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MTI MINETA TRANSPORTATION INSTITUTE

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

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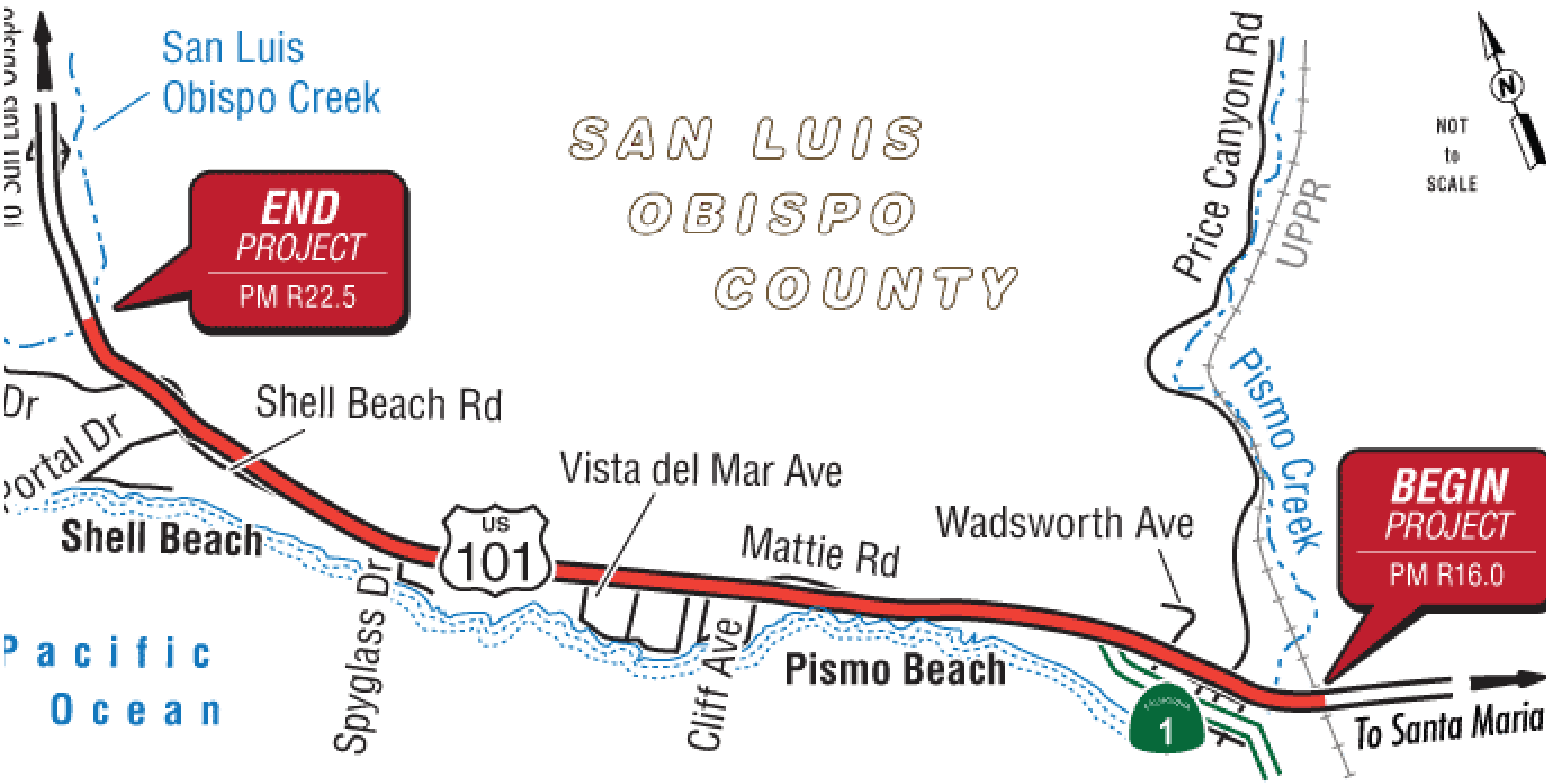

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Permanent capacity expansion, such as adding new lanes, is no longer a viable strategy to address traffic congestion in California; hence, ITS (Intelligent Transportation System) strategies, such as part-time use of the shoulder as a travel lane, need 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.</td></tr>
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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

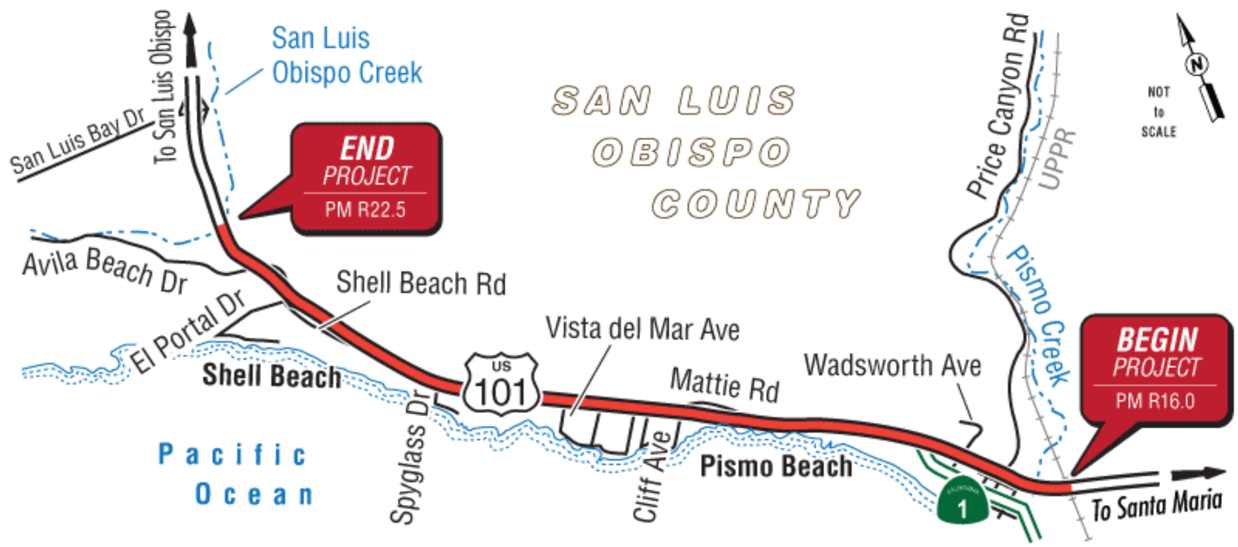
Surrogate Safety Assessment Model (SSAM) by the Federal Highway Administration (FHWA). Overall, the measures related to surrogate safety and travel time differences between the designs served as the basis for the evaluation of the alternatives.

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).

Figure 3. Dynamic Shoulder lane. (Vejdirektoratet, i.e., Danish Road Directorate)

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)

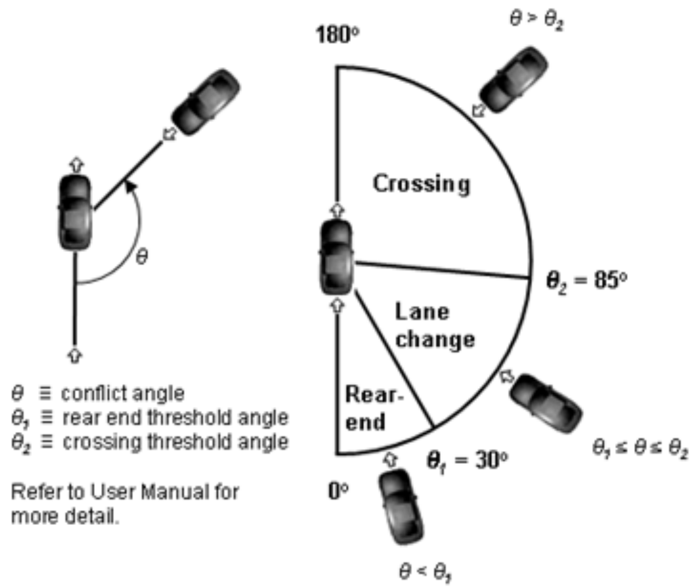
Note that since the LSPTTL on US 101 is a future installation and has not yet been implemented, the safety assessment needs to be based on surrogate safety measures that may be derived using the microscopic simulation models. The surrogate measures are based on the occurrence of a conflict event between 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).

