Evaluation of Left Shoulder as Part-Time Travel Lane Design Alternatives and Transportation Management Center Staff Training Module Development

Zhuohang Deng
*California Polytechnic State University, San Luis Obispo*

Zhiliang Luo
*California Polytechnic State University, San Luis Obispo*

Neil Hockaday
*California Polytechnic State University, San Luis Obispo*

Ahmed Farid
*California Polytechnic State University, San Luis Obispo*

Anurag Pande
*California Polytechnic State University, San Luis Obispo*

Follow this and additional works at: [https://scholarworks.sjsu.edu/mti_publications](https://scholarworks.sjsu.edu/mti_publications)

Part of the Construction Engineering and Management Commons, Infrastructure Commons, and the Transportation Commons

**Recommended Citation**

This Report is brought to you for free and open access by SJSU ScholarWorks. It has been accepted for inclusion in Mineta Transportation Institute Publications by an authorized administrator of SJSU ScholarWorks. For more information, please contact scholarworks@sjsu.edu.
Evaluation of Left Shoulder as Part-Time Travel Lane Design Alternatives and Transportation Management Center Staff Training Module Development

Zhuohang Deng  Neil Hockaday  Anurag Pande, PhD
Zhiliang Luo  Ahmed Farid, PhD
Mineta Transportation Institute

Founded in 1991, the Mineta Transportation Institute (MTI), an organized research and training unit in partnership with the Lucas College and Graduate School of Business at San José State University (SJSU), increases mobility for all by improving the safety, efficiency, accessibility, and convenience of our nation’s transportation system. Through research, education, workforce development, and technology transfer, we help create a connected world. MTI leads the Mineta Consortium for Transportation Mobility (MCTM) funded by the U.S. Department of Transportation and the California State University Transportation Consortium (CSUTC) funded by the State of California through Senate Bill 1. MTI focuses on three primary responsibilities:

Research

MTI conducts multi-disciplinary research focused on surface transportation that contributes to effective decision making. Research areas include: active transportation; planning and policy; security and counterterrorism; sustainable transportation and land use; transit and passenger rail; transportation engineering; transportation finance; transportation technology; and workforce and labor. MTI research publications undergo expert peer review to ensure the quality of the research.

Education and Workforce

To ensure the efficient movement of people and products, we must prepare a new cohort of transportation professionals who are ready to lead a more diverse, inclusive, and equitable transportation industry. To help achieve this, MTI sponsors a suite of workforce development and education opportunities. The Institute supports educational programs offered by the Lucas Graduate School of Business: a Master of Science in Transportation Management, plus graduate certificates that include High-Speed and Intercity Rail Management and Transportation Security Management. These flexible programs offer live online classes so that working transportation professionals can pursue an advanced degree regardless of their location.

Information and Technology Transfer

MTI utilizes a diverse array of dissemination methods and media to ensure research results reach those responsible for managing change. These methods include publication, seminars, workshops, websites, social media, webinars, and other technology transfer mechanisms. Additionally, MTI promotes the availability of completed research to professional organizations and works to integrate the research findings into the graduate education program. MTI’s extensive collection of transportation-related publications is integrated into San José State University’s world-class Martin Luther King, Jr. Library.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the information presented herein. This document is disseminated in the interest of information exchange. MTI’s research is funded, partially or entirely, by grants from the California Department of Transportation, the California State University Office of the Chancellor, the U.S. Department of Homeland Security, and the U.S. Department of Transportation, who assume no liability for the contents or use thereof. This report does not constitute a standard specification, design standard, or regulation.
Evaluation of Left Shoulder as Part-Time Travel Lane Design Alternatives and Transportation Management Center Staff Training Module Development

Zhuohang Deng
Zhiliang Luo
Neil Hockaday
Ahmed Farid, PhD
Anurag Pande, PhD

January 2023
### Abstract
Permanent capacity expansion, such as adding new lanes, is no longer a viable strategy to address traffic congestion in California; hence, ITS (Intelligent Transportation System) strategies, such as part-time use of the shoulder as a travel lane, need to be explored. The use of the shoulder as a travel lane during peak traffic hours has limited applications in the US, and most use the right shoulder as a part-time travel lane even though either the right or left shoulder (but not both) may be used. Caltrans District 5 is exploring the use of Left Shoulder as a Part-time Travel Lane (LSPTTL) as a piece of the larger project, titled Five Cities Multimodal Transportation Network Enhancement Project (FCMTNEP), aimed at congestion relief near Pismo Beach, CA. Construction is expected to begin in Winter 2025 with a Winter 2027 completion date. Given that this would be the first instance of LSPTTL in California, it is a Project of Division Interest (PoDI) for the California division of Federal Highway Administration (FHWA), and the District 5 experience may guide similar future installations of the shoulder as travel lane projects in the state. This research uses a microsimulation-based approach to evaluate design alternatives being explored by Caltrans District 5. This approach allows for evaluating the operational and safety effects of each of the alternatives. Furthermore, a Transportation Management Center (TMC) operator training framework has also been developed to ensure that the local TMC personnel can effectively deploy the LSPTTL during routine operations and emergencies. Based on the operational evaluation, the study found no significant difference in travel times associated with the three design alternatives. Alternative 2, which involves the longest segment with LSPTTL among the alternatives, was found to be the safest based on a surrogate safety measure-based evaluation. This framework for evaluating design alternatives for operations and safety effectiveness may be used for future projects that involve the use of the shoulder as a travel lane. For TMC operator training, this report documents key learning objectives. A hands-on training program that involves operators executing the opening and closing of the shoulder for routine and emergency conditions was developed. As the project nears implementation, there is some scope for improvement in the training modules through replication of the exact features of the LSPTTL design and introducing more realism in the TMC simulator training exercises.

### Key Words
Transportation System Management and Operation (TSMO), Part-time Shoulder Use, Microsimulation, Transportation Management Center (TMC), Intelligent Transportation Systems (ITS)
ACKNOWLEDGMENTS

We acknowledge the advice and support of Caltrans District 5 staff, and, in particular, Mr. Sam Toh and Mr. Paul Valadao. Furthermore, we acknowledge the work of Cal Poly students Ms. Peyton Ratto and Mr. Nick Sauciur, who helped the project team reach out to nationwide agencies that have implemented part-time use of the shoulder as travel lanes in different configurations. Mr. Sauciur also helped organize the formatted references for the report. We are also thankful to the agency personnel from multiple states in the US, who graciously agreed to share their experiences in implementing part-time shoulder use as travel lanes. All opinions presented herein are the authors' alone.
CONTENTS

Acknowledgments ................................................................................................................... vi

List of Figures ........................................................................................................................ ix

List of Tables .......................................................................................................................... x

1. Introduction ....................................................................................................................... 1
   1.1 Background and Motivation ...................................................................................... 1
   1.2 Project Context .......................................................................................................... 2
   1.3 Research Objectives ................................................................................................. 3
   1.4 Report Organization ................................................................................................. 4

2. Literature Review ............................................................................................................. 5
   2.1 Background on Part-time Shoulder Use for Travel .................................................. 5
   2.2 Left-shoulder part-time travel lane (LSPTTL) .......................................................... 6
   2.3 Surrogate Safety Assessment Model (SSAM) .............................................................. 9
   2.4 TMC Operator Training ........................................................................................... 11
   2.5 Conclusions from the Literature Review ................................................................. 12

3. Simulation Modeling: Base and Scenario Networks ......................................................... 14
   3.1 Simulation Modeling for 2018 Base Conditions ...................................................... 14
   3.2 Alternative Design Scenarios ................................................................................. 19
   3.3 Conclusion ................................................................................................................ 25

4. The TMC Staff Training Framework ............................................................................. 26
   4.1 Overview ................................................................................................................... 26
   4.2 Lesson Plan and Learning Objectives ...................................................................... 29
4.3 Development of a Hands-on Training Environment ........................................... 30

4.4 Future Refinements ......................................................................................... 35

5. Summary & Conclusions .................................................................................. 36

5.1 Training Module Development ....................................................................... 36

5.2 Future Scope.................................................................................................... 36

Appendix A: Traffic Data and Growth Factors for Calibration and Validation......... 38

Appendix B: Behavioral Parameters for Microsimulation...................................... 42

Bibliography ......................................................................................................... 48

About the Authors................................................................................................. 51
LIST OF FIGURES

Figure 1. US 101 Southbound Study Corridor (Source: Caltrans) ........................................... 3

Figure 2. Dynamic Shoulder Lane Open ................................................................................ 6

Figure 3. Dynamic Shoulder Lane ........................................................................................ 7

Figure 4. Conflict Angle Diagram in SSAM ............................................................................. 11

Figure 5. Freeway Link Car Following Behavior Parameters Used in the Model Figure .... 19

Figure 6. Options for the Left Shoulder Part-Time Travel Lane (Caltrans District 5) ........ 20

Figure 7. Through Traffic Travel Time Comparison ................................................................. 24

Figure 8. TMC Simulator during one of the trainings at Cal Poly San Luis Obispo ........... 26

Figure 9. A real TMC image sourced from FHWA (Neudorff et al., 2003) ....................... 27

Figure 10. Existing Caltrans CCTV Infrastructure ................................................................. 31

Figure 11. Facsimile of the Network in the TMC Simulator .................................................... 32

Figure 12. TMC Simulator Manager GUI (graphical user interface) ................................. 33

Figure 13. TMC Simulator Script Builder Tool ................................................................. 33

Figure 14. XML Script Governing the Simulated Training Scenario .................................. 34
**LIST OF TABLES**

Table 1. List of Surrogate Safety Conflict Measures .......................................................... 10

Table 2. GEH Statistics for Traffic Volumes at Off Ramps and Freeway Mainline Segments of US 101 SB .................................................................................................................. 17

Table 3. Operational Measurements Locations ..................................................................... 21

Table 4. Maximum Queue Delay Results................................................................................ 22

Table 5. Through Traffic Travel Time Results ...................................................................... 23

Table 6. Surrogate Measurement Averages ........................................................................... 24

Table 7. Number of Conflicts Based on Thresholds on Surrogate Safety Measures’ Averages ......................................................................................................................... 25

Table 8. Agencies Implementing Part-Time Shoulder Use Projects ....................................... 28
1. Introduction

1.1 Background and Motivation

Transportation system management and operation (TSMO) strategies are a potential solution for addressing congestion and reliability issues within the transportation system. TSMO strategies focus on operational improvements to the existing transportation system instead of the permanent addition of extra capacity (e.g., widening of freeways). A wide range of strategies fit under the TSMO umbrella, including variable speed limits, high-occupancy vehicle/toll lanes, ramp metering, transportation demand management etc. These strategies are particularly effective when other alternatives for adding permanent lanes are infeasible or cost-prohibitive. Several TSMO strategies involve construction, but, usually, the costs are much lower than for adding lanes. TSMO alternatives for freeway corridors may cost-effectively reduce delays and improve travel-time reliability during peak hour travel.

