the adoption of on-demand ride services in California." Travel Behaviour and Society 13 (2018): 88-104.

reasons: the difference in sampling approaches and survey design.[28] For the survey design, the choice options that were provided to respondents were different among the studies. In addition, some studies included the option “wouldn’t have traveled or would take fewer trips” in their choice set, while others did not. However, the findings reported in Table 6.1 provide an overview of the somewhat diverse impacts that the availability of these services can have on travel patterns, a topic often ignored in large-scale regional travel demand models.

---

[28] Tirachini, Alejandro. "Ride-hailing, travel behaviour and sustainable mobility: an international review." Transportation 47, no. 4 (2020): 2011-2047.

Table 6.1 Summary of ridehailing and mode substitution effects according to literature (values expressed as percentages)

Research area	**San Francisco**	**US cities**	**Austin**	**Denver**	**California**	**Boston**	**Santiago, Chile**
Research articles	Rayle et al. (2016)	Clewlow & Mishra (2017)	Hampshire et al. (2017)	Henao & Marshall (2018)	Alemi et al. (2018)	Gehrke et al. (2019)	Tirachini & Gomez-Lobo (2019)
Drive alone	6.0	21.0	45.0	19.0	37.8 - 38.3	18.0	12.1
Carpool/ Get a ride	1.0	18.0	3.7	13.8	19.9-32.3	-	
Taxi	39.0	1.0	1.7	9.6	45.2-55.7	22.8	40.7
Public transport	33.0	15.0	3.0	22.2	11.9-27.4	42.1	32.5
Bicycle	2.0	7.0	1.8	11.9	11.9-27.4	12.1	1.3
Walking	8.0	17.0	0.7				2.4
Other modes	11.0	-	44.1	11.3	4.5-6.5	-	5.7
Would not have traveled /Fewer trips.	-	22.0	-	12.2	7.0-9.2	5.0	5.4

Another considerable portion of the literature focuses on ridehailing impacts on VMT. Many authors believed that measuring the impact of ridehailing on aggregate VMT is rather complicated. For instance, Anderson (2014) summarized that ridehailing and ridesharing (or pooled ridehailing) have the potential to reduce overall VMT because they can eliminate wasteful driving such as searching for parking, encourage shared rides, and supplement fixed-route transit systems by enabling multi-modal trips.[29] However, on the other hand, induced demand for ridehailing drivers to pick-up passengers certainly increases VMT. Clewlow and Mishra (2017) and Rodier (2018) collected influencing factors of ridehailing on VMT and greenhouse gas emissions.[30] The impacts of ridehailing on car ownership could have an indirect potential to reduce VMT, whereas trip generation and network effects are likely to increase VMT. The impact of mode choice and destination choice on VMT varied by case. Increasing auto mode share in mode choice and increasing demand for travel to suburban areas in destination choice both have the potential to increase VMT. Increasing transit mode share and increasing demand for travel to the central area may decrease VMT. Other factors in traffic externalities such as congestion and accidents, as Tirachini pointed, are all related to VMT. [31]

On the other hand, Henao and Marshall (2019) indicated that ridehailing has significantly increased VMT.[32] They sent their researchers to work as Uber and Lyft drivers in Denver, Colorado to do a quasi-natural experiment from 416 ridehailing trips. The results turned out that VMT was increased by 83.5% in the total system when accounting for deadheading (vehicle without passenger) and induced travel. Comparable results were found in Santiago in Chile,[33] based on

---

[29] Anderson, Donald N. "“Not just a taxi”? For-profit ridesharing, driver strategies, and VMT." Transportation 41, no. 5 (2014): 1099-1117.

[30] Clewlow, Regina R., and Gouri S. Mishra. "Disruptive transportation: The adoption, utilization, and impacts of ride-hailing in the United States." (2017).

Rodier, Caroline Jane. "The effects of ride hailing services on travel and associated greenhouse gas emissions." (2018).

[31] Tirachini, Alejandro. "Ride-hailing, travel behaviour and sustainable mobility: an international review." Transportation 47, no. 4 (2020): 2011-2047.

[32] Henao, Alejandro, and Wesley E. Marshall. "The impact of ride-hailing on vehicle miles traveled." Transportation 46, no. 6 (2019): 2173-2194.

[33] Tirachini, Alejandro, and Andres Gomez-Lobo. "Does ride-hailing increase or decrease vehicle kilometers traveled (VKT)? A simulation approach for Santiago de Chile." International journal of sustainable transportation 14, no. 3 (2020): 187-204.

the analysis of survey data collected among Uber users, and in the San Francisco Bay Area through the application of a travel demand forecasting model[34].

Researchers also found a positive effect of ridehailing on trip generation activity. Jiao et al. (2020) used negative binomial regression models to 2017 national household travel survey data and suggest that the number of trips made per day (trip making rate) was significantly related to the adoption of ridehailing.[35] People who used app-based ridehailing had a greater probability to have more trips. In other words, ridehailing was a significant predictor of trip generation activity, though this might not be true causal relationship, but rather (at least in part) the impact of spurious correlations and other unobserved factors associated with both ridehailing use and higher trip generation.

Overall, ridehailing is an emerging mobility service that is based on app-based matching between drivers and users, pricing mechanisms, eventual matching with other riders for pooled ridehailing services, and rebalancing of fleet vehicles. Calderon and Miller (2020) summarized two key considerations when modeling ridehailing[36]:

1. Need to model drivers/vehicles specifically, and
2. Need to include service provider components to model matching between users and drivers, and the impacts of pricing mechanisms; to control fleet rebalancing; and to deal with pooled ridehailing.