Table 1. List of Surrogate Safety Conflict Measures

Surrogate Conflict Measure	Description
Gap Time (GT)	Time lapse between completion of encroachment by turning vehicle and the arrival time of crossing vehicle if they continue with same speed and path.
Encroachment Time (ET)	Time duration during which the turning vehicle infringes upon the right-of-way of through vehicle.
Deceleration Rate (DR)	Rate at which crossing vehicle must decelerate to avoid collision.
Proportion of Stopping Distance (PSD)	Ratio of distance available to maneuver to the distance remaining to the projected location of collision.
Post-Encroachment Time (PET)	Time lapse between end of encroachment of turning vehicle and the time that the through vehicle actually arrives at the potential point of collision.
Initially Attempted Post-Encroachment Time (IAPT)	Time lapse between commencement of encroachment by turning vehicle plus the expected time for the through vehicle to reach the point of collision and the completion time of encroachment by turning vehicle.
Time to Collision (TTC)	Expected time for two vehicles to collide if they remain at their present speed and on the same path.

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.

Figure 4. Conflict Angle Diagram in SSAM (Source: FHWA)



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, theGeoffrey 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.

$$GEH = \sqrt{\frac{2\,(M-C)^2}{M+C}} \tag{1}$$

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

Ramp or Freeway Mainline Location	**Post Mileage (Miles)**	**VISSIM Results (vehicles per hour) (Average of multiple simulation runs; M in Equation 1)**	**2018 Real-world volumes (vehicles per hour; C in Equation 1)**	**GEH Statistic**
Avila Beach Off-ramp	21.28	562	478	3.67
Spyglass Off-ramp	19.97	587	567	0.83
Price St Off-ramp	17.66	287	253	2.04
SR-1 Off-ramp	17.24	662	634	1.12
Hinds Off-ramp	16.72	292	258	2.04
Price St to Five Cities	16.11	2657	2622	0.67
Subsection 11 (Mainline)	17.7	10727	10137	5.78
Subsection 21 (Mainline)	Upstream of 16.6	13268	12658	5.36

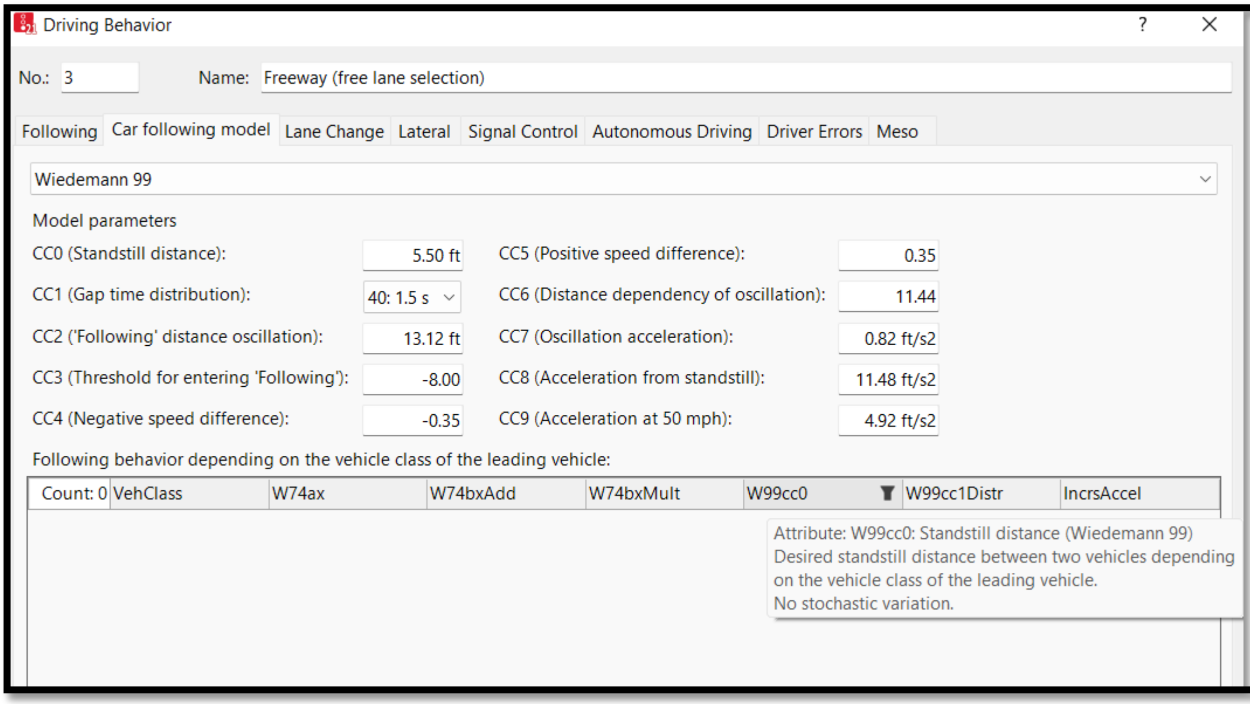
Data collected from model runs using ten different seed numbers were averaged and used to calculate the GEH statistic for traffic volume on off-ramps and mainline segments. These statistics are shown in Table 2. The GEH statistic is helpful in comparing real-world and simulated traffic volumes because 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.

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



3.2 Alternative Design Scenarios

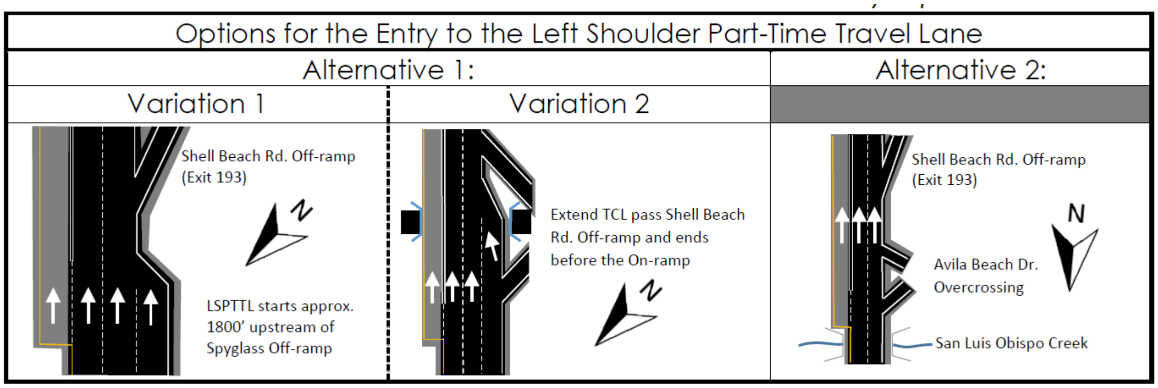
The validated network is used to then evaluate the following design alternatives California Department of Transportation (Caltrans) District 5 included in the ConOps for the LSPTTL corridor.

- 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.