Part-time shoulder use (PTSU) is one strategy for addressing congestion without permanent capacity expansion through lane addition, which is especially relevant for California, where there is widespread recognition of environmental concerns related to permanent capacity addition. According to the Federal Highway Administration (FHWA), PTSU falls under the umbrella of managed lane strategies, where the shoulder is used for travel only during the times of day when adjoining lanes are heavily congested (e.g., during peak hours) (Jenior et al., 2016). The earliest application of part-time shoulder use launched in the mid-1970s on Seattle's SR 520. A policy brief by the Texas Transportation Institute (TTI) noted that since the 1970s, PTSU has seen widespread use in Europe, but its applications in the US have been limited and have varied significantly across states (How to Fix Congestion, 2016a).

This research project aims to evaluate operation/safety for specific designs of the left-shoulder part-time travel lane (LSPTTL) and develop a training program to prepare the California transportation management center (TMC) workforce for Caltrans (District 5). The LSPTTL is a piece of the Five Cities Multimodal Transportation Network Enhancement Project (FCMTNEP, formerly known as the Pismo Congestion Relief Pilot Project) (California, n.d.-b). This larger project also includes the construction of a new park-and-ride lot in the city of Pismo Beach, even though this research is limited to the LSPTTL. The operational/safety evaluation framework for various LSPTTL alternatives demonstrated here, based on a segment of the US 101 Southbound corridor in San Luis Obispo County, would support the role of the LSPTTL project as a pilot for future LSPTTL applications in the state.

The operational evaluation relies on microscopic simulation models (calibrated and validated for the 2018 base conditions) of three alternative design configurations for the left shoulder lane to estimate network-wide performance measures. For the alternatives proposed by Caltrans District 5, surrogate safety measures are estimated by supplying the simulation model output to the
Surrogate Safety Assessment Model (SSAM) by the Federal Highway Administration (FHWA). Overall, the measures related to surrogate safety and travel time differences between the designs served as the basis for the evaluation of the alternatives.

Following the operational and safety evaluation of the alternatives, a framework for training transportation management center (TMC) staff for the operation of the LSPTTL was developed and presented to the stakeholders. The training framework was based on the concept of operations (ConOps) for the FCMTNEP approved on January 7, 2021. According to FHWA’s (California division) Systems Engineering Guidebook v3.0 (Krueger et al., 2009), the ConOps document the planned ITS (intelligent transportation system) project and its context in a non-technical and easy-to-understand manner, representing the viewpoints and needs of multiple stakeholders. In other words, it translates the problem space, and stakeholder needs, to system-level requirements for the ITS project. ITS refers to a wide array of technologies (e.g., ramp metering, variable message signs, variable speed limits) that make the transportation system more adaptive to prevailing dynamic conditions on a transportation network.

1.2 Project Context

The freeway corridor under consideration (See Figure 1) serves the primary employment centers in the city of San Luis Obispo (e.g., Cal Poly San Luis Obispo) with northbound morning commuters from Santa Maria, Nipomo, and the Five Cities Area commuting daily to San Luis Obispo and returning via the southbound US 101 corridor in the late afternoon hours. This afternoon commute is a source of significant congestion on the corridor. According to the ConOps developed by Caltrans District 5, the southbound US 101 within the project vicinity consists of “...a short and steep upgrade from San Luis Obispo Creek to just south of Avila Beach Drive southbound on-ramp merge.” Figure 1 shows the study area. In 2009, a climbing lane was added within the study area to address the issues of heavy trucks navigating the steep upgrade. The truck lane starts at San Luis Obispo Creek and drops 0.25 miles north of Spyglass Drive. The existing left shoulder varies from three to ten feet where the part-time travel lane would be implemented. Sensitive Native American and coastal resources are found throughout the corridor. Therefore, widening the freeway to full standards is not a practical solution.
Figure 1. US 101 Southbound Study Corridor (Source: Caltrans)

Given that this would be the first LSPTTL corridor in the state and one of only three across the US, LSPTTL implementation is one of the Projects of Division Interest (PoDI) for the FHWA California division.

1.3 Research Objectives

This research, as it relates to the broader Caltrans District 5's broader FCMTNEP, has the following objectives:

A. Evaluate the alternative designs of LSPTTL for surrogate safety and traffic operational measures. The alternatives to be evaluated in the research are formulated by Caltrans District 5, in collaboration with the FHWA California Division, as part of a detailed LSPTTL Concept of Operations (ConOps) for the Five Cities Multimodal Transportation Network Enhancement Project. Different design alternatives evaluated as part of this research are discussed in Chapter III.

B. Create a model and basic training module for the TMC operators to prepare them for the LSPTTL operation. The feedback from stakeholders on the basic training module will support future TMC operator training programs.

The lessons learned from the operational evaluation and preliminary training will support the proposed LSPTLL in District 5 and provide guidance to other Caltrans Districts that may consider part-time use of shoulders as a general-purpose lane.
1.4 Report Organization

This report is organized as follows: A detailed review of the literature that covers past studies on the use of the shoulder as a part-time travel lane, the use of simulation and surrogate measures for operational/safety evaluation, and documented training (if any) on part-time use of shoulders as a travel lane for the TMC staff. Chapter III discusses the details of the LSPTTL design alternatives and methodology for operational and safety evaluation, followed by the evaluation results. Chapter IV provides details of the outreach efforts to agencies that have implemented part-time shoulder use, along with the process of developing the training framework. Chapter V provides conclusions and future applications of this research.
2. Literature Review

2.1 Background on Part-time Shoulder Use for Travel

Part-time shoulder use (PTSU), sometimes also referred to as Hard Shoulder Running (HSR), is one of the TSMO strategies. It provides additional roadway capacity and preserves the benefits of a full-width shoulder during off-peak hours. PTSU can be a feasible option when full freeway expansion is not viable due to cost and environmental concerns. According to the FHWA, PTSU is one of the managed lane strategies where the shoulder is used for travel only during the times of day when the adjoining lanes are heavily congested (e.g., during peak hours) (Jenior et al., 2016). The earliest application of PTSU launched in the mid-1970s on Seattle’s SR 520. A policy brief by the Texas Transportation Institute (TTI) noted that since the 1970s, PTSU had seen widespread use in Europe, but its applications in the US have been limited and have varied significantly across states (How to Fix Congestion, 2016b).

According to a 2016 FHWA publication on the use of freeway shoulders for vehicle travel, PTSU may be implemented as dynamic PTSU (D-PTSU), static PTSU (S-PTSU), and bus-on-shoulder (BOS). D-PTSU involves the opening of the shoulder for vehicular travel in response to traffic conditions, while S-PTSU may be used in locations with well-defined and predictable peak hours. In California, the typical PTSU applications thus far have included BOS on the right side of the right-of-way. A list of successful PTSU case studies in the US may be found in the Appendix of the FHWA publication (Jenior et al., 2016).

The FHWA guide (Jenior et al., 2016) noted different configurations and design choices in which PTSU may be implemented. These include the left/right shoulder option and vehicle-use option (bus only, truck-use restrictions), among others. The guide noted the need for additional research to provide more specific direction to practitioners.

Recent research has addressed the effectiveness of certain design choices. For example, Coffey & Park (2018) found that left shoulder use can be more effective than right shoulder use. Also, a more recent FHWA report examined different merge designs (Jenior et al., 2019). In general, applications of left shoulder use are less common than right shoulder use even though the former has benefits, including lower noise impact. The rarer use of the left shoulder as a travel lane is likely due to the limitations associated with the size of the roadway median on typical urban freeways.

The 2016 FHWA guide also noted that PTSU has unique maintenance, incident management, and law enforcement needs, necessitating training of the TMC staff involved in the day-to-day operation of PTSU facilities (Jenior et al., 2016). However, the existing TMC staff training resources cover the most common managed lane situations, i.e., high occupancy vehicle (HOV)
lanes, express toll lanes (ETLs), and high occupancy/toll (HOT) lanes (Kuhn et al., 2005; Tantillo et al., 2014).

2.2 Left-shoulder part-time travel lane (LSPTTL)

The LSPTTL is a variation of the PTSU design. Coffey & Park found that left shoulder use can be more effective than the right shoulder (Coffey & Park, 2018). The FHWA guide noted that, in choosing whether to use the left or right shoulder as a part-time travel lane, the planning process should consider regional needs, reliability, safety performance, other regional goals, and the maturity of the existing TSMO programs in the region. Based on these guidelines, Caltrans decided to use the D-PTSU design to match regional needs as part of the FCMTNEP. Figure 2 shows the US-23 D-PTSU in Ann Arbor, Michigan.

Figure 2. Photo. Dynamic Shoulder Lane Open (Michigan State DOT)

A lane-use control sign on the far-left side indicates whether the shoulder is open or closed to traffic, which is a typical design for D-PTSU. Sometimes a dynamic speed limit will also be indicated (e.g., see Figure 3).
In order to decide on the opening and closing of the shoulder, most part-time shoulder use facilities are accompanied by Intelligent Transportation Systems (ITS) technologies. These technologies are absolutely essential for dynamic part-time shoulder use (D-PTSU). Some examples of critical ITS technologies include (Jenior et al., 2019):

- Speed sensors and cameras to help agencies monitor and manage the facility in real-time.
- Electronic lane control signs (LCS).
- Changeable message signs (CMS).
- Driver information ITS treatments to communicate information such as when the shoulder is open to traffic.
- Regulatory and warning signs that must be turned on and off as the shoulder opens and closes.

TMC operators use ITS software algorithms to determine when to open and close the shoulder at the D-PTSU section. A high density of detectors is required to measure volumes and spot speeds at each sign location. TMC can also change speed limits or provide queue warnings based on the collected data.
Operational Effects of PTSU

A study conducted in Germany reported a 20–25% increase in the capacity of a freeway after the implementation of D-PTSU (Geistefeldt, 2012). The German Highway Capacity Manual includes the design capacities for freeways with D-PTSU presence internal and external to the urban areas. The design capacities in vehicles per hour (veh/hr) for basic freeway segments with a gradient of less than or equal to 2% with the presence of D-PTSU are:

- Two lanes plus PTSU in a rural area: 4,200 veh/hr to 4,700 veh/hr.
- Two lanes plus PTSU in an urban area: 4,400 veh/hr to 5,200 veh/hr.
- Three lanes plus PTSU in a rural area: 5,600 veh/hr to 6,300 veh/hr.
- Three lanes plus PTSU in an urban area: 6,000 veh/hr to 7,000 veh/hr.