Nourinejad and Roorda (2015) discussed solutions for matching algorithms for ridesharing problems, in terms of centralized and decentralized approaches.[37] In the decentralized agent-based optimization, Nourinejad and Roorda incorporated a bidding process with an agent-based model that allowed two-way selection between TNC drivers and passengers, rather than finding the smallest systematic detours. On the other hand, Dubernet et al. (2013) studied ridesharing potentials with the MATSim microsimulation environment in the metropolitan area of Zurich, Switzerland.[38] The study used a time window with constraint and a detour fraction constraint to

---

[34] Erhardt, Gregory D., Richard Alexander Mucci, Drew Cooper, Bhargava Sana, Mei Chen, and Joe Castiglione. "Do transportation network companies increase or decrease transit ridership? Empirical evidence from San Francisco." Transportation (2021): 1-30.

[35] Jiao, Junfeng, Chris Bischak, and Sarah Hyden. "The impact of shared mobility on trip generation behavior in the US: Findings from the 2017 National Household Travel Survey." Travel Behaviour and Society 19 (2020): 1-7.

[36] Calderón, Francisco, and Eric J. Miller. "A literature review of mobility services: definitions, modelling state-of-the-art, and key considerations for a conceptual modelling framework." *Transport Reviews* 40, no. 3 (2020): 312-332.

[37] Nourinejad, Mehdi, and Matthew J. Roorda. "Carsharing operations policies: a comparison between one-way and two-way systems." Transportation 42, no. 3 (2015): 497-518.

[38] Dubernet, Thibaut, and Kay W. Axhausen. "Including joint decision mechanisms in a multiagent transport simulation." Transportation Letters 5, no. 4 (2013): 175-183.

identify the participation of the potential ridesharing individuals. The results showed that high percentage of daily trips could be matched and replaced by high-occupancy vehicle trips.

While these studies are noteworthy and important for their findings for advancing scientific research in the field, these modeling experiences are largely based on complex agent-based modeling solutions that could be of difficult to implement in an operational large-scale travel demand forecasting model. Still, these studies suggest that activity-based models could be improved by including ridehailing.

For example, the early efforts from Ciari et al. (2016) in modeling carsharing (a form of shared mobility that has a larger role in Europe, but is less common in the US) with an agent-based model can be inspiring in showing the way new shared mobility options can be accounted for and included in modeling studies.[39] For the initial demand, the behavior of each agent was modeled through a function that evaluates all components of their daily activity plan. For each mode, the function also included all elements characteristic of the mode, which could be modified to the carsharing scenario. The components of the utility function included calibration parameter, time-dependent and distance-dependent variables, reservation time, the monetary cost for the reservation time, the marginal utility of an additional unit of money spent on traveling with carsharing, access and egress time, and the marginal utility of an additional unit of time spent on traveling with carsharing.

6.3 Micromobility

This subsection first summarizes the potential impacts on travel demand from shared micromobility services, including shared bikes, e-bikes and e-scooters. Then, suggestions on how those impacts can be integrated into the travel demand modeling are provided.

A growing number of studies has focused on the impacts of shared micromobility on travel behavior, including its role on eventual VMT reduction[40]. For a review of the major findings from the literature to date on the impact of adoption of shared bikes and e-scooter services on travel,

---

[39] Ciari, Francesco, Claude Weis, and Milos Balac. "Evaluating the influence of carsharing stations’ location on potential membership: a Swiss case study." EURO Journal on Transportation and Logistics 5, no. 3 (2016): 345-369.

[40] Hosseinzadeh, Aryan, Abolfazl Karimpour, and Robert Kluger. "Factors influencing shared micromobility services: An analysis of e-scooters and bikeshare." Transportation Research Part D: Transport and Environment 100 (2021): 103047.

Fitch, Dillon T., Hossain Mohiuddin, and Susan L. Handy. "Examining the effects of the Sacramento dockless e-bike share on bicycling and driving." Sustainability 13, no. 1 (2021): 368.

refer to the recent paper from Wang et al. (2022).[41] Overall, the study highlights how the impacts of shared micromobility on mode substitution and travel demand can significantly vary by region, with many studies from North America, for example, pointing to relatively environmentally-beneficial impacts of shared mobility in terms of its replacement for trips often made by private cars and/or ridehailing services in many cities. Instead, replacement of public transit trips and active travel with shared e-scooters and bikes was found to be more common in European cities.

A survey report from the San Francisco Municipal Transportation Agency showed statistics for shared micro-mobility trips on VMT reduction: bikeshare can reduce 1,033,855 miles per year and e-scooter can reduce 244,905 miles annually in San Francisco.[42] As a point of reference, the total VMT in San Francisco was around 10 million miles in 2015 (VITAL SIGNS 2015). From the perspective of reduction in VMT, the e-scooter can approximately reduce 2% VMT in San Francisco, which is much smaller that its mode substitution rate, mainly due to the short distance of e-scooter trips. However, bikeshare can reduce VMT significantly more than scooters can, by replacing more and longer auto trips, while e-scooter trips are more likely to be short trips connected with transit.

By reducing personal vehicle trips, bikeshare programs can mitigate traffic congestion. However, the total impacts on traffic congestion are mixed. Bikeshare or e-scooter may use parts of the vehicle lanes on roadways, usually because of an insufficiency of bike lanes. The phenomenon of sharing a lane will reduce vehicle speed and could cause traffic congestion and risks of collisions. In addition, docking stations near to vehicle lanes may cause reduced vehicle speed.