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



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

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

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

	Alt 1A	Alt 1B	Alt 2
Max Queue Delay (s)	49.96	51.16	52.64
Time Period of Occurrence	17:45-18:00	17:45-18:00	17:45-18:00
Location of Occurrence	PM 15.21 (Location #35 in Table 3)	PM 15.21 (Location #35 in Table 3)	PM 15.21 (Location #35 in Table 3)

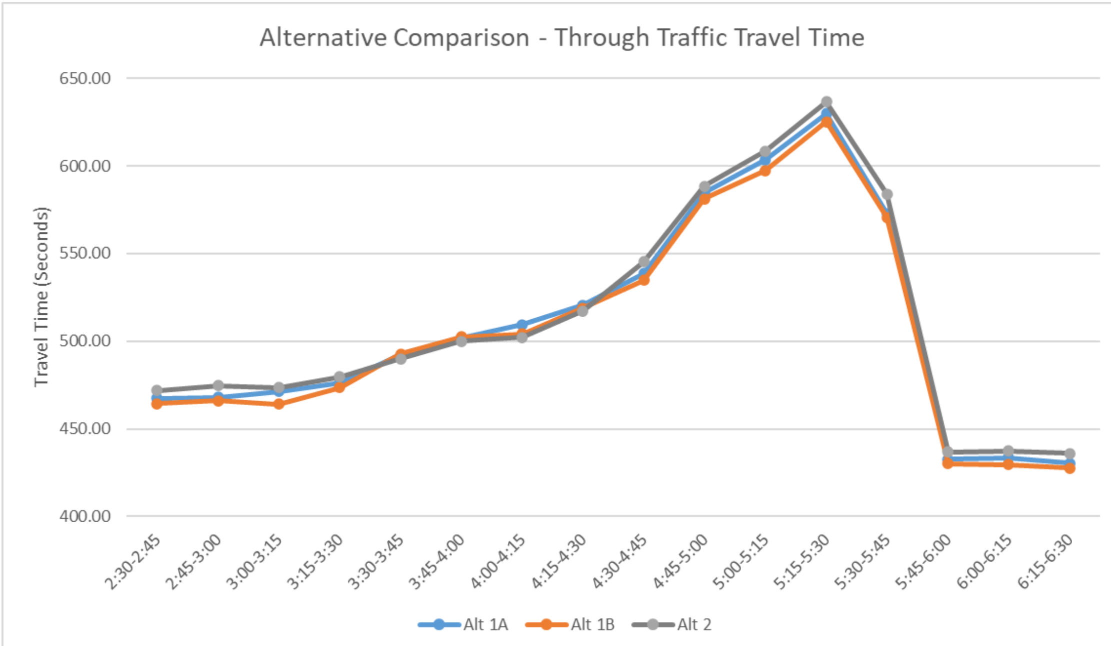
Average through traffic vehicle travel times for each alternative are shown in Table 5 and Figure 7 that shows the same results graphically. Although Alternative 2 has a relatively higher travel time for the through traffic than the other two alternatives, it is very close to Alternatives 1A and 1B.

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

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

Figure 7. Through Traffic Travel Time Comparison.



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

		Alt 1A	Alt 1B	Alt 2
SSAM_Measure		Mean/Avg	Mean/Avg	Mean/Avg
	TTC(s)	0.77	0.73	0.77
	PET(s)	1.21	1.14	1.20
	DR(m/s2)	-2.04	-1.92	-2.01

Table 7. Number of Conflicts Based on Thresholds in Surrogate Safety Measures' Measurement Averages

Conflict Type	Alt 1A	Alt 1B	Alt 2
Total	7577	8108	7441
Crossing concflicts	428	438	452
Rear-end conflicts	5848	6408	5877
Lane-change conflicts	1301	1262	1112

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

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

TMC Personnel Training: Agency Outreach

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

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

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

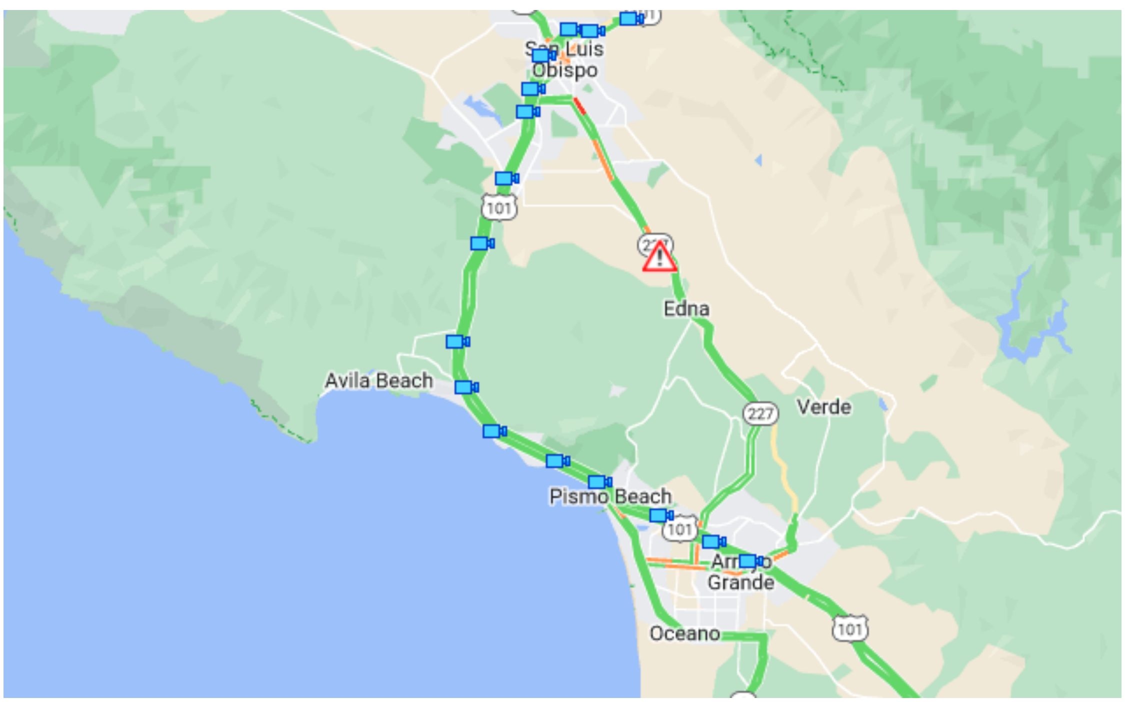
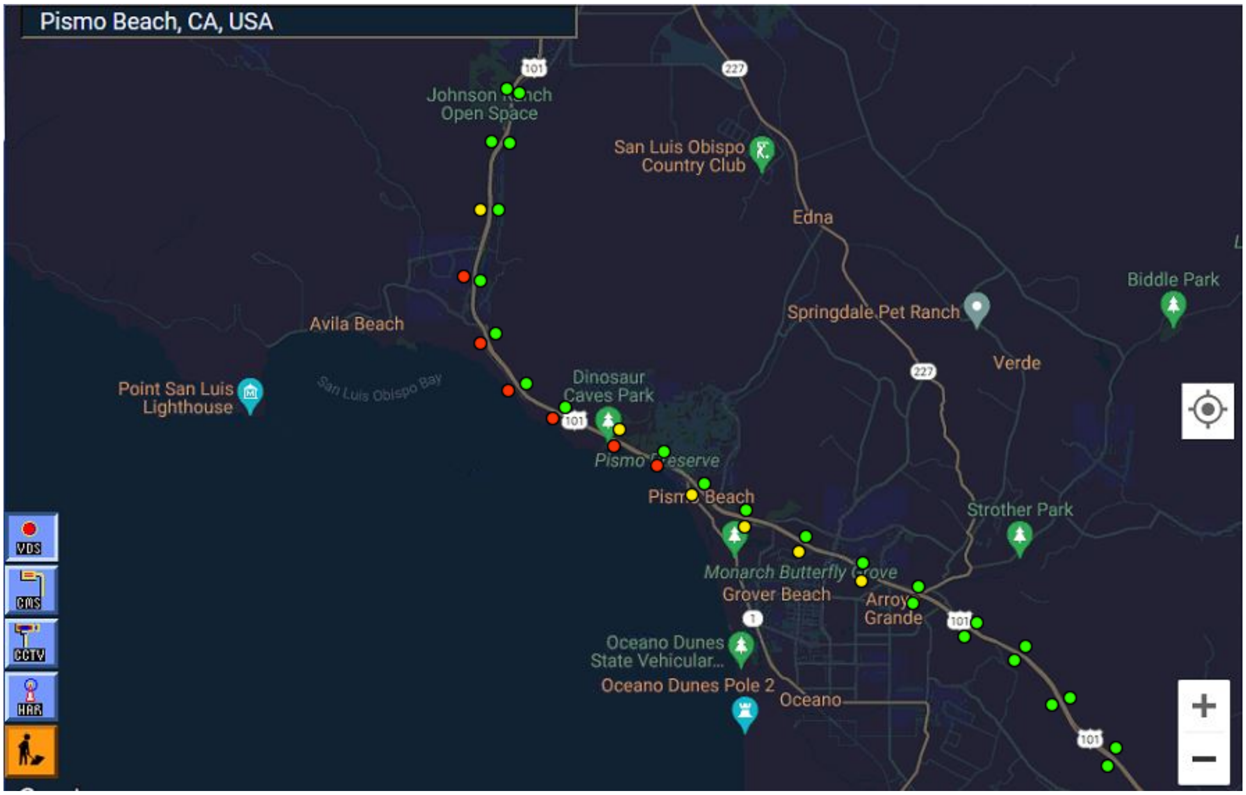