These numbers correspond to heavy vehicle percentages ranging from five percent to 30%. In the US context, the Colorado DOT reported 15% more throughput and 18% faster speeds across all lanes of eastbound I-70 during high traffic volumes on the weekends.

Safety Effects of PTSU

A study in Germany analyzed the collision data for seven freeways with hard shoulder running (HSR), which is another name for PTSU (Waleczek & Geistefeldt, 2021). The study found that the additional capacity of the HSR reduced the extent of congestion, which reduced rear-end collisions by 25%–28%. An overall reduction of the crash rates by 35% was reported after the implementation of HSR.

In the US context, the Virginia Department of Transportation (VDOT) also reported that crash data from I-66 showed 6%, 10%, and 11% reductions in total (all severity), multiple-vehicle (all severity), and rear-end (all severity) crash, respectively (Dutta et al., 2018). The locations with HSR have crash reductions of 25% to 40%. The results of the analysis showed that HSR could produce statistically significant operational and safety benefits but that the effects of other Advanced Traffic Management (ATM) components were more limited.

Some safety studies concluded that there are negative effects on safety performance. An old report from VDOT reported their S-PTSU section on I-66 results in a 38% increase in crashes during adverse light conditions at merging and diverging areas (Lee et al., 2007).

By reducing queuing and increasing speed through a bottleneck area, researchers noted that D-PTSU can reduce upstream congestion-related crashes. This positive feedback leads Germany to implement D-PTSU on multiple freeways (Jones et al., 2011). Note that since this study is aimed
at examining the potential safety effects of a future LSPTTL installation, for now a before-after study based on historical crash data may not be applicable for this context. Such a study can be conducted in the post-installation period if desired. We provide this review of such before-after studies to show the safety benefits, even as the safety analysis for this research will be based on surrogate safety measures that can be derived using microscopic simulation models.

**Simulation Modeling**

To estimate the operational impacts of PTSU, we used microscopic simulation modeling. Microscopic models provide a detailed representation of the traffic process, considering the characteristics of individual vehicles and simulating vehicle interactions in the traffic stream based on car-following and lane-changing models (Liu et al., 2020). Microsimulation models are especially appropriate where detailed modeling of smaller networks is desired (e.g., one freeway corridor). We chose PTV VISSIM for this study since it allows for detailed modeling of the interaction of different agents traversing the network (i.e., vehicles, including heavy trucks). Furthermore, PTV VISSIM allows for the flexibility of modeling advanced ITS strategies through the use of a Component Object Model (COM) application programming interface (API) (Wang & Niu, 2019).

Another advantage of microsimulation models is that they can provide detailed vehicle trajectory data that may be used for safety evaluations with surrogate measures of safety.

### 2.3 Surrogate Safety Assessment Model (SSAM)

Note that since the LSPTTL on US 101 is a future installation and has not yet been implemented, the safety assessment needs to be based on surrogate safety measures that may be derived using the microscopic simulation models. The surrogate measures are based on the occurrence of a conflict event between vehicles and/or other road users. A conflict is defined as an observable situation in which road users approach each other to such an extent that there is the risk of collision if their movements remain unchanged (Gettman D. et al., 2008). Most effective surrogate measures include time to collision (TTC), post encroachment time (PET), deceleration rate (DR) along with maximum speed, and speed differential (Gettman & Head, 2003). A list of surrogate measures for defining and characterizing the conflicts is presented in Table 1 (Allen et al., 1978; Ghaffari, 1990).
The Federal Highway Administration (FHWA) released the first version of SSAM in 2008. The version used in this study (SSAM 3.0) was released in 2017. SSAM uses vehicle trajectory data from traffic simulation models to identify the type and frequency of interactions between road users during the simulation period (Gettman D. et al., 2008). Figure 4 depicts the conflict angle diagram used in SSAM to recognize the type of conflicts. Key questions in determining whether or not VISSIM trajectory data may be used for safety evaluation of different design alternatives include: (1) whether the estimate of conflicts from the simulation model corresponds to conflicts in the field; and (2) whether or not the estimated number of conflicts on a network correlate with the historical crash experience of the network.
To ensure satisfactory calibration between collisions and measures derived from SSAM, past studies have suggested appropriately calibrating driver behavior in the simulation environment (Essa & Sayed, 2020; Fan et al., 2013; Huang et al., 2013). Fan et al. compared the frequency of near misses observed in a field study with the estimated number of VISSIM & SSAM model estimates (Fan et al., 2013). They reported an acceptable consistency between simulated and observed conflicts.

2.4 TMC Operator Training

TMCs serve as the technical and institutional hubs that facilitate interagency coordination and integrate a wide range of traffic management strategies to achieve the collective goal of providing safe, efficient, and sustainable transportation network infrastructure. The TMC may be considered the hub or nerve center of most freeway management systems, and its role is especially critical in implementing TSMO strategies such as LSPTTL (Neudorff et al., 2003).

TMCs face complex institutional issues in coordinating with service providers and their timely response to incidents is critical. Therefore, it is critical to provide TMC staff with the necessary resources, experience, skills, and training (Jin et al., 2014).

TMC personnel would continue to play a critical role in the implementation of the TSMO strategies. In fact, staffing and skill needs have been identified as one of the five major areas of need (Jin et al., 2014), along with current tools and applications used in TMC operations, data.
collection and information sharing, potential enhancements with new technologies, and incident management performance measures. The prognostications of a TMC with no humans in the loop, being considered in the early 1990s (Kelly et al., 1993) by futurists, have not panned out, and TMCs would continue to require dedicated management and staff with specialized skills and training (Kergaye et al., 2014).

The following items are recommended for the development of effective formalized training programs for TMC operators (Jin et al., 2014):

- Evaluate gaps between staff qualifications and desired skills.
- Use data from system performance to identify training topics.
- Provide training programs up to date with emerging technologies.

Sullivan et al. noted that microscopic simulation models could support the TMC operator training programs (Sullivan et al., 2004) by providing necessary realism with respect to the traffic conditions observed by the operators. TMC Academy, funded by Caltrans and managed by Cal Poly researchers, uses the PTV VISSIM model to simulate the traffic for the hands-on traffic module (TMC Simulator Revolutionizes Traffic Management in California, n.d.).

In 2014, five agencies in the US were using TMC operator support for implementing hard shoulder running strategies (Kergaye et al., 2014). However, the literature and documentation on the training provided to the TMC staff for the shoulder as a part-time travel lane are not available through published sources.

2.5 Conclusions from the Literature Review

This chapter reviewed background literature relevant to the development of an operational/safety evaluation framework and training program for TMC staff critical to the implementation of LSPTTL as part of the FCMTNEP project being planned by Caltrans District 5. The literature search was conducted using Google Scholar, Google web search, and Web of Science. For the most part, sources in English or those with readily available English translations were reviewed. We cite sources primarily from Europe and North America since the studies most relevant to the context of systematic use of the shoulder as part-time travel lane in California are limited to these geographies. Before-after comparisons have generally demonstrated that PTSU reduced congestion by temporarily increasing freeway capacity during peak hours. It also enhances safety likely by reducing rear-end collisions associated with congestion.

For the specific case of LSPTTL on the US 101 SB corridor near Pismo Beach, we plan to evaluate the future design alternative in a microsimulation environment. The literature showed that the microscopic simulation model can help assess the operational and safety performance of design
alternatives. The safety evaluation can be conducted by analyzing the vehicle trajectory data from the microsimulation using a tool developed by FHWA, namely, SSAM. The design alternatives and their safety and operational performance are described in the next chapter.

Last but not least, there is a lack of published literature and documentation on training that examines specific TSMO strategies involving the part-time use of the shoulder as a travel lane. Existing TMC operator training resources primarily cover the more common managed lane situations (e.g., high occupancy vehicle (HOV) lanes, express toll lanes (ETLs), and high occupancy/toll (HOT) lanes). Therefore, instead of relying on published sources, we decided to reach out to the agencies that have implemented part-time use of shoulders as a travel lane in their jurisdictions. The outreach efforts and training module developments are described in Chapter IV.
3. Simulation Modeling: Base and Scenario Networks

3.1 Simulation Modeling for 2018 Base Conditions

Traffic simulation models are powerful analytical tools for evaluating different scenarios that cannot be practically tested in real-world conditions by providing various network performance measures for comparison between the scenarios (Liu et al., 2020). Microsimulation approaches have certain limitations and shortcomings (see Liu et al., 2020 for a more detailed discussion), including unrealistic driver behavior, time and expertise needed to develop simulation models, and difficulty in interpretation of the output data. Despite these limitations, microsimulation is an increasingly popular tool for analyzing the behavior and interactions of traffic systems. Due to its ability to capture road user behavior, it is especially effective for understanding the evolution of traffic congestion and evaluating transportation management strategies (Gettman et al., 2008).

Therefore, this study uses a microsimulation model to evaluate three different LSPTTL designs for the study corridor since the objective is to propose and evaluate the future framework and proposed design. The microsimulation model is used for operational evaluation as well as for surrogate safety assessment. PTV VISSIM was chosen as the tool to model the proposed designs because VISSIM can realistically model various traffic patterns with detailed geometric features and drivers’ behavioral characteristics (Fan et al., 2013). VISSIM models also provide detailed vehicle trajectory data that may be used directly with SSAM. This chapter describes the steps to build the simulation models to evaluate the LSPTTL alternatives identified in the ConOps by Caltrans District 5.

Simulation Modeling Process

Successfully using a microscopic simulation model, which is a mathematical representation of real-world traffic models, requires understanding its operations and input data. Lieberman and Rathi (Lieberman & Rathi, 1997) suggested the following process to build and apply traffic simulation models:

- Define the problem and model objectives.
- Define the system to be studied.
- Develop the model.
- Calibrate the model.
- Verify the model.
- Validate the model.
Liu et al. (Liu et al., 2020) used these steps to simulate the multimodal network for downtown San Jose. The first step includes stating the model's purpose and identifying the information desired from the model such as travel time, travel volume, queue lengths, and vehicle trajectory data output. For this study, the scope of the problem was defined based on the ConOps provided by stakeholders at Caltrans District 5.

The second step is to identify the geographical boundary of the physical area being modeled, along with any associated data, including highway geometrics, peak hour factor (PHF), volumes, and speed data. The physical boundary of the simulation model was specified in the ConOps, and the relevant data were obtained from Caltrans.

The third step, model development, identifies the type of model that should be used depending on the level of complexity needed to satisfy the study objectives. Calibration criteria and a logical structure for integrating model components (such as street network and traffic controls) are established. Towards that end, a baseline VISSIM model for the study area previously used by Caltrans staff was obtained.