When developing a model to estimate travel demand, modelers need to consider the uncertainties in changes to travel behavior resulting from shared micromobility. In summary, these include:

1. A portion of short-distance personal vehicle trips and transit bus trips in urban areas may be replaced by shared micromobility services;
2. The connection between transit services and shared micromobility services is likely to be higher in the urban periphery than in urban centers;
3. A portion of walking trips will be replaced by shared micro-mobility services if these become available; and
4. The uptake in the use of shared micromobility will be higher if dedicated bike/e-scooter lanes are provided.

---

[41] Wang, Kailai, Xiaodong Qian, Dillon Taylor Fitch, Yongsung Lee, Jai Malik, and Giovanni Circella. "What travel modes do shared e-scooters displace? A review of recent research findings." Transport Reviews (2022): 1-27.

[42] Barnes, Forest. "A scoot, skip, and a JUMP away: Learning from shared micromobility systems in San Francisco." (2019).

Depending on the priorities of modeling projects, various potential improvements in activity-based models, to account for new shared micromobility, can be considered. If these services are considered important for the purposes of the modeling project, the model can be updated to account for the ability of members in a household to access more travel mode options, particularly for short-distance trips, but also as potential access-egress modes for public transportation stations. The availability of shared micro-mobility services can affect how vehicles are allocated and used among household members. In the end, travel patterns will also be influenced in the form of mode substitutions, e.g., personal vehicle trips replaced by transit trips if shared micromobility provides a smooth connection with public transit. In general, all factors and sources of uncertainties associated with shared micromobility summarized here could be considered in every step of the activity-based travel demand model, even though some effects may be limited.

6.4 Mobility as a Service (MaaS)

Mobility-as-a-Service (MaaS) is emerging as a tool that integrates transportation options—including public transportation, shared mobility services, and new mobility technologies—and allows for institutional overlay. Most of the current research related to MaaS is based on pilots, e.g., from Finland[43], the United Kingdom[44] and Belgium.[45] These studies focused on travel demand increase vs. decrease, environmental impacts, and mode shift associated with the introduction of MaaS. Much research mentioned the positive impacts of MaaS on the environment. In general, MaaS can lead to a reduction in car dependence and air pollution[46].

---

[43] Eckhardt, Jenni, Lasse Nykänen, Aki Aapaoja, and Petri Niemi. "MaaS in rural areas-case Finland." Research in Transportation Business & Management 27 (2018): 75-83.

[44] Pangbourne, Kate, Miloš N. Mladenović, Dominic Stead, and Dimitris Milakis. "Questioning mobility as a service: Unanticipated implications for society and governance." Transportation research part A: policy and practice 131 (2020): 35-49.

[45] Storme, Tom, Jonas De Vos, Leen De Paepe, and Frank Witlox. "Limitations to the car-substitution effect of MaaS. Findings from a Belgian pilot study." Transportation Research Part A: Policy and Practice 131 (2020): 196-205.

[46] Mulley, Corinne. "Mobility as a Services (MaaS)–does it have critical mass?" Transport Reviews 37, no. 3 (2017): 247-251.

Gonçalves, Luísa, João Pedro Silva, Sara Baltazar, Luís Barreto, and António Amaral. "Challenges and implications of Mobility as a Service (MaaS)." In Implications of Mobility as a Service (MaaS) in Urban and Rural Environments: Emerging Research and Opportunities, pp. 1-20. IGI Global, 2020.

A qualitative study by Karlsson et al. (2020) covers four different MaaS systems in Europe.[47] Their analytical results include findings from macro, meso, and micro levels. Among many concerns raised, they discuss what role the public sector vs. private companies could play in the development of MaaS. There are still uncertainties in the business model, legislation, and the cooperation format between different stakeholders. Therefore, the effects of MaaS on travel demand are still uncertain since there is limited information on the way this can be deployed and shaped.

Various sources of uncertainty are associated with MaaS impacts on travel demand, including MaaS adoption, travel model choices, and travel demand:

First, different groups of individuals might have different probabilities of adopting MaaS. For example, Alonso-González et al (2020) found that the adoption potential for MaaS positively correlates with the percentage of public transport users, cost sensitivity, and technological capabilities.[48] At the same time, high car ownership and low technology adoption will set barriers for MaaS adoption. In addition, Butler et al. (2021) identified the critical barrier from both supply and demand sides, such as lack of collaboration and service coverage on the supply side and lack of appeal with older generations on the demand side.[49] Durand et al. (2018) conducted a comprehensive literature review and found that the adoption of MaaS has a close relationship with the value provided by MaaS, cost, and flexibility of system design[50]:

- The influences of MaaS on mode choice or travel behaviors will likely depend on the level of integration, which includes information integration, ticketing and payment integration, service integration, and integration of societal goals;
- The relationship between MaaS use and car ownership (and use) is more complex than generally acknowledged. The most illustrative example of this uncertainty is how MaaS may influence car use.

---

[47] Karlsson, I. C. M., Dalia Mukhtar-Landgren, Göran Smith, Till Koglin, Annica Kronsell, Emma Lund, Steven Sarasini, and Jana Sochor. "Development and implementation of Mobility-as-a-Service–A qualitative study of barriers and enabling factors." Transportation Research Part A: Policy and Practice 131 (2020): 283-295.

[48] Alonso-González, María J., Sascha Hoogendoorn-Lanser, Niels van Oort, Oded Cats, and Serge Hoogendoorn. "Drivers and barriers in adopting Mobility as a Service (MaaS)–A latent class cluster analysis of attitudes." Transportation Research Part A: Policy and Practice 132 (2020): 378-401.

[49] Butler, Luke, Tan Yigitcanlar, and Alexander Paz. "Barriers and risks of Mobility-as-a-Service (MaaS) adoption in cities: A systematic review of the literature." Cities 109 (2021): 103036.