Figure 11. Facsimile of the Network in the TMC Simulator



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)

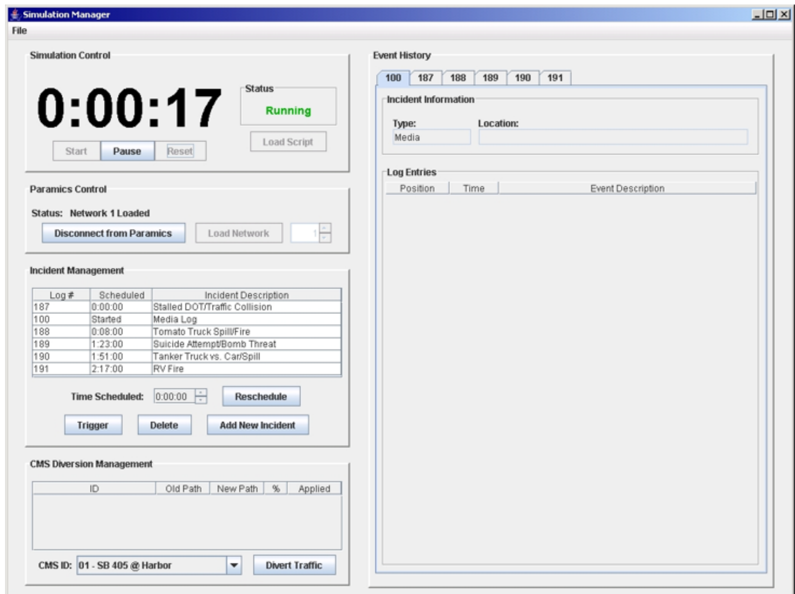
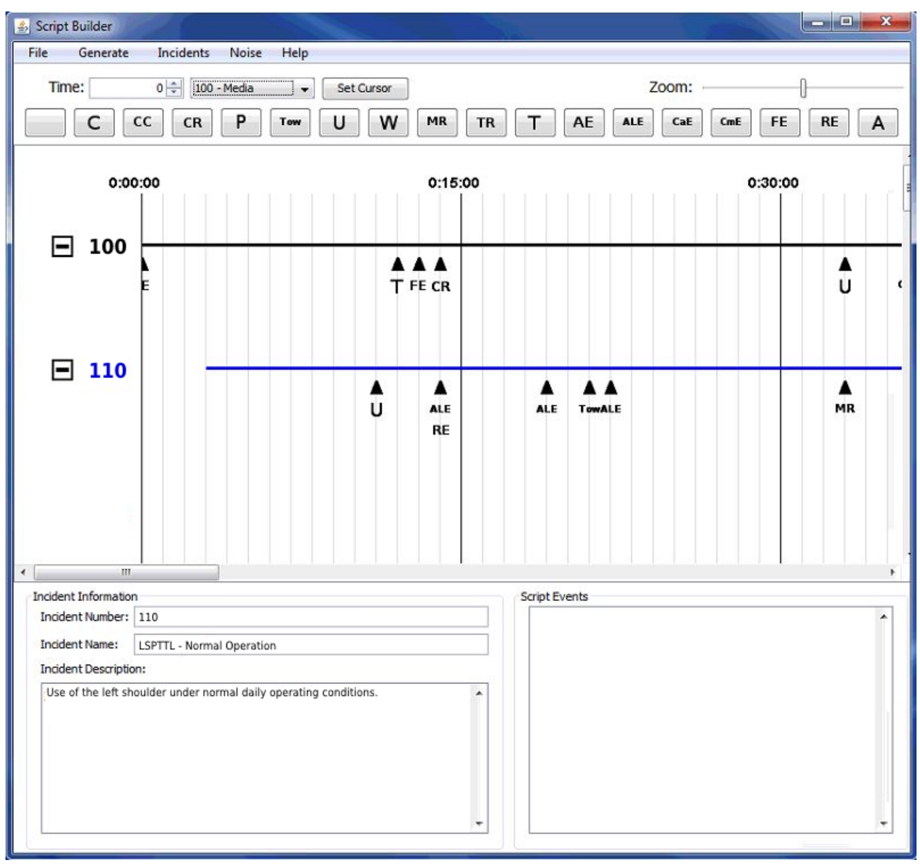
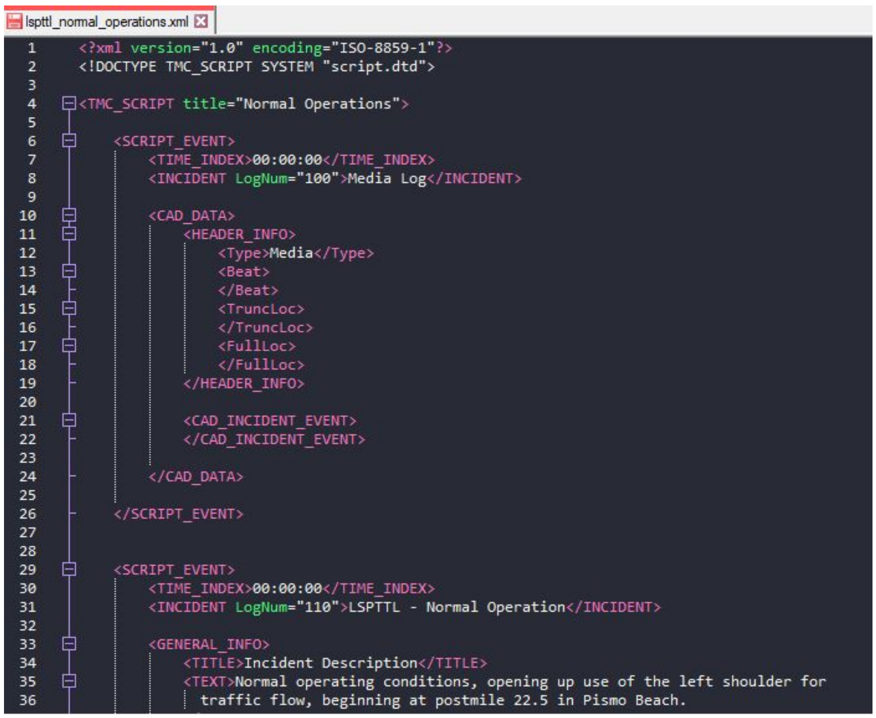


Figure 13. TMC Simulator Script Builder Tool



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



lsptl_normal_operations.xml

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<!DOCTYPE TMC_SCRIPT SYSTEM "script.dtd">

<TMC_SCRIPT title="Normal Operations">

    <SCRIPT_EVENT>
        <TIME_INDEX>00:00:00</TIME_INDEX>
        <INCIDENT LogNum="100">Media Log</INCIDENT>

        <CAD_DATA>
            <HEADER_INFO>
                <Type>Media</Type>
                <Beat>
                </Beat>
                <TruncLoc>
                </TruncLoc>
                <FullLoc>
                </FullLoc>
            </HEADER_INFO>