The fourth step is to calibrate the model. The real-world data needed for calibration includes satellite imagery, vehicle composition, speeds, and traffic demand. This step also entails adjusting simulation factors such as perception time, headway allocations, and driver behavior parameters to ensure that the model is accurately calibrated for real-world conditions.

The fifth step, verification of the model, includes a visual check to monitor any unrealistic and unusual network behavior. If such unusual behavior is observed, it is recommended to go back to step four, model calibration.

The sixth step is to validate the model by collecting, reducing, and organizing data from the model to compare it to actual data. At this step, the Geoffrey E. Havers (GEH) statistic is used to ascertain whether the model describes the real system at an acceptable level of accuracy. The three steps of calibration, verification, and validation are often iterative and go along with each other. These six steps provide a validated microsimulation model for the base conditions.

With a validated model for the base conditions, the base model for US 101 would be ready to evaluate the LSPTTL design strategies outlined in the ConOps.

Road Network and Required Data

PTV VISSIM has built-in maps with to-scale satellite imagery, which can be used to trace desired transportation networks. In PTV VISSIM, links are used to model street segments, while connectors are used to join links with each other. Specific lane geometries were verified through satellite images and street views in Google Maps, especially for merge and diverge areas. The
relative proportion of cars and heavy goods vehicles (HGV), i.e., trucks, were included based on the data available from Caltrans.

To create an accurate existing baseline PM-peak traffic model, i.e., the time of day when the LSPTTL is expected to be in operation, the 2018 traffic count data from Caltrans were used. Note that we used 2018 data since that was the base year used by Caltrans District 5 for project planning. The traffic count data also provide the percentage of heavy vehicles in the traffic mix. The travel demand data collected by Caltrans on 4/18/2018 and 4/19/2018 (Wednesday and Thursday, respectively) was used to build the model. Note that using peak hour data from mid-week days allowed us to capture typical prevailing traffic conditions. The complete base data used in calibrating the VISSIM model are shown in Appendix A. Note that the travel demand growth factors based on SLOCOG’s projected growth in the region are applied to the 2018 data (Regional Growth Forecasts | SLOCOG, n.d.) for future scenario evaluation. The Appendix with the projected 2026 volumes used in the model shows the growth factors used.

**Base Model Validation**

A validated network justifies the simulation’s usage for evaluating future scenarios for the same network (Liu et al., 2020). The validation process compared output data from multiple runs of the well-calibrated simulated network to the traffic volume observed in the real world (i.e., 2018 data). This process required estimation of the GEH statistic (Balakrishna et al., 2007) discussed later in this section. Estimated GEH statistics for the base model (i.e., the model for 2018 network traffic conditions) indicated that the network represented real world conditions reasonably well.

Similar to our approach in one of the past studies led by the PI (Liu et al., 2020), the base network for this project was validated based on ten simulation runs. Validation of the base model requires multiple simulation model runs using different seed numbers (Liu et al., 2020). Random seed numbers in PTV VISSIM affect the values of the driver behavior and input traffic volume generators. Seed values influence the arrival times of vehicles in the networks and stochastic variability of the driving behaviors, allowing for the accommodation of random variations in traffic patterns at the same location (Vision, 2013). Simulating with the same seed number would produce identical outputs for volumes, speeds, queue lengths, and travel times at any given network location. Changing the seed number would output differing results based on the actual values of the driving behavior parameters derived from the specified distribution for these parameters.

**GEH Statistics**

The GEH Statistic is a formula commonly used in transportation analysis to compare two sets of traffic volumes. The formula is defined by Equation 1. The empirically measured GEH Statistic was used to compare field counts obtained in 2018 to simulation turning volumes.
\[
GEH = \sqrt{\frac{2(M-C)^2}{M+C}}
\]

\(M\): Traffic volume from the simulation model

\(C\): Traffic volume observed in the real world

The GEH Statistic is preferred because it avoids the pitfalls of using simple percentages. For example, the US 101 corridor modeled in this study has both mainline freeway segments and ramp segments. The amount of traffic carried by these two classes of segments varies widely. Therefore, it would not be appropriate to use the same percentage threshold to determine if the flows are accurately modeled on both these classes of segments. The formulation for GEH statistic (See Equation 1) addresses this issue and allows the use of use a single acceptance threshold for all for links even when various links have a wide variation in traffic flows (Protocol for VISSIM Simulation, n.d.).

<table>
<thead>
<tr>
<th>Ramp or Freeway Mainline Location</th>
<th>Post Mileage (Miles)</th>
<th>VISSIM Results (vehicles per hour) (Average of multiple simulation runs; M in Equation 1)</th>
<th>2018 Real-world volumes (vehicles per hour; C in Equation 1)</th>
<th>GEH Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avila Beach Off-ramp</td>
<td>21.28</td>
<td>562</td>
<td>478</td>
<td>3.67</td>
</tr>
<tr>
<td>Spyglass Off-ramp</td>
<td>19.97</td>
<td>587</td>
<td>567</td>
<td>0.83</td>
</tr>
<tr>
<td>Price St Off-ramp</td>
<td>17.66</td>
<td>287</td>
<td>253</td>
<td>2.04</td>
</tr>
<tr>
<td>SR-1 Off-ramp</td>
<td>17.24</td>
<td>662</td>
<td>634</td>
<td>1.12</td>
</tr>
<tr>
<td>Hinds Off-ramp</td>
<td>16.72</td>
<td>292</td>
<td>258</td>
<td>2.04</td>
</tr>
<tr>
<td>Price St to Five Cities</td>
<td>16.11</td>
<td>2657</td>
<td>2622</td>
<td>0.67</td>
</tr>
<tr>
<td>Subsection 11 (Mainline)</td>
<td>17.7</td>
<td>10727</td>
<td>10137</td>
<td>5.78</td>
</tr>
<tr>
<td>Subsection 21 (Mainline)</td>
<td>Upstream of 16.6</td>
<td>13268</td>
<td>12658</td>
<td>5.36</td>
</tr>
</tbody>
</table>
Data collected from model runs using ten different seed numbers were averaged and used to calculate the GEH statistic for traffic volume on off-ramps and mainline segments. These statistics are shown in Table 2. The GEH statistic is helpful in comparing real-world and simulated traffic volumes because the formula does not follow a linear pattern, thereby avoiding common pitfalls witnessed in using simple percentage comparisons (Kilbert, 2011). According to the Washington State DOT protocol for VISSIM simulation, a GEH of less than 5.0 is an excellent match between the modeled and observed volumes. The measurements with GEHs in the 5.0–10.0 range are acceptable, while those with GEHs greater than 10.0 have a high probability of error (Protocol for VISSIM Simulation, n.d.). With all GEH statistics shown in Table 2 being less than 6.0 and only two above 5.0, these values meet the validation criteria defined based on the Washington State Department of Transportation (WSDOT) guidelines.

After calibrating and validating the existing condition baseline model, the LSPTTL design alternatives documented by Caltrans District 5 were implemented in PTV VISSIM.

**Final Road User Behavior Parameters**

Figure 5 shows a screenshot of the final parameter set relevant to car-following used in the PTV VISSIM model for the mainline freeway segments for US 101. Note that this set of parameters is the result of the iterative calibration, verification, and validation process (described in the previous section). Each of the parameters shown in Figure 5 below represents the central tendency or the average value for that parameter's distribution. Each agent (i.e., vehicle) in the simulation environment gets a value from the distribution assigned to it, and that assigned value controls its behavior. Furthermore, these parameter sets can help future researchers replicate this study's findings. A complete set of parameters that include all link types (mainline, on ramps, and off ramps), as well as for both critical behavior types (car-following and lane change), are provided in Appendix B.
3.2 Alternative Design Scenarios

The validated network is used to then evaluate the following design alternatives California Department of Transportation (Caltrans) District 5 included in the ConOps for the LSPTTL corridor.

- **Alternative 1A** (Alternative 1 Variation 1 in Figure 6) involves the beginning of LSPTTL at post mile R20.4 on the US 101 Southbound corridor in San Luis Obispo County. The existing outside lane, a Truck Climbing Lane (TCL), remains unchanged in this scenario and is dropped approximately at post mile R20.3.

- **Alternative 1B** is a variation for Alternative 1 (Variation 2 shown in Figure 6), in which the TCL is extended past Exit 193, as shown in Figure 6. The LSPTTL still begins at post mile R20.4.

- **Alternative 2** involves LSPTTL beginning upstream at post mile R21.5 near Avila Beach Drive. In this scenario, the TCL that currently exists on the corridor will be converted to become a general-purpose lane on the outside.
Note that for all alternatives, the LSPTTL extends to post mile 16.2. Hence, Alternative 2 involves the most extended segment having a shoulder travel lane.

As part of this proposed research effort, we used microscopic traffic simulation models for each of the three alternatives shown in Figure 6 to study the interaction of LSPTTL design options with the existing truck climbing lane. Surrogate safety and operational measures were derived from the simulation models using those modes for each of the three proposed alternatives. For the operational measures, the VISSIM model can provide the average travel time for the through traffic as well as for each on-ramp to off-ramp O-D (Origin-Destination) pair in the project section. Table 3 shows the list of data collection locations for operational measurements. As discussed in the previous chapter, surrogate measures of safety are indirect measures that reflect the crash experience of a facility. By using the vehicle trajectory files from VISSIM, SSAM can analyze the time-to-collision (TTC) threshold to identify the number and type of simulated conflicts between vehicles. Surrogate safety measures analyzed include a few more conflict measures listed in Table 1 in the previous chapter.
Table 3. Operational Measurements Locations