[50] Durand, Anne, Lucas Harms, Sascha Hoogendoorn-Lanser, and Toon Zijlstra. "Mobility-as-a-Service and changes in travel preferences and travel behaviour: a literature review." (2018).

6.5 Connected and Automated Vehicles (CAVs)

Autonomous driving technologies have made great strides forward and might become commercially available in the foreseeable future. The development of connected and automated vehicles (CAVs) depends on the development of the technologies in connectivity (e.g., 5G, GPS) and automation (e.g., Advanced Driver Assistance Systems [ADAS]), which will ultimately make vehicles capable of self-driving and communicating with each other.

The Society of Automobile Engineers (SAE) defines five levels of driving automation and four classes of cooperation for on-road vehicles, based on vehicle minimum capabilities on each level (Table 6.2). At level 1, the vehicle can perform basic tasks like steering and acceleration alone, but everything else needs intervention from the human driver. At level 2, vehicle control technology (e.g., adaptive cruise control) can ensure driving safely in some specific scenarios but needs an alert human driver. At level 3, the automated driving system is capable of monitoring the driving environment. At level 4, the vehicle can safely navigate to the destination of the journey without the intervention of a human driver in most situations. Level 5 means the automated system can take control of the vehicle in all circumstances, and there is no need for any assistance from human drivers. Levels 4 and 5 are the only ones that require no human intervention.

Table 6.2 SAE levels of vehicle automation (Source: adapted from SAE, 2014)

SAE Level	Name	Execution of steering, acceleration /deceleration	Monitoring of the driving environment	Fallback performance of a dynamic driving task	System capability
0	No automation	Human driver	Human driver	Human driver	NA
1	Driver assistance	Human driver	Human driver	Human driver	Some driving modes
2	Partial automation	System	Human driver	Human driver	Some driving modes
3	Conditional automation	System	System	Human driver	Some driving modes
4	High automation	System	System	System	Some driving modes
5	Full automation	System	System	System	All driving modes

Researchers have shown how the adoption and willingness to pay to own and/or use a CAV vary significantly across different segments of the population. Several main factors can affect adoption and WTP for CAVs: (1) socio-demographic attributes, (2) personal attitudes, (3) current travel behavior, and (4) built-environment variables.[51] Overall, the results of these studies showed that there is public support for CAV technology. The public is in a wait-and-see position in terms of acceptance and use of self-driving vehicles, partially due to a lack of knowledge and uncertainties about various technological and operational characteristics of CAVs.

With sufficient penetration and connective ability, CAVs will likely improve traffic flow, leading to the increased capacity and stability. However, the impact of CAVs on road capacity varies based on road types. With a certain penetration rate, increased highway capacity could be a direct benefit of vehicle automation.[52] However, on local roads, where the frequent pick-up and drop-off of passengers could often occur, capacity may drop because of more friction induced by the merging and weaving of CAVs.

CAVs can change both the fixed out-of-pocket costs of car ownership and the variable transportation costs, usually defined as distance-based costs. CAVs can increase the demand for traveling by car and potentially reduce the share of other alternatives such as public transportation and active modes.[53] Additionally, the possibility of dispatching an empty vehicle to conduct some activities (e.g., running errands) or to self-cruise to find parking or give a ride to another member of the household can lead to more VMT.[54] People might also choose more

---

[51] Krueger, Rico, Taha H Rashidi, and John M Rose. 2016. "Preferences for Shared Autonomous Vehicles." Transportation Research Part C: Emerging Technologies 69 (August): 343–55. https://doi.org/10.1016/J.TRC.2016.06.015.

Zmud, Johanna, Ipek N Sener, Jason Wagner, J Zmud, and D C Washington. 2016. "Self-Driving Vehicles Determinants of Adoption and Conditions of Usage." Transportation Research Record: Journal of the Transportation Research 2565: 57–64. https://doi.org/10.3141/2565-07.

Nordhoff, Sina, Miltos Kyriakidis, Bart Van Arem, and Riender Happee. 2019. "A Multi-Level Model on Automated Vehicle Acceptance (MAVA): A Review-Based Study." Theoretical Issues in Ergonomics Science 20 (6): 682–710.

[52] Shladover, Steven, Dongyan Su, and Xiao-Yun Lu. 2013. "Impacts of Cooperative Adaptive Cruise Control on Freeway Traffic Flow." Transportation Research Record: Journal of the Transportation Research Board 2324 (Idm): 63–70. https://doi.org/10.3141/2324-08.

[53] Circella, Giovanni, Miguel Jaller, Ran Sun, Xiaodong Qian, and Farzad Alemi. "Emissions Impact of Connected and Automated Vehicle Deployment in California." (2021). https://escholarship.org/uc/item/0qf4k22c.

[54] Harb, Mustapha, Yu Xiao, Giovanni Circella, Patricia L Mokhtarian, and Joan L Walker. 2018. "Projecting Travelers into a World of Self-Driving Vehicles: Estimating Travel Behavior Implications via a Naturalistic Experiment." Transportation 45 (6): 1671–85. https://doi.org/10.1007/s11116-018-9937-9.

Harb, Mustapha, Jai Malik, Giovanni Circella, and Joan Walker. "Glimpse of the Future: Simulating Life with Personally Owned Autonomous Vehicles and Their Implications on Travel Behaviors." Transportation Research Record (2021): 03611981211052543.

distant locations for living, working, leisure activities, among others, resulting in significant growth in the amount of time spent in the car. Consequently, various changes could happen, including mode choice, vehicle ownership, trip distance, and VMT.