            <CAD_INCIDENT_EVENT>
            </CAD_INCIDENT_EVENT>

        </CAD_DATA>

    </SCRIPT_EVENT>


    <SCRIPT_EVENT>
        <TIME_INDEX>00:00:00</TIME_INDEX>
        <INCIDENT LogNum="110">LSPTTL - Normal Operation</INCIDENT>

        <GENERAL_INFO>
            <TITLE>Incident Description</TITLE>
            <TEXT>Normal operating conditions, opening up use of the left shoulder for
              traffic flow, beginning at postmile 22.5 in Pismo Beach.
```

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.

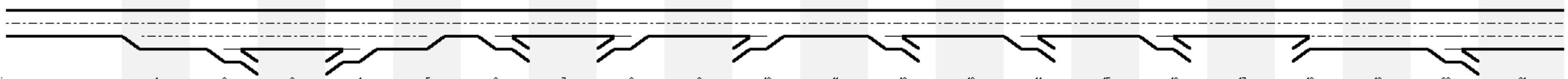
5.2 Future Scope

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

US-101 SB No Build PM
Wednesday, 04/18/2018

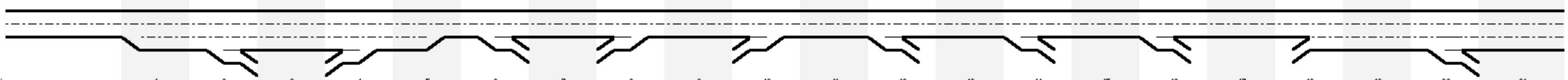


PM	21.8	21.28	21.105	20.85		19.97	19.812	19.66		18.28
Sub-Section	1	2	3	4	5	6	7	8	9	10
Name	North of Avila Beach	Avila Beach Off	Avila Beach	Avila Beach On	Avila to Spyglass	Spyglass Off	Spyglass	Spyglass On	South of Spyglass	N. Price On
Type	Basic	Diverge	Basic	Merge	Basic	Diverge	Basic	Merge	Basic	Merge
% Trucks	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%
Total	12,200	435	11,765	1,301	13,066	1,180	11,886	772	12,658	946
Length	875	1,500	2,400	1,500	1,500	1,500	2,000	1,500	5,800	1,500
2:00 PM	727	19	708	42	750	57	693	40	733	55
2:15 PM	671	21	650	54	704	48	656	34	690	35
2:30 PM	800	17	783	53	836	56	780	37	817	48
2:45 PM	786	20	766	59	825	59	766	36	802	51
3:00 PM	683	19	664	69	733	50	683	58	741	89
3:15 PM	768	25	743	53	796	58	738	41	779	53
3:30 PM	778	16	762	73	835	54	781	43	824	54
3:45 PM	739	24	715	61	776	69	707	40	747	39
4:00 PM	769	21	748	66	814	51	763	37	800	42
4:15 PM	794	15	779	76	855	54	801	37	838	44
4:30 PM	713	23	690	105	795	53	742	51	793	49
4:45 PM	677	30	647	106	753	66	687	39	726	41
5:00 PM	457	24	433	115	548	67	481	39	520	57
5:15 PM	509	37	472	77	549	80	469	50	519	53
5:30 PM	443	24	419	72	491	81	410	42	452	38
5:45 PM	467	28	439	46	485	74	411	39	450	44
6:00 PM	398	25	373	56	429	53	376	28	404	42
6:15 PM	337	15	322	48	370	53	317	28	345	31
6:30 PM	341	15	326	36	362	50	312	27	339	44
6:45 PM	343	17	326	34	360	47	313	26	339	37

PM	17.7 (Caltrans Station 441)	17.66		17.24		16.72	16.398	16.33		16.11	
Sub-Section	11	12	13	14	15	16	17	18	19	20	21
Name	Price	Price Off	North of SR-1	SR-1 Off	South of SR-1	Hinds Off	Hinds to Price	S. Price On	Price to 5 Cities	Price to 5 Cities	South of 5 Cities
Type	Basic	Diverge	Basic	Diverge	Basic	Diverge	Basic	Merge	Basic	Weave	Basic
% Trucks	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%
Total	13,604	394	13,210	935	12,275	363	11,912	4,547	16,459	3,193	13,266
Length	2,500	1,500	800	1,500	1,100	1,500	2,500	1,500	2,500	1,440	875
2:00 PM	788	23	765	49	716	18	698	201	899	147	752
2:15 PM	725	19	706	56	650	13	637	236	873	158	715
2:30 PM	865	26	839	47	792	13	779	207	986	160	826
2:45 PM	853	18	835	43	792	18	774	225	999	163	836
3:00 PM	830	13	817	50	767	19	748	209	957	156	801
3:15 PM	832	17	815	38	777	14	763	200	963	139	824
3:30 PM	878	28	850	49	801	14	787	245	1,032	186	846
3:45 PM	786	26	760	58	702	17	685	260	945	223	722
4:00 PM	842	24	818	58	760	17	743	266	1,009	176	833
4:15 PM	882	26	856	48	808	19	789	259	1,048	178	870
4:30 PM	842	18	824	39	785	21	764	259	1,023	180	843