<table>
<thead>
<tr>
<th>Measurement #</th>
<th>Name</th>
<th>Measurement #</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>US101-S PM 24.35</td>
<td>20</td>
<td>Price St. offramp</td>
</tr>
<tr>
<td>2</td>
<td>Higuera St. offramp</td>
<td>21</td>
<td>US101-S PM 17.52</td>
</tr>
<tr>
<td>3</td>
<td>US101-S PM 24.13</td>
<td>22</td>
<td>Hind St. offramp</td>
</tr>
<tr>
<td>4</td>
<td>Higuera St. onRamp</td>
<td>23</td>
<td>US101-S PM 16.86</td>
</tr>
<tr>
<td>5</td>
<td>US101-S PM 23.86</td>
<td>24</td>
<td>Hind Ave offramp</td>
</tr>
<tr>
<td>6</td>
<td>San Luis Bay Dr. offramp</td>
<td>25</td>
<td>US101-S PM 16.54</td>
</tr>
<tr>
<td>7</td>
<td>US101-S PM 22.42</td>
<td>26</td>
<td>Price St. SB onramp</td>
</tr>
<tr>
<td>8</td>
<td>San Luis Bay Dr. onramp</td>
<td>27</td>
<td>US101-S PM 16.2</td>
</tr>
<tr>
<td>9</td>
<td>US101-S PM 21.85</td>
<td>28</td>
<td>5 Cities Dr offramp</td>
</tr>
<tr>
<td>10</td>
<td>Avila Beach Dr. offramp</td>
<td>29</td>
<td>US101-S PM 15.9</td>
</tr>
<tr>
<td>11</td>
<td>US101-S PM 22.42</td>
<td>30</td>
<td>5 Cities Dr onramp</td>
</tr>
<tr>
<td>12</td>
<td>Avila Beach Dr. onramp</td>
<td>31</td>
<td>US101-S PM 15.67</td>
</tr>
<tr>
<td>13</td>
<td>Spyglass offramp</td>
<td>32</td>
<td>4th St. onramp</td>
</tr>
<tr>
<td>14</td>
<td>Spyglass onramp</td>
<td>33</td>
<td>US101-S PM 15.42</td>
</tr>
<tr>
<td>15</td>
<td>US101-S PM 19.81</td>
<td>34</td>
<td>El Camino Real onramp</td>
</tr>
<tr>
<td>16</td>
<td>Spyglass onramp</td>
<td>35</td>
<td>US101-S PM 15.21</td>
</tr>
<tr>
<td>17</td>
<td>US101-S PM 19.06</td>
<td>36</td>
<td>N12th St. offramp</td>
</tr>
<tr>
<td>18</td>
<td>Price St. onramp</td>
<td>37</td>
<td>US101-S PM 14.80</td>
</tr>
<tr>
<td>19</td>
<td>US101-S PM 18.00</td>
<td>38</td>
<td>N12th St. onramp</td>
</tr>
</tbody>
</table>

Operational Analysis

For operational analysis, the maximum queue delay and travel times for the through traffic on Southbound US 101 during PM peak hours were the measures of performance (MOP). Table 4 shows the maximum queue delay along with its time and location of occurrence. Note that these measures are all averaged over ten simulation runs. Based on Table 4, the maximum queue for all alternative designs occurred at US101-S at PM 15.21 between El Camino Real on-ramp and N12th St. off-ramp from 17:45 to 18:00. Alternative 1A has the lowest max queue delay of 49.96 seconds. Alternative 2 recorded 2.68 seconds higher on the max queue delay. Based on our discussions with the stakeholders, this additional 2.68 second queue delay for Alternative 2 is not a cause of concern. Therefore, it can be concluded that there is no significant difference in max queue delays between the three alternatives. As a reminder, for details of each alternative, please refer to Figure 6.
Table 4. Maximum Queue Delay Results

<table>
<thead>
<tr>
<th></th>
<th>Alt 1A</th>
<th>Alt 1B</th>
<th>Alt 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Queue Delay (s)</td>
<td>49.96</td>
<td>51.16</td>
<td>52.64</td>
</tr>
<tr>
<td>Time Period of</td>
<td>17:45-18:00</td>
<td>17:45-18:00</td>
<td>17:45-18:00</td>
</tr>
<tr>
<td>Occurrence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location of</td>
<td>PM 15.21 (Location #35 in Table 3)</td>
<td>PM 15.21 (Location #35 in Table 3)</td>
<td>PM 15.21 (Location #35 in Table 3)</td>
</tr>
<tr>
<td>Occurrence</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average through traffic vehicle travel times for each alternative are shown in Table 5 and Figure 7 that shows the same results graphically. Although Alternative 2 has a relatively higher travel time for the through traffic than the other two alternatives, it is very close to Alternatives 1A and 1B.

Alternative 1A has the best operational performance based on the max queue delay and travel time. Based on our discussion with the stakeholders, the differences between them are minor in terms of traffic operation performance measures. Therefore, we conclude that either of the three alternative designs would be acceptable for the section, given no material difference in the operational results.
Table 5. Through Traffic Travel Time Results

<table>
<thead>
<tr>
<th>Through Traffic Travel Time(s)</th>
<th>Alt 1A</th>
<th>Alt 1B</th>
<th>Alt 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:30-2:45</td>
<td>467.32</td>
<td>464.42</td>
<td>471.79</td>
</tr>
<tr>
<td>2:45-3:00</td>
<td>468.06</td>
<td>466.02</td>
<td>474.64</td>
</tr>
<tr>
<td>3:00-3:15</td>
<td>471.31</td>
<td>463.98</td>
<td>473.48</td>
</tr>
<tr>
<td>3:15-3:30</td>
<td>476.03</td>
<td>473.63</td>
<td>479.76</td>
</tr>
<tr>
<td>3:30-3:45</td>
<td>492.08</td>
<td>492.61</td>
<td>489.89</td>
</tr>
<tr>
<td>3:45-4:00</td>
<td>502.05</td>
<td>502.57</td>
<td>499.85</td>
</tr>
<tr>
<td>4:00-4:15</td>
<td>509.31</td>
<td>504.16</td>
<td>502.30</td>
</tr>
<tr>
<td>4:15-4:30</td>
<td>520.69</td>
<td>518.93</td>
<td>517.14</td>
</tr>
<tr>
<td>4:30-4:45</td>
<td>538.80</td>
<td>534.71</td>
<td>545.35</td>
</tr>
<tr>
<td>4:45-5:00</td>
<td>584.58</td>
<td>581.24</td>
<td>588.39</td>
</tr>
<tr>
<td>5:00-5:15</td>
<td>603.56</td>
<td>597.35</td>
<td>608.43</td>
</tr>
<tr>
<td>5:15-5:30</td>
<td>629.89</td>
<td>625.07</td>
<td>636.60</td>
</tr>
<tr>
<td>5:30-5:45</td>
<td>572.88</td>
<td>570.68</td>
<td>584.03</td>
</tr>
<tr>
<td>5:45-6:00</td>
<td>432.56</td>
<td>430.01</td>
<td>436.89</td>
</tr>
<tr>
<td>6:00-6:15</td>
<td>433.43</td>
<td>429.61</td>
<td>437.40</td>
</tr>
<tr>
<td>6:15-6:30</td>
<td>430.27</td>
<td>427.73</td>
<td>436.01</td>
</tr>
</tbody>
</table>
Surrogate Safety Analysis

For surrogate analysis, vehicle trajectory information from each of the simulation scenarios was used in SSAM to identify the number and type of simulated conflicts and surrogate measurements for each alternative. Tables 6 and 7 show the results from SSAM based on surrogate safety measures. Table 6 shows the averages for three surrogate safety measures: TTC, PET, and DR. Table 7 shows the total number of conflict events based on a TTC threshold of 1.5 seconds and a PET threshold of 5.0 seconds. These thresholds are used based on the SSAM user manual and other relevant research (Gettman, D. et al., 2008; Pu & Joshi, 2008).

Table 6. Surrogate Measurement Averages

<table>
<thead>
<tr>
<th>SSAM_Measure</th>
<th>Alt 1A</th>
<th>Alt 1B</th>
<th>Alt 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTC(s)</td>
<td>0.77</td>
<td>0.73</td>
<td>0.77</td>
</tr>
<tr>
<td>PET(s)</td>
<td>1.21</td>
<td>1.14</td>
<td>1.20</td>
</tr>
<tr>
<td>DR(m/s²)</td>
<td>-2.04</td>
<td>-1.92</td>
<td>-2.01</td>
</tr>
</tbody>
</table>
Table 7. Number of Conflicts Based on Thresholds in Surrogate Safety Measures’ Measurement Averages

<table>
<thead>
<tr>
<th>Conflict Type</th>
<th>Alt 1A</th>
<th>Alt 1B</th>
<th>Alt 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>7577</td>
<td>8108</td>
<td>7441</td>
</tr>
<tr>
<td>Crossing conflicts</td>
<td>428</td>
<td>438</td>
<td>452</td>
</tr>
<tr>
<td>Rear-end conflicts</td>
<td>5848</td>
<td>6408</td>
<td>5877</td>
</tr>
<tr>
<td>Lane-change conflicts</td>
<td>1301</td>
<td>1262</td>
<td>1112</td>
</tr>
</tbody>
</table>

Table 7 shows Alternative 2 would be the safest, based on the fewest total conflicts. Alternative 2 has significantly lower lane change conflict compared to Alternative 1A and 1B. A potential explanation is that traffic from the Avila Beach Dr. on-ramp causes extra lane-change conflicts. The other possible reason is Alternative 1 has the extra truck climb lane causing the additional weaving effects upstream of the Spyglass off-ramp. Therefore, Alternative 2 should be chosen based on the surrogate safety analysis.

3.3 Conclusions

Microscopic simulation analysis revealed that while there was no significant difference between the three scenarios in terms of operational measures of performance, Alternative 2 (see Figure 6) provided superior performance in terms of safety with the fewest conflicts as measured by the SSAM analysis. Therefore, the research team recommends that Alternative 2 should be chosen for LSPTTL implementation on the US 101 SB corridor. Furthermore, since simulation modeling is typically carried out by agencies when evaluating ITS technology deployment, surrogate safety analysis using SSAM should be conducted in addition to operational analysis. Surrogate safety analysis can help differentiate between options with similar operational performance.
4. The TMC Staff Training Framework

4.1 Overview

Cal Poly San Luis Obispo maintains a Transportation Management Center (TMC) Simulator for use by Caltrans for training purposes. This simulator provides a realistic facsimile of a Caltrans district TMC and allows personnel an interactive, hands-on training environment to practice techniques learned from traditional training materials. Figure 8 shows an image from the Cal Poly TMC simulator, while Figure 9 shows a real-world TMC. This training facility at Cal Poly is primarily used as part of TMC Academy training for Caltrans and California Highway Patrol (CHP) personnel, funded by Caltrans. One of the objectives of this research was to leverage the TMC academy facility to develop a training module for TMC operators designed explicitly for managing LSPTTL operations.

This chapter first reviews the existing TMC personnel training practices adopted by agencies throughout the country for managing the use of shoulders as a travel lane. As noted at the conclusion of Chapter 2, given the sparse documentation of such training, this review is based on outreach to individual agencies that have implemented or plan on implementing PTSU. Based on this outreach to state agencies and documentation from the FHWA, a checklist for planning and operations is provided for LSPTTL implementation. Elements of the training module and associated coursework are then described for assisting TMC operators with the management of the left shoulder as a part-time travel lane for all vehicles. The training module provides TMC operators with an overview of the usage and management of the LSPTTL as part of normal (and emergency) operations, as well as potential impediments to usage.