Private ownership and shared ownership are likely to co-exist in the CAV era. Fully-automated CAVs are likely to be brought to the market later than shared automated vehicles (SAVs), though private vehicles already feature many partial automation features, which can lead to certain similar impacts on travel demand. Overall, CAVs could provide safe, reliable, and efficient mobility options. They can also allow various types of in-vehicle activities to be conducted while traveling, including work, entertainment, sleep. However, the cost of owning a CAVs is believed to be relatively high, due to, for example, the cost of advanced vehicle technology (sensors, cameras, control systems) and regular maintenance requirements (to ensure safety). Also for these reasons, SAV deployment is expected to be financially and technologically viable before privately-owned CAVs will be on the market.

With properly designed fleet management systems, SAVs can ensure efficiently matching between vehicle supply and travel demand. The success of SAVs would heavily depend on the operation cost, vehicle availability and service response time for the customers. Although the cost structure for SAVs is not yet clear, it is very likely to be more affordable than privately-owned CAVs, especially for areas with high population density and high vehicle travel demand. While the impacts of this new technology are still largely unclear, both ownership options might lead to more congestion, induced demand, and possibly increased transportation emissions (though tailpipe emissions would be zeroed out with electric vehicle adoption, as will be required by forthcoming mandates in California). This would add pressure to current roadway infrastructure supply and could attract customers away from public transit.

MPOs and transportation modeling consultants have started to incorporate modeling components to account for recent changes in transportation, including the deployment of CAVs. While the topic largely remains a research topic, several factors that could be considered in the modeling of CAV impacts include[55]:

1) Travel demand
    a) Trip generation
    b) Vehicle ownership
    c) Location choice

---

[55] Kuhr, James, Natalia Ruiz Juri, Chandra Bhat, Jackson Archer, Jennifer Duthie, Edgar Varela, Maitri Zalawadia, Thomas Bamonte, Arash Mirzaei, and Hong Zheng. 2017. “Travel Modeling in an Era of Connected and Automated Transportation Systems: An Investigation in the Dallas-Fort Worth Area.”

NCHRP 20-102. ‘Impacts of Connected Vehicles and Automated Vehicles on State and Local Transportation Agencies’. https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3824

    d) Mode split
2) Traffic assignment
    a) Route choice
    b) Flow stability, travel time, and capacity
3) System performance
    a) Fleet characteristics
    b) Automation technology
    c) Communication technology

However, the currently widely used four-step model and activity-based model are not well equipped to precisely monitor the behavior of CAVs in the system. This is mainly because: 1) it is difficult to trace CAVs in particular under mixed traffic flow circumstances in the system; and 2) there are multiple secondary effects to consider when modeling travel behavior and travel choice with CAVs.

For the newly emerging technologies and CAVs, there is also a lack of data for the modelers and practitioners to calibrate and validate the models. Besides, the market penetration and consumer adoption rate would also affect the travel demand of CAVs, which are expected to depend on the cost of technology, the business/operation model, experience and comfort, roadway and parking infrastructure, and policies that are implemented (Zmud et al. 2018). For all these reasons, explicitly modeling the impacts of CAVs as part of the Link21 program seems to be a lower priority. In addition, modeling the impacts of CAVs is still largely a research topic, for which no universally accepted approaches and solutions have been identified to date. Finally, incorporating CAV impacts into the initial model being developed for the Link21 program would be difficult given the 18-month timeline . Future model update releases could eventually consider adding experimental modules to account for potential impacts of CAV deployment on travel demand, also based on the experiment already under way with the development of similar modules in the MTC model and other models used by planning agencies in California.

7 Conclusions

This report discusses the modeling needs for the development of a travel demand forecasting model that meets the requirements and timeline of the Link21 program. The Link21 program has been proposed as a significant rail investment program that will considerably improve and upgrade the rail services in the Northern California megaregion. The program is centered around the construction of a newly proposed rail crossing in the Transbay Corridor between Oakland and San Francisco in the San Francisco Bay Area. Together with additional improvements in rail lines and services in the megaregion, the new crossing is expected to transform the passenger experience and considerably improve mobility options and accessibility by public transportation. The program has been proposed as a way to address the growing traffic congestion and accessibility problems in the megaregion, promote equity and livability, support economic opportunity and global competitiveness, and advance environmental stewardship and protection.

To support the travel demand forecasting process for the Link21 program, a new travel demand model is expected to be built in approximately 18 months. This report was prepared to support and inform the development of the travel demand modeling framework that will assist with the ridership forecast and support decision-making in the program. Among the motivations for conducting this research project is the awareness that, to date, no existing travel demand forecasting model satisfies two important requirements for the Link21 program: 1) the model should cover the entire Northern California megaregion, which is composed of 21 counties; and 2) the model should have a sufficient level of spatial, temporal, and behavioral details to support the evaluation processes of the Link21 program, especially for the modeling of transit infrastructure and level of service, and its competitiveness when compared with other travel modes in the megaregion.

While no existing model fully satisfies the modeling needs of the Link21 program, Northern California benefits from a wealth of modeling and planning resources that have been developed by various planning agencies and their consultants, and that can help jumpstart the model development to support the program. Currently, several regional travel demand models are in operation in the Northern California megaregion, each partially covering certain portions of the study area. These include the San Francisco Metropolitan Transportation Commission (MTC) Travel Demand 1.5 (TM 1.5) model (with the new version TM 2.1 that is currently under development), the SACSIM model maintained by the Sacramento Area Council of Governments (SACOG), the SF-CHAMP maintained by the San Francisco County Transportation Authority (SFCTA), among others. While these sophisticated activity-based regional travel demand models share many features that could be desirable for the Link21 program, these models are designed to model local and regional travel inside their areas of study (which are subsets of the 21-county megaregion). However, it is not easy to directly combine the outputs from these regional models with the longer-distance flows of travel, either on corridors inside the megaregion or for cross-regional travel. Usually, these longer-distance travel flows are included in the regional models as static trip table inputs estimated from other sources (e.g., a statewide model).