4:45 PM	767	16	751	57	694	15	679	264	943	178	765
5:00 PM	577	19	558	46	512	18	494	278	772	172	600
5:15 PM	572	20	552	55	497	18	479	263	742	174	568
5:30 PM	490	24	466	50	416	21	395	241	636	171	465
5:45 PM	494	21	473	52	421	33	388	244	632	189	443
6:00 PM	446	14	432	35	397	22	375	223	598	118	480
6:15 PM	376	16	360	36	324	22	302	158	460	119	341
6:30 PM	383	10	373	37	336	15	321	163	484	109	375
6:45 PM	376	16	360	32	328	16	312	146	458	97	361

Traffic Volume data from Thursday, 4/19/2018

US-101 SB No Build PM Thursday, 04/19/2018	21.8	21.28	21.105	20.85		19.97	19.812	19.66		18.28	17.7 Caltrans Station 441	17.66		17.24		16.72	16.398	16.33		16.11	
Sub-Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Name	North of Avila Beach	Avila Beach Off	Avila Beach	Avila Beach On	Avila to Spyglass	Spyglass Off	Spyglass	Spyglass On	South of Spyglass	N. Price On	Price	Price Off	North of SR-1	SR-1 Off	South of SR-1	Hinds Off	Hinds to Price	S. Price On	Price to 5 Cities	Price to 5 Cities	South of 5 Cities
Type	Basic	Diverge	Basic	Merge	Basic	Diverge	Basic	Merge	Basic	Merge	Basic	Diverge	Basic	Diverge	Basic	Diverge	Basic	Merge	Basic	Weave	Basic
% Trucks	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%
Total	13,087	620	12,467	1,152	13,619	1,187	12,432	860	13,292	994	14,286	425	13,861	1,045	12,816	413	12,403	4,660	17,063	3,185	13,878
Length	875	1,500	2,400	1,500	1,500	1,500	2,000	1,500	5,800	1,500	2,500	1,500	800	1,500	1,100	1,500	2,500	1,500	2,500	1,440	875
2:00 PM	698	24	674	58	732	52	680	43	723	63	786	32	754	55	699	27	672	189	861	156	705
2:15 PM	773	25	748	48	796	52	744	39	783	42	825	22	803	50	753	21	732	242	974	145	829
2:30 PM	782	26	756	60	816	46	770	35	805	43	848	19	829	55	774	14	760	221	981	142	839
2:45 PM	776	24	752	71	823	57	766	41	807	51	858	19	839	49	790	16	774	215	989	169	820
3:00 PM	738	27	711	59	770	52	718	49	767	90	857	30	827	49	778	23	755	193	948	158	790
3:15 PM	776	23	753	62	815	56	759	50	809	58	867	18	849	67	782	21	761	242	1,003	169	834
3:30 PM	745	21	724	58	782	60	722	32	754	50	804	25	779	67	712	22	690	240	930	191	739
3:45 PM	807	31	776	72	848	73	775	43	818	41	859	24	835	54	781	30	751	273	1,024	192	832
4:00 PM	696	22	674	75	749	53	696	31	727	60	787	23	764	59	705	28	677	263	940	189	751
4:15 PM	778	20	758	73	831	65	766	45	811	46	857	18	839	53	786	24	762	247	1,009	164	845
4:30 PM	767	30	737	99	836	69	767	51	818	61	879	18	861	53	808	22	786	267	1,053	161	892
4:45 PM	770	35	735	86	821	63	758	62	820	47	867	22	845	54	791	19	772	249	1,021	172	849
5:00 PM	660	56	604	59	663	66	597	75	672	70	742	21	721	52	669	17	652	312	964	182	782
5:15 PM	599	59	540	44	584	75	509	43	552	47	599	16	583	41	542	24	518	308	826	183	643
5:30 PM	554	66	488	49	537	74	463	60	523	55	578	15	563	63	500	15	485	245	730	185	545
5:45 PM	472	38	434	35	469	79	390	44	434	47	481	20	461	48	413	24	389	266	655	173	482
6:00 PM	470	26	444	42	486	72	414	34	448	39	487	21	466	56	410	16	394	185	579	125	454
6:15 PM	404	26	378	33	411	41	370	37	407	32	439	23	416	35	381	17	364	163	527	127	400
6:30 PM	411	23	388	40	428	39	389	16	405	37	442	22	420	46	374	16	358	172	530	119	411
6:45 PM	411	18	393	29	422	43	379	30	409	15	424	17	407	39	368	17	351	168	519	83	436



Projected Traffic Volumes for 2026 and relevant SLOCOG growth factors (original counts based on Wednesday, 4/18/2018)