Figure 8. TMC Simulator during one of the trainings at Cal Poly San Luis Obispo
As a first step, we reached out to the managing agencies of existing/planned PTSU projects. Note that, among these agencies, only Colorado and Minnesota use the left shoulder as a travel lane. This is consistent with the FHWA documentation, which noted that right shoulder use as a part-time travel lane is more common because the shoulder on the right is usually wider than the one on the left (Jenior et al., 2016). Agency experience of those using the right shoulder was still deemed relevant for this research since the role of TMC operators is similar for both left and right shoulder use.
Table 8. Agencies Implementing Part-Time Shoulder Use Projects

<table>
<thead>
<tr>
<th>Agency</th>
<th>Program/Manager Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSDOT</td>
<td>I-405 Program Administrator</td>
</tr>
<tr>
<td>MnDOT</td>
<td>RTMC Director of Operations, I-35W</td>
</tr>
<tr>
<td>CDOT (Colorado)</td>
<td>Operations Manager and Traffic Engineer, I-70 Shoulder Project District 1</td>
</tr>
<tr>
<td>VDOT (Virginia)</td>
<td>Manager for Central District, I-496, I-66</td>
</tr>
<tr>
<td>GDOT</td>
<td>Operations District 7, GA 400</td>
</tr>
<tr>
<td>NJDOT</td>
<td>Route 1, Shoulder Running</td>
</tr>
<tr>
<td>MDOT (Michigan)</td>
<td>Liaison for Traffic Operations for US-23 Flex Route</td>
</tr>
<tr>
<td>ODOT (Ohio)</td>
<td>I-670 SmartLANE</td>
</tr>
<tr>
<td>WisDOT</td>
<td>US-12 Flexlane (Madison Beltline), Not Yet Completed</td>
</tr>
</tbody>
</table>

The existing and planned PTSU project information was collected from multiple sources via Internet search and is synthesized in Table 8. Readers looking for contact information for specific personnel leading/managing these projects are encouraged to reach out to the PI. In discussions with the agency personnel in conjunction with the guidance provided by the FHWA (Jenior et al., 2019), the following conclusions were drawn regarding the role of TMC operators during the routine operations of LSPTTL:

- Opening or closing a shoulder as a *fully* automated process is neither implemented nor recommended.

- Human TMC operators need to ultimately decide whether to open or close a shoulder.

- Although expert systems can be used for sweeping before opening the shoulder as a travel lane, it is still necessary to have incident response vehicles on standby to clear debris or disabled vehicles if needed.

Since the FCMTNEP and LSPTTL are still a few years from implementation, the following items on the planning checklist should be of interest to Caltrans District 5, SLOCOG (San Luis Obispo
Council of Governments), and CHP. These three agencies collaborate for smooth traffic operations on the study area corridor:

- Appropriate interagency agreement(s) that define the roles and responsibilities of each agency.

- Avoid introducing too much variability, especially in the opening time of the part-time travel lane. Extending open times is more acceptable than changing the opening time in either direction (i.e., sooner or later).

- Parts of the process for opening and closing the part-time travel lane may be automated even if part-time shoulder use is static (as opposed to dynamic, where decisions are subject to the traffic conditions being observed). Any introduction of automation requires sufficient ITS infrastructure (e.g., CCTV) to be in place. It should be noted that full automation without a human operator in the loop is not recommended.

More relevant for the development of TMC operator training exercises, the operational initiation checklist for routine and emergency operations of LSPTTL includes:

- A shoulder should be inspected in its entirety before each opening by "sweeping" (driving) the length of the facility or viewing CCTV.

- Any debris or disabled vehicles should be cleared before the scheduled opening time of the shoulder.

If an incident occurs while the shoulder lane is open and the shoulder becomes blocked, then the shoulder should be closed as soon as possible (automated opening/closing may be utilized).

4.2 Lesson Plan and Learning Objectives

Based on the lessons from other state DOT personnel and the key challenges for the part-time use of the shoulder as a travel lane operation, we formulated the following learning objectives for the TMC operator training:

- Become familiar with the checklist to initiate and conclude the operation of LSPTTL.

- Become familiar with any applicable interagency agreements.

- Utilize information from manual and/or electronic sweeps to go through the checklist for specific scenarios.

- Decide to extend the LSPTTL using real-time data and ITS infrastructure for specific scenarios.
The training program to achieve these learning objectives would include the following activities:

- A 45-minute "lecture" based on lessons from other DOTs and our past TMC training experience as in the TMC academy (Sullivan et al., 2004).
- 60 to 90-minute "hands-on" sessions focused on key scenarios identified based on the feedback from Caltrans District 5 staff.

The process of developing hands-on training is described in the next section and how to achieve these learning objectives is described in the next section.

4.3 Development of a Hands-on Training Environment

The steps to create hands-on training include:

1. Develop functional training scenarios from provided operation scenarios.
2. Develop a simulated highway network.
3. Prototype scripts.
4. Develop the training environment.

Develop Functional Scenarios

During the planning phase of the LSPTTL project, Caltrans District 5 developed a ConOps to establish policies and procedures for the safe operation of the LSPTTL. This document identified common operational scenarios to help guide decision-making processes during normal operating modes and during abnormal conditions. These identified operational scenarios for abnormal conditions cover both incident and inclement weather operations and are listed as follows:

- Left shoulder blocked ahead of peak hour.
- #2 Travel lane blocked in off-peak.
- Increased demand (weekend/tourist season).
- Part-time lane blocked during peak hour.
- Weather-related incident.

In order to be utilized in a simulated training environment, these operational scenarios (in addition to the normal daily operating conditions) were converted to functional scenarios for use as part of
training. This process involved "storyboarding" the conditions identified under a specific scenario, outlining simulated environment interactions within the TMC Simulator, and potential communications and notifications between students (i.e., TMC operators being trained) and simulated third parties such as allied agencies and/or the public. The instructor teams typically play the role of these simulated third parties. This storyboarding process also identifies the simulated tools to be utilized within a particular scenario and potential student interactions with them.

Develop a Simulated Highway Network

The next step was to develop the highway network of interest. The existing Caltrans CCTV camera infrastructure shown in Figure 10 is used. Note that the training network is larger than the network simulated in VISSIM for evaluating design alternatives. This larger area simulation is required to ensure realism in the options available to the TMC operators for managing and diverting traffic as needed. Note that Figure 10 shows the map from the Caltrans Performance Measurement System (PeMS; https://pems.dot.ca.gov/). Figure 11 shows the facsimile of the system as simulated in the TMC simulator.

Figure 10. Existing Caltrans CCTV Infrastructure
Note that the VISSIM model used in the previous chapter for operational and safety evaluation provided input to the TMC Simulator traffic model, and scripted simulator traffic input was used based on the requirement of each scenario.

Prototype Scripts

The Cal Poly TMC Simulator is controlled and managed using a custom-developed management tool—the Simulation Manager (see Figure 12). This application drives all aspects of the simulated environment and directs the training based upon a predetermined script loaded into the application at the beginning of a training session. This XML-based script describes all interactions within the loaded scenario, including vehicular traffic within the simulated roadway environment, events generated and visible within the simulated tools, and prompts for expected student-instructor interactions. These interactions include scenarios where instructional team members work as simulated third parties. The interface for the script builder tool is shown in Figure 13.
Figure 12. TMC Simulator Manager GUI (graphical user interface)

Figure 13. TMC Simulator Script Builder Tool
The functional scenarios and associated storyboarding are utilized in the creation of the XML scripts for each scenario (see Figure 14 for an example script). The script includes microscale traffic modeling inputs for roadway conditions, network and roadway layout, including lane speed and occupancy sensor points, prompts for highway traffic loading, and scripted events for associated tools such as CHP VisiCAD, Caltrans TMCAD, and the Caltrans Lane Closure System. The script also includes instructor prompts for expected student interactions to assist instructors during the simulator session.

Figure 14. XML Script Governing the Simulated Training Scenario

Training Environment Workflow

The last step is to combine the work from the previous three steps into the hands-on training environment. An example workflow for routine opening and closing of the LSPTTL on the US 101 SB corridor appears below:

- Trainee operator commences lane-open procedures.
- Trainee directs the instructor posing as FSP (freeway service patrol) to inspect the lane before opening.
- FSP confirms clear and ready.
Trainee initiates activation of lane-use control signage (simulated).

Trainee confirms operation with FSP.

Trainee operator initiates lane-closure procedures.

Trainee deactivates lane-use Control signage.

Trainee confirms closure with FSP.

At the conclusion of this research project, the detailed workflow for all functional scenarios was shared with the stakeholders at Caltrans District 5. Their feedback will be incorporated into the training modules for the TMC staff when the Five Cities project is functional (expected to be by the year 2027). We will also explore the possibility of incorporating the training into Cal Poly’s existing TMC Academy project with Caltrans.

4.4 Future Refinements

The training module development for this project was based on existing CCTV installations. According to the System Architecture Plan in the ConOps, Caltrans plans to have 19 CCTVs with AI analytics capabilities. For example, an AI-capable CCTV will accompany each lane-use control signal. Furthermore, per California MUTCD guidance (Chapter 4M), each lane-use control signal cannot be spaced more than 2,300 feet, apart from each other and the drivers must be able to see at least one signal indication at all times as they drive through the part-time lane (California, 2021a). As the specific locations for the CCTV camera are finalized for FCMTNEP, the training module may be easily modified to incorporate those locations within the Cal Poly TMC simulator. The video data from those AI-capable CCTVs would also add to the realism of the training simulator.

Caltrans is also in the process of enhancing the System Engineering Management Plan (SEMP), and the plan is in the "final approval for dissemination" phase. Once the SEMP is released, we can ensure that the TMC simulator is fully compliant and mimics the capabilities of the new systems.
5. Summary & Conclusions

This research report described the process for evaluating LSPTTL design alternatives to be implemented as part of a larger multimodal congestion relief project along with the training module development for TMC operators responsible for the day-to-day operation of the part-time travel lane on the left shoulder.

The study showed the effectiveness of a microsimulation-based approach in evaluating design alternatives for operational measures (e.g., travel time or maximum queue lengths) and safety. The safety evaluation of the alternatives is based on surrogate safety measures and requires analysis of vehicle trajectory data generated by the PTV-VISSIM microsimulation model through the SSAM.

Most agencies, including Caltrans, use microsimulation for assessing the benefits of future ITS projects. The approach presented here is viable for operational and safety evaluation of future part-time shoulder use projects.

5.1 Training Module Development

The study found that the training provided to TMC operators specifically to operate part-time use of the shoulder as a travel lane is not well-documented in the publicly available or published sources. The research team conducted significant outreach to agencies with PTSU implementation experience prior to developing the training module and used the information gathered through the outreach to inform the learning objectives for the TMC operator training module.

The learning objectives for the training would be achieved through the following elements of the modules: (1) A 45-60 minute discussion on lessons learned from other agencies nationwide and past emergency response training conducted by the research team for TMC staff. (2) A hands-on training session conducted using the TMC simulator housed at Cal Poly, replicating the study corridor’s real-world conditions.