There are also statewide models that are currently in operation, or are being developed, in California. These include the CSTDM developed and maintained by the Caltrans, the statewide model maintained by the California High Speed Rail Authority, and a new statewide rail model that is being developed by Caltrans to support the state rail plan. However, statewide models are not equipped with the level of spatial resolution and nuanced behavioral modeling components that are required to capture local and regional travel.

Given the lack of an existing modeling framework that could easily fulfill the Link21 program needs, this project was carried out to provide the guidelines and recommendations that can facilitate building a travel demand model that addresses the goals and objectives of the Link21 program, while building upon, and harvesting some of the benefits from, the rich modeling ecosystem that is already available in the Northern California megaregion. In fact, creating a new travel demand model that is specifically designed for the Link21 program, while desirable in principle, would face several challenges and limitations due to its massive scope and required activities, and would be subject to potential delays and uncertainties that would make it ill-suited for the limited timeline of the Link21 program.

Therefore, this research project focused on potential opportunities and requirements for developing a travel demand forecasting model for the Link21 program building on the available existing modeling resources. To do this, in this report, we first summarize the current travel market within the study area, which was investigated to put into context the Link21 program and its requirements. While Section 2 of this report is not an exhaustive investigation of the travel markets for the Link21 program (which would be beyond the scope of this project), the section provides summary information on the volumes of travel, by travel mode and component of travel, in the megaregion, using input data from a recent Link21 travel market analysis and CSTDM modeling results. In Section 3, we review 11 existing models that could be considered potentially useful for the development of the travel model for the Link21 program. In the project, we also interviewed experts for their knowledgeable advice on modeling approaches, modeling uncertainties, and potential risks associated with the Link21 modeling needs. Section 4 summarizes the modeling recommendations from the expert interviews. Based on the information from the review of the travel markets, the available travel demand modeling tools existing to date, the recommendations from the experts, and the goals and objectives of the Link21 program. In Section 5 we propose a list of 20 critical, important, and optional modeling features that should be considered for the Link21 program. We then evaluated the 11 existing models based on the 20 main modeling features. Based on that analysis, we identify four different modeling options that could be pursued to accomplish the Link21 goals. For each modeling approach, we discuss the degree that approach could fulfill the requirements of the Link21 program and how it (eventually) handles each required modeling feature. In Section 6, we discuss several sources of uncertainties that potentially affect future travel demand, including the impacts of the COVID-19 pandemic and the eventual persistence of telework, and the way emerging transportation technologies and new mobility options are revolutionizing transportation. Recommendations for future travel modeling approaches are provided in that section.

This comprehensive research approach enabled our research team, in collaboration with the funding agency, to provide a holistic view of the modeling challenges that a program the size of Link21 faces and to suggest guidelines to build robust future travel demand forecasts for the program. Whichever solution for the new Link21 transbay crossing is chosen—the program is currently considering a rail crossing that only serves the BART system or one built to serve as a regional rail connection between Oakland and San Francisco Peninsula or both—the Link21 program will likely represent a revolutionary upgrade of public transportation in the region. Existing travel demand estimates (built without considering the Link21 program) show that in both the current year and future scenario years, car travel dominates transportation flows in the 21-county megaregion, accounting for around 95 percent of megaregional-relevant trips (not including very short-distance trips made by active modes) according to both data from the Link21 travel market analysis and CSTDM forecasts for 2040. This status quo is associated with high traffic congestion level on the highway network and several limitations of the current public transportation system. Specifically, BART operated at capacity during peak time on its major corridors in the pre-pandemic period, has limited connectivity to other regional and local transit lines, and limited service outside of its major corridors. The analysis of data from the Link21 travel market analysis for 2040 highlights how the vast majority of rail trips within Northern California megaregion happens within the nine Bay Area counties (MTC region). When accounting for all modes (auto, rail, and non-rail transit), the nine Bay Area counties make-up almost two-thirds of all trips within the megaregion. The spatial distribution of trips centered around the San Francisco Bay Area together with the characteristics of the MTC model, which is designed with an advanced activity-based travel demand modeling structure and will be (in its MTC 2.1 version) well equipped to model public transportation, suggests that a model that builds upon the MTC model structure or other models centered at the Bay area could be a good solution. However, the eventual inclusion of a proper long-distance modeling component could be beneficial to model improved rail services and potential mode choice shift for the regional and interregional travel (e.g., commuter and intercity rail corridors) of relevance for the Link21 study area.

Given the relatively short period of time (18 months) during which an operational model needs to be developed, understanding the existing modeling practice for the California context is fundamental to bring insights on potential new model development or possible extension of existing models to the Link21 region. In this Sections 3 and 5, we review the modeling features of eleven existing travel demand/trip forecasting models, which we categorize into three major groups: statewide models, regional MPO models, and transit-oriented forecasting models. Several features of these models were highlighted, including coverage of the megaregion, level of spatial detail, complexity, software environment, period of analysis, time periods, main travel modes, access/egress modes. All eleven models were evaluated with pros and cons as well as their relevance to the goals of the Link21 program. This helps provide a background of the capabilities, limitations and uncertainties of these travel demand modeling frameworks.