US-101 SB No Build PM

Wednesday, 04/18/2018

		21.8	21.28	21.105	20.85		19.97	19.812	19.66		18.28
Sub-Section		1	2	3	4	5	6	7	8	9	10
Name		North of Avila Beach	Avila Beach Off	Avila Beach	Avila Beach On	Avila to Spyglass	Spyglass Off	Spyglass	Spyglass On	South of Spyglass	N. Price On
Type		Basic	Diverge	Basic	Merge	Basic	Diverge	Basic	Merge	Basic	Merge
% Trucks		7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%
Total		12,920	500	12,420	1,350	13,770	1,220	12,550	815	13,365	985
Length		875	1,500	2,400	1,500	1,500	1,500	2,000	1,500	5,800	1,500
	Growth	5.9%	14.9%	5.6%	3.8%	5.4%	3.4%	5.6%	5.6%	5.6%	4.1%
2:00 PM		770	20	750	45	795	60	735	40	775	55
2:15 PM		710	25	685	55	740	50	690	35	725	35
2:30 PM		845	20	825	55	880	60	820	40	860	50
2:45 PM		830	25	805	60	865	60	805	40	845	55
3:00 PM		725	20	705	70	775	50	725	60	785	90
3:15 PM		815	30	785	55	840	60	780	45	825	55
3:30 PM		825	20	805	75	880	55	825	45	870	55
3:45 PM		780	25	755	65	820	70	750	40	790	40
4:00 PM		815	25	790	70	860	55	805	40	845	45
4:15 PM		840	20	820	80	900	55	845	40	885	45
4:30 PM		755	25	730	105	835	55	780	55	835	50
4:45 PM		715	35	680	110	790	70	720	40	760	45
5:00 PM		485	25	460	115	575	70	505	40	545	60
5:15 PM		540	40	500	80	580	80	500	50	550	55
5:30 PM		470	25	445	75	520	85	435	45	480	40
5:45 PM		495	30	465	50	515	75	440	40	480	45
6:00 PM		420	30	390	60	450	55	395	30	425	45
6:15 PM		360	20	340	50	390	55	335	30	365	35
6:30 PM		360	20	340	40	380	50	330	30	360	45
6:45 PM		365	20	345	35	380	50	330	30	360	40

		17.7 Caltrans Station 441	17.66		17.24		16.72	16.398	16.33		16.11	
Sub-Section		11	12	13	14	15	16	17	18	19	20	21
Name		Price	Price Off	North of SR-1	SR-1 Off	South of SR-1	Hinds Off	Hinds to Price	S. Price On	Price to 5 Cities	Price to 5 Cities	South of 5 Cities
Type		Basic	Diverge	Basic	Diverge	Basic	Diverge	Basic	Merge	Basic	Weave	Basic
% Trucks		7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%
Total		14,350	440	13,910	975	12,935	405	12,530	4,585	17,115	3,235	13,880
Length		2,500	1,500	800	1,500	1,100	1,500	2,500	1,500	2,500	1,440	875
	Growth	5.5%	11.7%	5.3%	4.3%	5.4%	11.6%	5.2%	0.8%	4.0%	1.3%	4.6%
2:00 PM		830	25	805	50	755	20	735	205	940	150	790
2:15 PM		760	20	740	60	680	15	665	240	905	160	745
2:30 PM		910	30	880	50	830	15	815	210	1,025	160	865
2:45 PM		900	20	880	45	835	20	815	225	1,040	165	875
3:00 PM		875	15	860	50	810	20	790	210	1,000	160	840
3:15 PM		880	20	860	40	820	15	805	200	1,005	140	865
3:30 PM		925	30	895	50	845	15	830	245	1,075	190	885
3:45 PM		830	30	800	60	740	20	720	260	980	225	755
4:00 PM		890	25	865	60	805	20	785	270	1,055	180	875
4:15 PM		930	30	900	50	850	20	830	260	1,090	180	910
4:30 PM		885	20	865	40	825	25	800	260	1,060	180	880
4:45 PM		805	20	785	60	725	15	710	265	975	180	795
5:00 PM		605	20	585	50	535	20	515	280	795	175	620
5:15 PM		605	20	585	55	530	20	510	265	775	175	600
5:30 PM		520	25	495	50	445	25	420	245	665	175	490
5:45 PM		525	25	500	55	445	35	410	245	655	190	465
6:00 PM		470	15	455	35	420	25	395	225	620	120	500
6:15 PM		400	20	380	40	340	25	315	160	475	120	355
6:30 PM		405	10	395	40	355	15	340	165	505	110	395
6:45 PM		400	20	380	35	345	20	325	150	475	100	375

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