These elements are also informed by the traffic simulation models developed as part of this research to introduce realism regarding traffic conditions observed by the TMC operators.

5.2 Future Scope

The research has shown the viability of conducting safety and operational evaluation of alternatives using a microsimulation-based approach. For the training module, there is room for improvement. As the project gets closer to implementation and the details are finalized, those details can be more precisely replicated in the hands-on element of the training module. These precise details include,
e.g., lane-use signage placement and the use of CCTV footage to further improve the realism. The training module developed as part of this research will serve as the starting point for training the staff prior to the planned operation of the LSPTTL as part of the larger FCMTNEP being implemented by Caltrans District 5.
## Appendix A: Traffic Data and Growth Factors for Calibration and Validation

Traffic Volume data from Wednesday, 4/18/2018

<table>
<thead>
<tr>
<th>Time</th>
<th>SB No Build PM</th>
<th>SB No Build PM</th>
<th>SB No Build PM</th>
<th>SB No Build PM</th>
<th>SB No Build PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:45 PM</td>
<td>727</td>
<td>51</td>
<td>799</td>
<td>42</td>
<td>750</td>
</tr>
<tr>
<td>6:00 PM</td>
<td>671</td>
<td>31</td>
<td>680</td>
<td>14</td>
<td>601</td>
</tr>
<tr>
<td>5:30 PM</td>
<td>708</td>
<td>28</td>
<td>786</td>
<td>59</td>
<td>835</td>
</tr>
<tr>
<td>5:00 PM</td>
<td>833</td>
<td>58</td>
<td>884</td>
<td>63</td>
<td>983</td>
</tr>
<tr>
<td>4:45 PM</td>
<td>778</td>
<td>86</td>
<td>782</td>
<td>72</td>
<td>825</td>
</tr>
<tr>
<td>4:30 PM</td>
<td>718</td>
<td>24</td>
<td>748</td>
<td>61</td>
<td>775</td>
</tr>
<tr>
<td>3:45 PM</td>
<td>745</td>
<td>91</td>
<td>783</td>
<td>37</td>
<td>886</td>
</tr>
<tr>
<td>3:30 PM</td>
<td>770</td>
<td>56</td>
<td>790</td>
<td>54</td>
<td>881</td>
</tr>
<tr>
<td>3:00 PM</td>
<td>153</td>
<td>23</td>
<td>690</td>
<td>108</td>
<td>799</td>
</tr>
<tr>
<td>2:30 PM</td>
<td>617</td>
<td>38</td>
<td>661</td>
<td>56</td>
<td>752</td>
</tr>
<tr>
<td>2:00 PM</td>
<td>457</td>
<td>24</td>
<td>640</td>
<td>85</td>
<td>740</td>
</tr>
<tr>
<td>1:30 PM</td>
<td>600</td>
<td>32</td>
<td>647</td>
<td>77</td>
<td>740</td>
</tr>
<tr>
<td>1:00 PM</td>
<td>443</td>
<td>24</td>
<td>652</td>
<td>81</td>
<td>740</td>
</tr>
<tr>
<td>0:30 PM</td>
<td>607</td>
<td>25</td>
<td>653</td>
<td>86</td>
<td>745</td>
</tr>
<tr>
<td>0:00 PM</td>
<td>398</td>
<td>28</td>
<td>655</td>
<td>90</td>
<td>749</td>
</tr>
<tr>
<td>11:30 PM</td>
<td>337</td>
<td>15</td>
<td>658</td>
<td>95</td>
<td>752</td>
</tr>
<tr>
<td>10:30 PM</td>
<td>341</td>
<td>17</td>
<td>659</td>
<td>98</td>
<td>752</td>
</tr>
<tr>
<td>9:30 PM</td>
<td>341</td>
<td>17</td>
<td>660</td>
<td>98</td>
<td>752</td>
</tr>
<tr>
<td>8:30 PM</td>
<td>341</td>
<td>17</td>
<td>660</td>
<td>98</td>
<td>752</td>
</tr>
<tr>
<td>7:30 PM</td>
<td>341</td>
<td>17</td>
<td>660</td>
<td>98</td>
<td>752</td>
</tr>
<tr>
<td>6:30 PM</td>
<td>341</td>
<td>17</td>
<td>660</td>
<td>98</td>
<td>752</td>
</tr>
</tbody>
</table>

**Mineta Transportation Institute**

38
<table>
<thead>
<tr>
<th>Sub-Section</th>
<th>Name</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Section</td>
<td>Length</td>
<td>Total</td>
<td>No</td>
<td>Avail</td>
<td>Beach</td>
<td>South</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td>Price</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>--------</td>
<td>-------</td>
<td>----</td>
<td>-------</td>
<td>--------</td>
<td>--------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>SB No Build</td>
<td>Build</td>
<td>6:45PM</td>
<td>5:45PM</td>
<td>5:30PM</td>
<td>5:00PM</td>
<td>4:45PM</td>
<td>4:30PM</td>
<td>4:00PM</td>
<td>3:45PM</td>
<td>3:30PM</td>
<td>3:00PM</td>
<td>2:45PM</td>
<td>2:30PM</td>
<td>2:00PM</td>
<td>1:45PM</td>
<td>1:30PM</td>
<td>1:00PM</td>
<td>0:45PM</td>
<td>0:30PM</td>
<td>0:00PM</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>--------</td>
<td>-------</td>
<td>----</td>
<td>-------</td>
<td>--------</td>
<td>--------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Traffic Volume data from Thursday, 4/19/2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Projected Traffic Volumes for 2026 and relevant SLOCOG growth factors (original counts based on Wednesday, 4/18/2018)

<table>
<thead>
<tr>
<th>Sub-Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub-Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MINETA TRANSPORTATION INSTITUTE

40
Projected Traffic Volumes for 2026 and relevant SLOCOG growth factors (original counts based on Thursday, 4/19/2018)

<table>
<thead>
<tr>
<th>Sub-Service</th>
<th>Name</th>
<th>North of Austin</th>
<th>Austin to Bee Cutoff</th>
<th>Bee Cutoff to Austin</th>
<th>South of Austin</th>
<th>Austin to Bee Cutoff</th>
<th>Bee Cutoff to Austin</th>
<th>South of Austin</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:00 PM</td>
<td></td>
<td>7.00%</td>
<td>7.00%</td>
<td>7.00%</td>
<td>7.00%</td>
<td>7.00%</td>
<td>7.00%</td>
<td>7.00%</td>
</tr>
<tr>
<td>3:00 PM</td>
<td></td>
<td>21.8</td>
<td>21.28</td>
<td>21.10</td>
<td>20.85</td>
<td>19.97</td>
<td>20.15</td>
<td>19.62</td>
</tr>
<tr>
<td>4:00 PM</td>
<td></td>
<td>21.8</td>
<td>21.28</td>
<td>21.10</td>
<td>20.85</td>
<td>19.97</td>
<td>20.15</td>
<td>19.62</td>
</tr>
<tr>
<td>5:00 PM</td>
<td></td>
<td>21.8</td>
<td>21.28</td>
<td>21.10</td>
<td>20.85</td>
<td>19.97</td>
<td>20.15</td>
<td>19.62</td>
</tr>
<tr>
<td>6:00 PM</td>
<td></td>
<td>21.8</td>
<td>21.28</td>
<td>21.10</td>
<td>20.85</td>
<td>19.97</td>
<td>20.15</td>
<td>19.62</td>
</tr>
</tbody>
</table>

M INETA TRANSPORTATION I NSTITUTE

41
### Appendix B: Behavioral Parameters for Microsimulation

<table>
<thead>
<tr>
<th>Mainline Freeway (Basic Following Behavior Modeling Parameters)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Driving Behavior</strong></td>
</tr>
<tr>
<td><strong>No.:</strong></td>
</tr>
<tr>
<td><strong>Name:</strong></td>
</tr>
</tbody>
</table>

#### Look ahead distance
- **Minimum:** 0.00 ft
- **Maximum:** 820.21 ft
- **Number of interaction objects:** 2
- **Number of interaction vehicles:** 99

#### Look back distance
- **Minimum:** 0.00 ft
- **Maximum:** 492.13 ft

#### Behavior during recovery from speed breakdown
- **Slow recovery**
  - **Speed:** 60.0%
  - **Acceleration:** 40.0%
  - **Safety distance:** 110.0%
  - **Distance:** 6562 ft

- **Standstill distance for static obstacles:** 1.64 ft
Mainline Freeway (Car-Following Behavior Modeling Parameters)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC0 (Standstill distance)</td>
<td>5.50 ft</td>
</tr>
<tr>
<td>CC1 (Gap time distribution)</td>
<td>40.15 s</td>
</tr>
<tr>
<td>CC2 ('Following' distance oscillation)</td>
<td>13.12 ft</td>
</tr>
<tr>
<td>CC3 (Threshold for entering 'Following')</td>
<td>-8.00</td>
</tr>
<tr>
<td>CC4 (Negative speed difference)</td>
<td>-0.35</td>
</tr>
<tr>
<td>CC5 (Positive speed difference)</td>
<td>0.35</td>
</tr>
<tr>
<td>CC6 (Distance dependency of oscillation)</td>
<td>11.44</td>
</tr>
<tr>
<td>CC7 (Oscillation acceleration)</td>
<td>0.82 ft/s²</td>
</tr>
<tr>
<td>CC8 (Acceleration from standstill)</td>
<td>11.48 ft/s²</td>
</tr>
<tr>
<td>CC9 (Acceleration at 50 mph)</td>
<td>4.92 ft/s²</td>
</tr>
</tbody>
</table>

Following behavior depending on the vehicle class of the leading vehicle:

<table>
<thead>
<tr>
<th>VehClass</th>
<th>W74ax</th>
<th>W74bxAdd</th>
<th>W74bxMult</th>
<th>W99cc0</th>
<th>W99cc1Distr</th>
<th>IncrsAccel</th>
</tr>
</thead>
</table>

Attribute: W99cc0: Standstill distance (Wiedemann 99)
Desired standstill distance between two vehicles depending on the vehicle class of the leading vehicle.
No stochastic variation.
Mainline Freeway (Lane-Change Behavior Modeling Parameters)
Freeway Ramps (Basic Following Behavior Parameters)