The interviews with modeling experts (Section 4) helped define the travel demand modeling suggestions for the Link21 program. In the interviews, we asked the experts about their opinions on various topics related to the creation of a future travel demand model that fulfills the needs of the Link21 program. Among others topics, the interviews focused on: 1) the eventual options of building on existing models versus developing a new model for the Link21 program “from scratch”; and 2) the recommended modeling features, also in consideration of the need to account for uncertainties associated with the impacts of the COVID-19 pandemic, the future deployment of CAVs, the role of ridehailing (in its solo vs. pooled options), micromobility (e.g., bike sharing, e-scooter sharing), mobility as a service (MaaS), e-shopping, etc. The majority of the experts recommended building on an existing travel demand model as the most promising option, especially given the limited timeline of 18 months.

Building from the goals, objectives, and the requested 18-month timeline for developing a new travel demand model for the Link21 program, we defined a set of 20 main modeling features (with additional detailed sub-modeling features for certain aspects of the modeling framework) that should be considered for this travel demand model. *Critical* modeling features are characteristics that a model should absolutely have to meet the Link21 goals. A model lacking these should be considered unable to meet the purposes of the program. *Important* modeling features are those that the final model should include; still, if/when needed, on a selected basis, it could be possible to drop some of these modeling features, for example if their implementation would cause an excessive delay in the model development. *Optional* modeling features include other desirable characteristics of the model that could be sacrificed without a significant detriment when they are absent.

We assessed the eleven existing models following the list of 20 suggested modeling features. The assessment helped identify the ways each model includes or lacks each of the modeling features. This exhaustive analysis provided a foundation for suggesting modeling options that can be considered for the Link21 program. Based on the list of proposed modeling features, we evaluated the statewide, MPO, and transit-oriented models for the purposes of this project. Since these models are developed and deployed each with their unique intended use cases, no model could directly satisfy all requirements and provide all suggested modeling features. However, some models present selected features that could be useful to support the development of the Link21 travel demand model.

Based on the knowledge developed for this project, we identify and discuss four modeling options that could be considered for the Link21 program, namely:

1. building on the MTC TM 2.1 regional model without a dedicated long-distance travel model component;
2. building on the MTC TM 2.1 regional model with a dedicated long-distance travel model component;
3. building on the SFCTA regional model, with or without a dedicated long-distance travel model component; and
4. building on the CHSR or the new statewide rail model.

We summarized the pros and cons of these four modeling options with regard to the needs of the Link21 program. In summary, Option 2 emerges as a very desirable and comprehensive option to implement. It builds on the MTC TM 2.1, the advanced regional travel demand model for the San Francisco Bay Area. It has a fine level of spatial resolution with its detailed zoning system and network representation, which is important to capture local and regional travel. And its development will benefit from the continuous MTC TM development improvement process, including the development of the forthcoming version 2.1 of the model, which will feature improved modeling capabilities for public transportation in particular. Adding a long(er)-distance travel demand component would enhance the capacity of this model to account for the different components of travel beyond short-distance trips, though it would add complexity to the model development. Further, the way the two model components for short-distance and long-distance travel interact has proved to be problematic in some existing statewide and larger-scale models, due to the difficulty of identifying good thresholds for separating the two travel components. Potentially, an alternative approach separating trips based on travel purposes: frequent, mainly short-distance, regional trips can be modeled by the activity-based travel demand model component, while relatively less-frequent longer-distance trips carried out for either business/work or leisure/vacation purposes would be modeled by the long-distance travel demand model components. Option 1 would be a solid alternative, as this modeling approach would also benefit from all valuable modeling features in the MTC TM model structure. However, it may underperform in modeling longer-distance travel components, as long-distance travels would be modeled to the extent possible using the same modeling framework of short-distance travel. The model, though, would be simpler to develop, and this approach could be defensible if modeling long-distance travel were considered as not strategically important for the Link21 program. However, such an approach would lose many abilities to evaluate scenarios that integrate investments for intercity/longer-distance rail services with other regional public transportation investments. The two options could somehow be combined, eventually, if a first model release for the Link21 model system is prepared largely based on Option 1, while a proper long-distance travel model component could be included in a future model update. Option 3, on the other hand, is less preferable because SFCTA has several limitations compared to the MTC model, in particular it does not consider various public transportation modeling features (e.g., transit crowding and capacity constraints). However, this option would be a low-uncertainty approach that builds on an operational model, with very low risk of potential delays, as it would not rely on the timeline for the parallel completion and release of MTC TM 2.1. The least preferable option is Option 4, i.e., building a new travel demand model for the Link21 program based on the CSHR or the new statewide rail model. The current structure of these models has relatively low spatial resolution, and they do not include enough detail and components to properly model local/regional travel. Considerable efforts would be required to add detail in many modeling aspects, including re-defining the zoning system, the activity and trip generation modules, the local network representation, and the many components and utility functions used in the various steps of the travel demand model. However, these larger-scale travel demand models could represent a source for the long-distance travel component that could be integrated in one of the other options that are described.

The research approach used in this study, which builds on the analysis of travel markets for the Link21 program and a comparison of its project goals and modeling needs, uses the input from experts, evaluates existing transportation models, and identifies various modeling approaches that can be used to support the Link21 program. Section 5 of this report provides more detailed discussion of these modeling recommendations, and we refer the readers to that section for more details on the topic. The recommendations contained in this report are expected to help the funding agency and its modeling consultants develop a satisfactory solution to develop the Link21 modeling framework and build future travel demand forecasts for the program. Given the complexity of the Link21 program, its needs to integrate various components of travel demand and develop travel forecasts for complex long-term scenarios. In line with modeling practice in the transportation field, we recommend that the model development for the Link21 program use a modular system, which can be updated over time. While an initial modeling system for the Link21 program could be released in the initial proposed timeline of 18 months, future model releases and updates could include additional features and improvements in components. This process would be also well-suited to address eventual issues that could arise with the initial model release but also harvest the additional benefits from the development and updates of other models in the Northern California megaregion that are carried out in parallel, e.g., the MTC TM version 2.2 (and following versions) and/or the new statewide rail travel model that is being developed by Caltrans.

Appendix A

This appendix contains detailed feedback received from Jim Ryan on ridership forecasting for transit projects.

1. Thoughts from a customer of ridership forecasts
    a. FTA: 40 years as a customer of ridership forecasts used for decision making
    b. Reservations on traditional practice:
        i. Too much about the models; too little about the forecasts
        ii. Undervalued forecasting tasks; insufficient skills and resources
        iii. Fancier models seem to:
            1. Be complicating themselves beyond usefulness
            2. Take long time to develop
            3. Rarely be ready for ridership forecasting for proposed FTA projects
        iv. Long-range forecasts tend to be wildly unreliable—and borderline useless
        v. Forecasters/planners struggle to extract key findings and insights from “model outputs,” leaving themselves in the dark, decision makers uninformed, and the outputs untested against real-world conditions and possibilities
    c. Long-range forecasts need a companion method in addition to the model to foster:
        i. Careful thought about the future and the key components of change
        ii. An analytical description of “today” grounded in data on the key components
        iii. A rigorous validation framework for the model forecast for “today”
        iv. An “easy” and open way to test alternative big-picture changes/scenarios
        v. An explicit statement on how each component may change in the scenarios
        vi. A framework for summarizing and scrutinizing the model forecasts
        vii. An analytical basis for constructing a narrative about each forecast that is meaningful to decision makers and the public
2. Model-centric approach
    a. Model preparation:
        i. Do not let the model development exhaust the available time and budget
        ii. Build in quality control reporting and checks; and presentation materials
        iii. Require meaningful validation against pre-COVID data
    b. Forecasts:
        i. Think of forecasting as constructing a story with lots of narrative detail supported by quantified key characteristics of travel markets important to the alternative projects/assumptions being considered:
            1. Current conditions
            2. Impacts of projects/policies on current conditions (“today”)
            3. Scenario assumptions on changes between now and the future

            4. Contributions of each change to conditions in the future year
            5. A useful, accessible, and well-presented scenario forecast for the future
        ii. Make sure that model outputs are reported and processed to support a story
        iii. Require that the first forecasting tasks be done for "today"
        iv. Prepare/build forecasts with step-wise forecasts—for today
        v. Then go to the future, again through a step-wise build-up
        vi. Recognize that model outputs are just collections of millions of numbers; forecasts are the well-presented insights on what aspects the models consider and why they are included

3. Companion approach (to complement a full-scale travel demand forecasting model):
    a. Spreadsheet-based
    b. Focused on Transbay markets
    c. Large-area geography within the markets
    d. Key characteristics of each large-area geography (examples):
        i. Households/population, employed persons in households, and employment
        ii. Income and auto-sufficiency of households
        iii. Census Transportation Planning Products (CTPP) work-at-home workers
        iv. CTPP worker flow to jobs in San Francisco / other peninsula locations
        v. CTPP worker flow on transit (total, rail)
        vi. Rider survey transit trips to San Francisco / other peninsula locations separately for rail and bus and separately for work and non-work purposes
    e. Cells populated for:
        i. Past census years, as available
        ii. Today
        iii. For each scenario tested in the companion approach
        iv. From the model outputs for each scenario tested with the models
    f. Used for:
        i. An early start of forecasting during model development period
        ii. A backup for delayed/failed model development
        iii. Understanding current (and past) contributors to Transbay transit travel
        iv. Discovery of actual patterns over geography and over time
        v. Validation of the model-based approach

vi. Basis for narrative presentation of forecasts from model and companion methods

vii. Checks on the plausibility of numbers derived from the model

Appendix B

This appendix contains the recent revisions made to the Link21 goals, objectives and performance metrics.

V. Transform the Passenger Experience
  1 Provide better service
    - Network integration
    - Total travel time
    - In-vehicle travel time
    - Service hours
    - Service frequency
    - Crowding
  2 Improve reliability and system performance
    - Reliability
    - Expected recovery times from incidents
    - Ability to maintain existing and new infrastructure
    - Flexibility to meet future growth
    - Viability in the event of seismic events and other emergencies
  3 Build ridership and mode share
    - Ridership
    - Mode share
    - Vehicle miles traveled (VMT) reduction

VI. Promote Equity and Livability
  1 Connect people and places
    - Jobs accessible from people's homes
    - Non-work destinations accessible from people's homes
    - Work/Non-work trips on network
    - Availability/accessibility of rail options
  2 Improve safety, health, and air quality
    - Pollutant levels
    - Auto-involved crashes
    - Active mode access to rail
    - Coverage of areas of health concern
  3 Advance equity and protect against community instability and displacement
    - Affordable transportation options

VII. Support Economic Opportunity and Global Competitiveness
  1 Improve access to opportunity and employment
    - Jobs accessible to new or improved service

    - Business access to potential employees
    - Business access to potential markets
    - Work trips on network
2. Connect major economic, research, and education centers
    - Travel times between major employment centers
    - Travel times between major centers and transportation hubs
    - Trips between major employment centers
3. Enable transit-supportive and equitable land use
    - Local land-use policies consistent with Link21 land use and equity strategy
    - Potential for future land uses within station catchment areas

VIII. Advance Environmental Stewardship and Protection

1. Increase climate change resilience
    - Viability under different sea-level rise inundation scenarios
2. Reduce greenhouse gas emissions
    - GHG emissions
3. Conserve resources
    - Energy consumption for transportation