<table>
<thead>
<tr>
<th>Following</th>
<th>Car following model</th>
<th>Lane Change</th>
<th>Lateral</th>
<th>Signal Control</th>
<th>Autonomous Driving</th>
<th>Driver Errors</th>
<th>Meso</th>
</tr>
</thead>
<tbody>
<tr>
<td>Look ahead distance</td>
<td>Minimum: 0.00 ft</td>
<td>Maximum: 820.21 ft</td>
<td>Number of interaction objects: 4</td>
<td>Number of interaction vehicles: 99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Look back distance</td>
<td>Minimum: 0.00 ft</td>
<td>Maximum: 492.13 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Behavior during recovery from speed breakdown</td>
<td></td>
<td></td>
<td>Slow recovery</td>
<td>Speed: 60.0 %</td>
<td>Acceleration: 40.0 %</td>
<td>Safety distance: 110.0 %</td>
<td>Distance: 6562 ft</td>
</tr>
<tr>
<td>Standstill distance for static obstacles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.64 ft</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Freeway Ramps (Car-Following Behavior Modeling Parameters)

<table>
<thead>
<tr>
<th>Driving Behavior</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No: 1</td>
<td>Name: Urban (motorized)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Following Car following model</td>
<td>Lane Change</td>
<td>Lateral</td>
<td>Signal Control</td>
<td>Autonomous Driving</td>
<td>Driver Errors</td>
<td>Meso</td>
</tr>
<tr>
<td>Wiedemann 74</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average standstill distance:</td>
<td>6.56 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additive part of safety distance:</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiplicative part of safety distance:</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Following behavior depending on the vehicle class of the leading vehicle:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count: 0</td>
<td>VehClass</td>
<td>W74xx</td>
<td>W74bxAdd</td>
<td>W74bxMult</td>
<td>W99cc0</td>
<td>W99cc1Distr</td>
</tr>
</tbody>
</table>
| There are no elements in this list. You can add new elements through the context menu.
Driving Behavior

No.: 1  Name: Urban (motorized)

Following Car following model  Lane Change  Lateral  Signal Control  Autonomous Driving  Driver Errors  Meso

General behavior: Free lane selection

Necessary lane change (route):

<table>
<thead>
<tr>
<th>Own</th>
<th>Trailing vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum deceleration:</td>
<td>Maximum deceleration:</td>
</tr>
<tr>
<td>-13.12 ft/s²</td>
<td>-9.84 ft/s²</td>
</tr>
<tr>
<td>-1 ft/s² per distance:</td>
<td>100.00 ft</td>
</tr>
<tr>
<td>Accepted deceleration:</td>
<td>3.28 ft/s²</td>
</tr>
</tbody>
</table>

Waiting time before diffusion: 60.0 s
Min. clearance (front/rear): 1.64 ft
To slower lane if collision time is above: 11.0 s
Safety distance reduction factor: 0.60
Maximum deceleration for cooperative braking: -9.84 ft/s²
Overtake reduced speed areas
Advanced merging
Vehicle routing decisions look ahead

Max. speed difference: 6.71 mph
Max. collision time: 10.00 s

Rear correction of lateral position
Max. speed: 1.86 mph
Active during time period from 1.00 s until 10.00 s after lane change start

Freeway Ramps (Lane-change Behavior Modeling Parameters)
Bibliography


About the Authors

Dr. Anurag Pande is a Professor of Civil Engineering at California Polytechnic State University (Cal Poly). His research interests include traffic simulation, data mining applications, and observational data analysis, including the areas of traffic safety and crashes, driver behavior, transportation resilience, and emergency evacuation.

Mr. Neil Hockaday is Research Associate at Cal Poly. He has played a key role in TMC simulation planning and implementation of the training capabilities in the previous UCI (University of California Irvine) facility, as well as the current iteration of the TMC academy at Cal Poly.

Dr. Farid is a Postdoctoral Fellow in the department of Civil Engineering at Cal Poly. His research interests include traffic safety, data mining applications, and observational data analysis, including the areas of traffic safety and crashes.

Mr. Deng is a graduate student in the department of Civil Engineering at Cal Poly.

Mr. Zhilinag Luo is a graduate student in the department of Civil Engineering at Cal Poly.
Founded in 1991, the Mineta Transportation Institute (MTI), an organized research and training unit in partnership with the Lucas College and Graduate School of Business at San José State University (SJSU), increases mobility for all by improving the safety, efficiency, accessibility, and convenience of our nation’s transportation system. Through research, education, workforce development, and technology transfer, we help create a connected world. MTI leads the Mineta Consortium for Transportation Mobility (MCTM) funded by the U.S. Department of Transportation and the California State University Transportation Consortium (CSUTC) funded by the State of California through Senate Bill 1. MTI focuses on three primary responsibilities:

Research
MTI conducts multi-disciplinary research focused on surface transportation that contributes to effective decision making. Research areas include: active transportation; planning and policy; security and counterterrorism; sustainable and resilient transportation systems; transportation finance; transportation technology; and workforce development. MTI research publications undergo expert peer review to ensure the quality of the research.

Education and Workforce Development
To ensure the efficient movement of people and products, we must prepare a new cohort of transportation professionals who are ready to lead a more diverse, inclusive, and equitable transportation industry. To help achieve this, MTI sponsors a suite of workforce development and education opportunities. The Institute supports educational programs offered by the Lucas College and Graduate School of Business; a Master of Science in Transportation Management, plus graduate certificates that include High-Speed Rail and Intercity Rail Management and Transportation Security Management. These flexible programs offer live online classes so that working transportation professionals can pursue an advanced degree regardless of their location.

Information and Technology Transfer
MTI utilizes a diverse array of dissemination methods and media to ensure research results reach those responsible for managing change. These methods include publication, seminars, workshops, websites, social media, webinars, and other technology transfer mechanisms. Additionally, MTI promotes the availability of completed research to professional organizations and works to integrate the research findings into the graduate education program. MTI’s extensive collection of transportation-related publications is integrated into San José State University’s world-class Martin Luther King, Jr. Library.

Disclaimer
The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the information presented herein. This document is disseminated in the interest of information exchange. MTI’s research is funded, partially or entirely, by grants from the U.S. Department of Transportation, the U.S. Department of Homeland Security, the California Department of Transportation, and the California State University Office of the Chancellor, who assume no liability for the contents or use thereof. This report does not constitute a standard specification, design standard, or regulation.

MTI BOARD OF TRUSTEES

MTI FOUNDER
Hon. Norman Y. Mineta

Directors
Karen Philbrick, PhD
Executive Director
Hilary Nixon, PhD
Deputy Executive Director
Asha Weinstein Agrawal, PhD
Education Director
National Transportation Finance Center Director
Brian Michael Jenkins
National Transportation Security Center Director

Grace Crunican**
Owner, Crunec LLC
Donna DeMartino
Retired Transportation Executive
John Flaherty
Senior Fellow, Silicon Valley Leadership Group
Stephen J. Gardner*
President & CEO, Amtrak
Rose Guibault
Board Member, San Mateo County Transit District (SamTrans)
Kylie Christina Holland
Senior Director, Special Projects, TAP Technologies, Los Angeles County Metropolitan Transportation Authority (L.A. Metro)
Ian Jeffries*
President & CEO, Association of American Railroads
Grace Crunican**
Owner, Crunec LLC
Donna DeMartino
Retired Transportation Executive
John Flaherty
Senior Fellow, Silicon Valley Leadership Group
Stephen J. Gardner*
President & CEO, Amtrak
Rose Guibault
Board Member, San Mateo County Transit District (SamTrans)
Kylie Christina Holland
Senior Director, Special Projects, TAP Technologies, Los Angeles County Metropolitan Transportation Authority (L.A. Metro)
Ian Jeffries*
President & CEO, Association of American Railroads
Diane Woodend Jones
Principal & Chair of Board, Lea + Eloff, Inc.
Theresa McMillan
Executive Director, Metropolitan Transportation Commission (MTC)
Abbas Mohaddess
CEO, Excalibur Group Inc.
Stephan Morrissey
Senior Director – Regulatory and Policy, United Airlines
Toks Omishakin*
Secretary, California State Transportation Agency (CALSTA)
Grace Crunican**
Owner, Crunec LLC
Donna DeMartino
Retired Transportation Executive
John Flaherty
Senior Fellow, Silicon Valley Leadership Group
Stephen J. Gardner*
President & CEO, Amtrak
Rose Guibault
Board Member, San Mateo County Transit District (SamTrans)
Kylie Christina Holland
Senior Director, Special Projects, TAP Technologies, Los Angeles County Metropolitan Transportation Authority (L.A. Metro)
Ian Jeffries*
President & CEO, Association of American Railroads
Diane Woodend Jones
Principal & Chair of Board, Lea + Eloff, Inc.
Theresa McMillan
Executive Director, Metropolitan Transportation Commission (MTC)
Abbas Mohaddess
CEO, Excalibur Group Inc.
Stephan Morrissey
Senior Director – Regulatory and Policy, United Airlines
Toks Omishakin*
Secretary, California State Transportation Agency (CALSTA)
Marco Pagani, PhD*
Interim Dean, College of Engineering and Technology, San José State University
Tony Tavares*
Director, California Department of Transportation (Caltrans)
Jim Tymon* Executive Director, American Association of State Highway and Transportation Officials (AASHTO)
Diane Woodend Jones
Principal & Chair of Board, Lea + Eloff, Inc.
Theresa McMillan
Executive Director, Metropolitan Transportation Commission (MTC)
Abbas Mohaddess
CEO, Excalibur Group Inc.
Stephan Morrissey
Senior Director – Regulatory and Policy, United Airlines
Toks Omishakin*
Secretary, California State Transportation Agency (CALSTA)
Marco Pagani, PhD*
Interim Dean, College of Engineering and Technology, San José State University
Tony Tavares*
Director, California Department of Transportation (Caltrans)
Jim Tymon* Executive Director, American Association of State Highway and Transportation Officials (AASHTO)
Diane Woodend Jones
Principal & Chair of Board, Lea + Eloff, Inc.
Theresa McMillan
Executive Director, Metropolitan Transportation Commission (MTC)
Abbas Mohaddess
CEO, Excalibur Group Inc.
Stephan Morrissey
Senior Director – Regulatory and Policy, United Airlines
Toks Omishakin*
Secretary, California State Transportation Agency (CALSTA)
Marco Pagani, PhD*
Interim Dean, College of Engineering and Technology, San José State University
Tony Tavares*
Director, California Department of Transportation (Caltrans)
Jim Tymon* Executive Director, American Association of State Highway and Transportation Officials (AASHTO)
Diane Woodend Jones
Principal & Chair of Board, Lea + Eloff, Inc.
Theresa McMillan
Executive Director, Metropolitan Transportation Commission (MTC)
Abbas Mohaddess
CEO, Excalibur Group Inc.
Stephan Morrissey
Senior Director – Regulatory and Policy, United Airlines
Toks Omishakin*
Secretary, California State Transportation Agency (CALSTA)
Marco Pagani, PhD*
Interim Dean, College of Engineering and Technology, San José State University
Tony Tavares*
Director, California Department of Transportation (Caltrans)
Jim Tymon* Executive Director, American Association of State Highway and Transportation Officials (AASHTO)