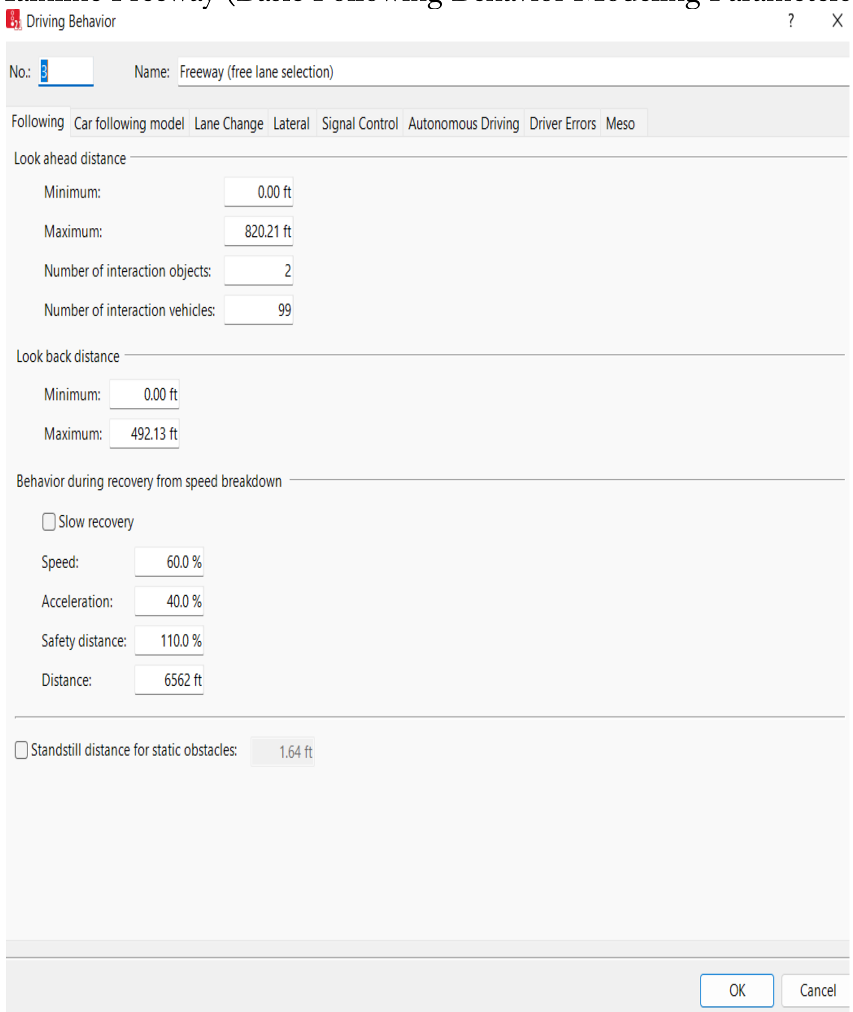
US-101 SB No Build PM

Thursday, 04/19/2018

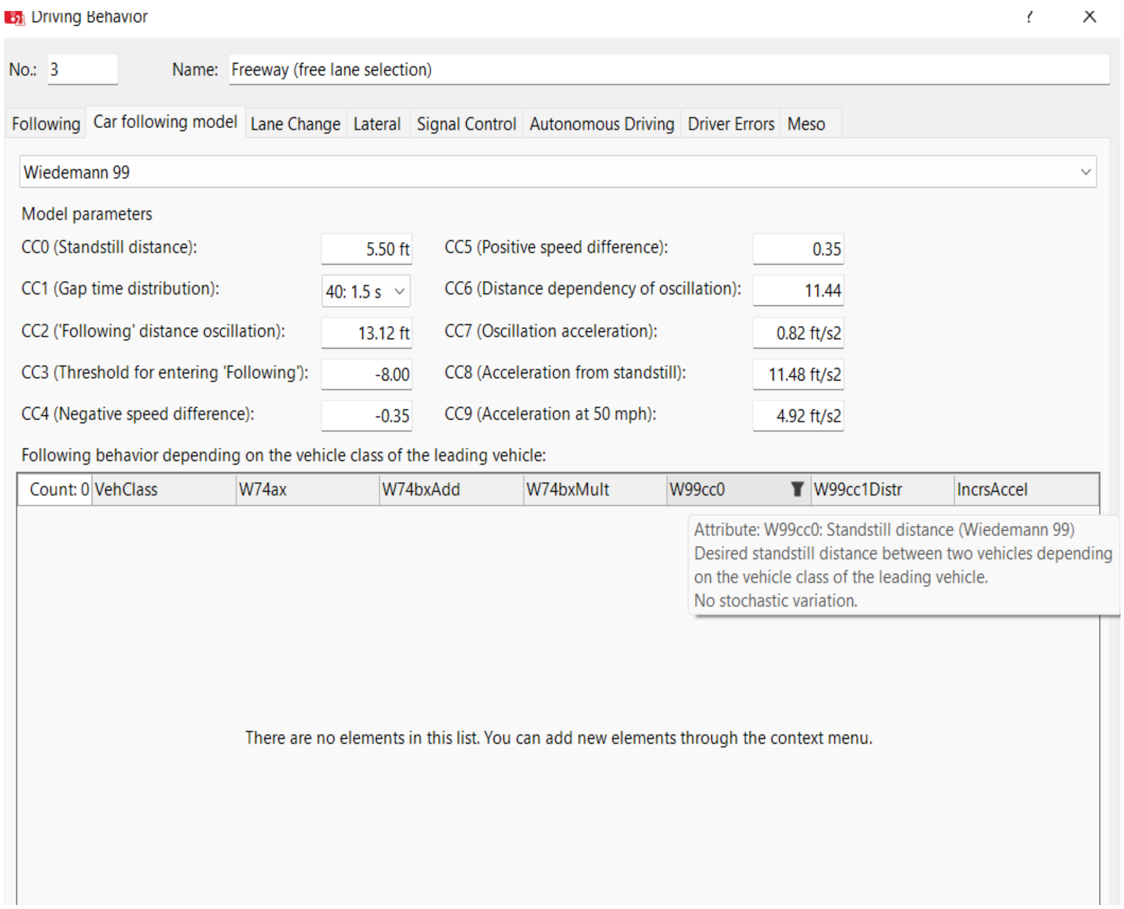
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
PM	21.8	21.28	21.105	20.85		19.97	19.812	19.66		18.28	17.7 Caltrans Station 441	17.66		17.24		16.72	16.398	16.33		16.11	
Sub-Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Name	North of Avila Beach	Avila Beach Off	Avila Beach	Avila Beach On	Avila to Spyglass	Spyglass Off	Spyglass	Spyglass On	South of Spyglass	N. Price On	Price	Price Off	North of SR-1	SR-1 Off	South of SR-1	Hinds Off	Hinds to Price	S. Price On	Price to 5 Cities	Price to 5 Cities	South of 5 Cities
Type	Basic	Diverge	Basic	Merge	Basic	Diverge	Basic	Merge	Basic	Merge	Basic	Diverge	Basic	Diverge	Basic	Diverge	Basic	Merge	Basic	Weave	Basic
% Trucks	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%	2.00%	7.00%
Total	13,860	685	13,175	1,185	14,360	1,230	13,130	895	14,025	1,035	15,060	465	14,595	1,080	13,515	460	13,055	4,700	17,755	3,225	14,530
Length	875	1,500	2,400	1,500	1,500	1,500	2,000	1,500	5,800	1,500	2,500	1,500	800	1,500	1,100	1,500	2,500	1,500	2,500	1,440	875
Growth	5.9%	10.5%	5.7%	2.9%	5.4%	3.6%	5.6%	4.1%	5.5%	4.1%	5.4%	9.4%	5.3%	3.3%	5.5%	11.4%	5.3%	0.9%	4.1%	1.3%	4.7%
2:00 PM	740	25	715	60	775	55	720	45	765	65	830	35	795	55	740	30	710	190	900	160	740
2:15 PM	820	30	790	50	840	55	785	40	825	45	870	25	845	50	795	25	770	245	1,015	145	870
2:30 PM	830	30	800	60	860	50	810	35	845	45	890	20	870	55	815	15	800	225	1,025	145	880
2:45 PM	820	25	795	75	870	60	810	45	855	55	910	20	890	50	840	20	820	215	1,035	170	865
3:00 PM	780	30	750	60	810	55	755	50	805	90	895	30	865	50	815	25	790	195	985	160	825
3:15 PM	820	25	795	65	860	60	800	50	850	60	910	20	890	70	820	25	795	245	1,040	170	870
3:30 PM	790	25	765	60	825	60	765	35	800	50	850	25	825	70	755	25	730	240	970	195	775
3:45 PM	855	35	820	75	895	75	820	45	865	45	910	25	885	55	830	30	800	275	1,075	195	880
4:00 PM	735	25	710	75	785	55	730	35	765	60	825	25	800	60	740	30	710	265	975	190	785
4:15 PM	825	25	800	75	875	65	810	45	855	50	905	20	885	55	830	25	805	250	1,055	165	890
4:30 PM	810	35	775	100	875	70	805	55	860	65	925	20	905	55	850	25	825	270	1,095	165	930
4:45 PM	815	40	775	90	865	65	800	65	865	50	915	25	890	55	835	20	815	250	1,065	175	890
5:00 PM	700	60	640	60	700	70	630	75	705	70	775	25	750	55	695	20	675	315	990	185	805
5:15 PM	635	60	575	45	620	75	545	45	590	50	640	20	620	45	575	25	550	310	860	185	675
5:30 PM	585	70	515	50	565	75	490	60	550	55	605	15	590	65	525	15	510	245	755	185	570
5:45 PM	500	40	460	35	495	80	415	45	460	50	510	20	490	50	440	25	415	270	685	175	510
6:00 PM	500	30	470	45	515	75	440	35	475	40	515	25	490	60	430	20	410	185	595	125	470
6:15 PM	430	30	400	35	435	45	390	40	430	35	465	25	440	35	405	20	385	165	550	130	420
6:30 PM	435	25	410	40	450	40	410	20	430	40	470	25	445	50	395	20	375	175	550	120	430
6:45 PM	435	20	415	30	445	45	400	30	430	15	445	20	425	40	385	20	365	170	535	85	450

Appendix B: Behavioral Parameters for Microsimulation

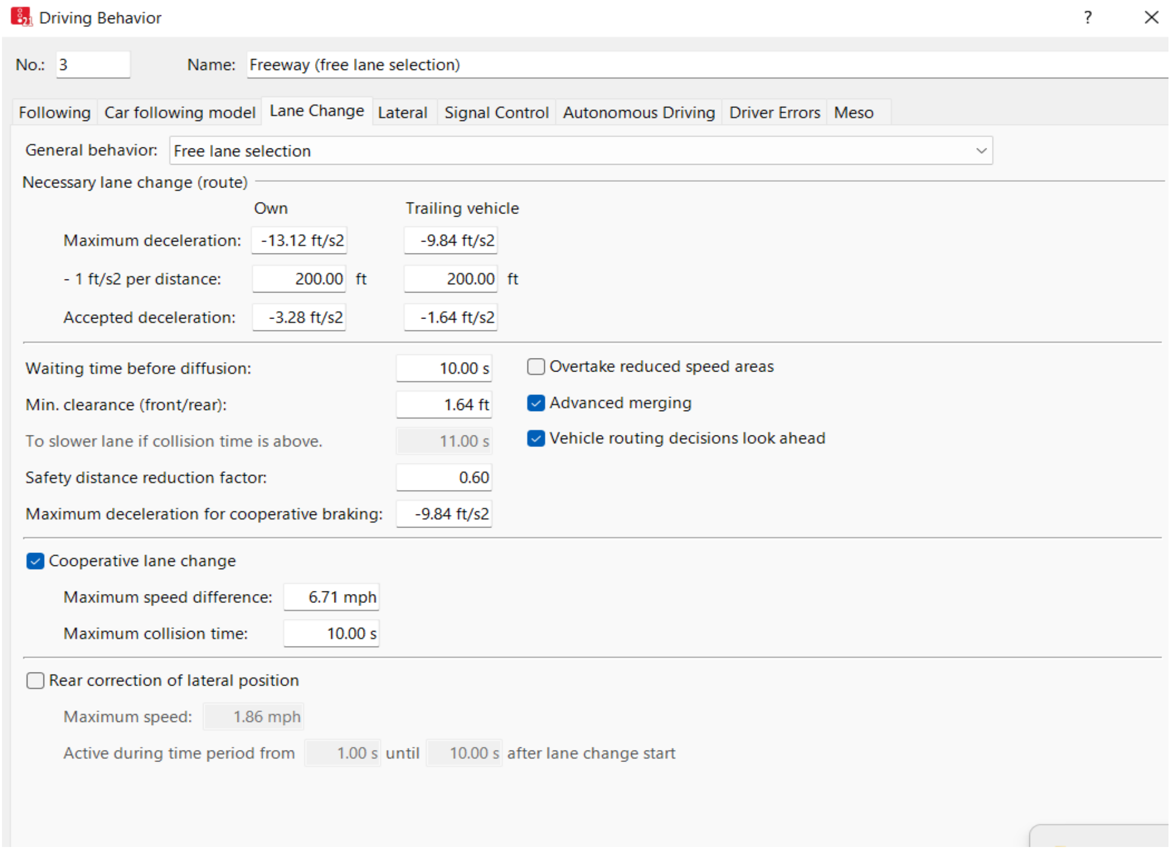
Mainline Freeway (Basic Following Behavior Modeling Parameters)



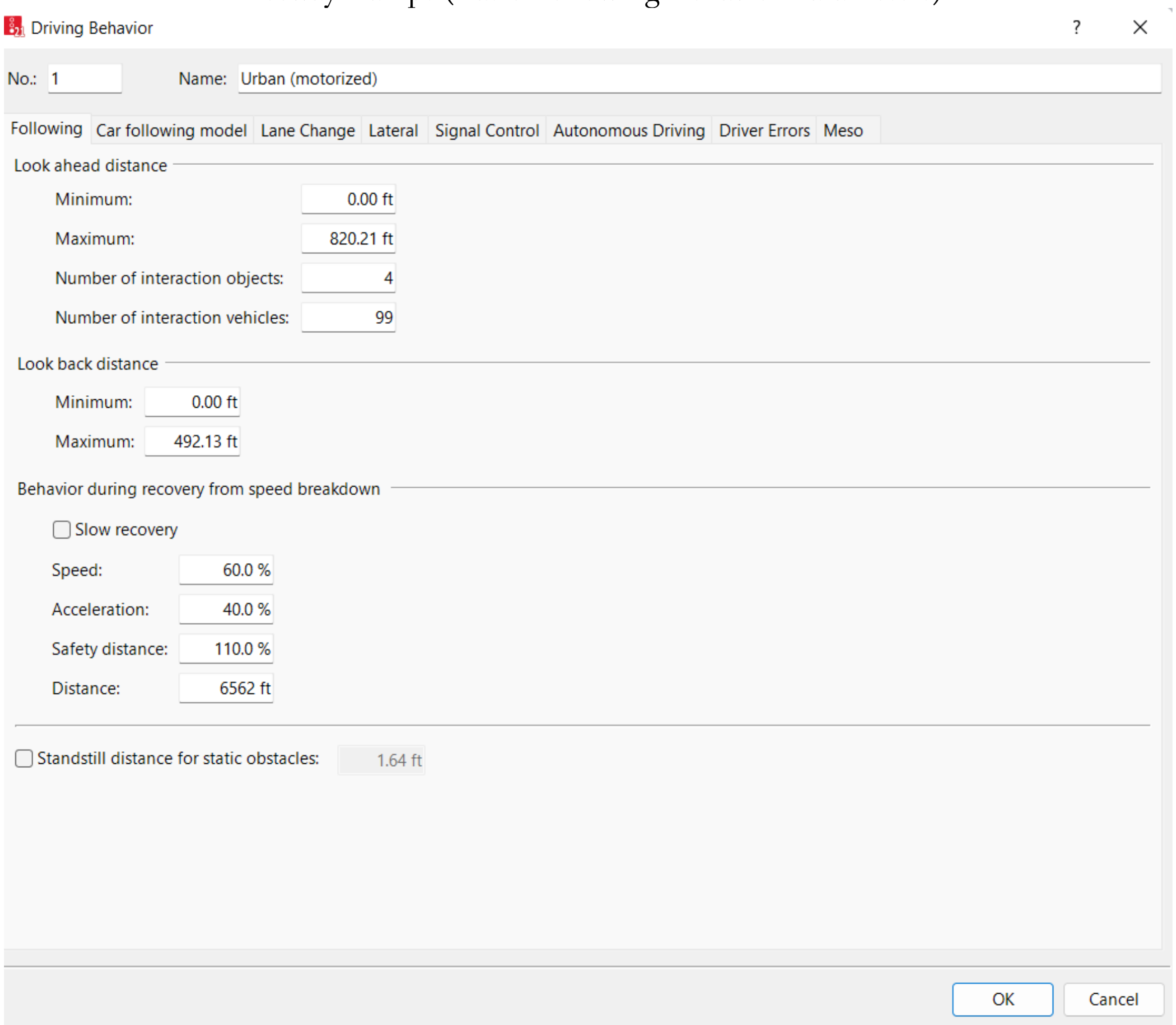
Mainline Freeway (Car-Following Behavior Modeling Parameters)



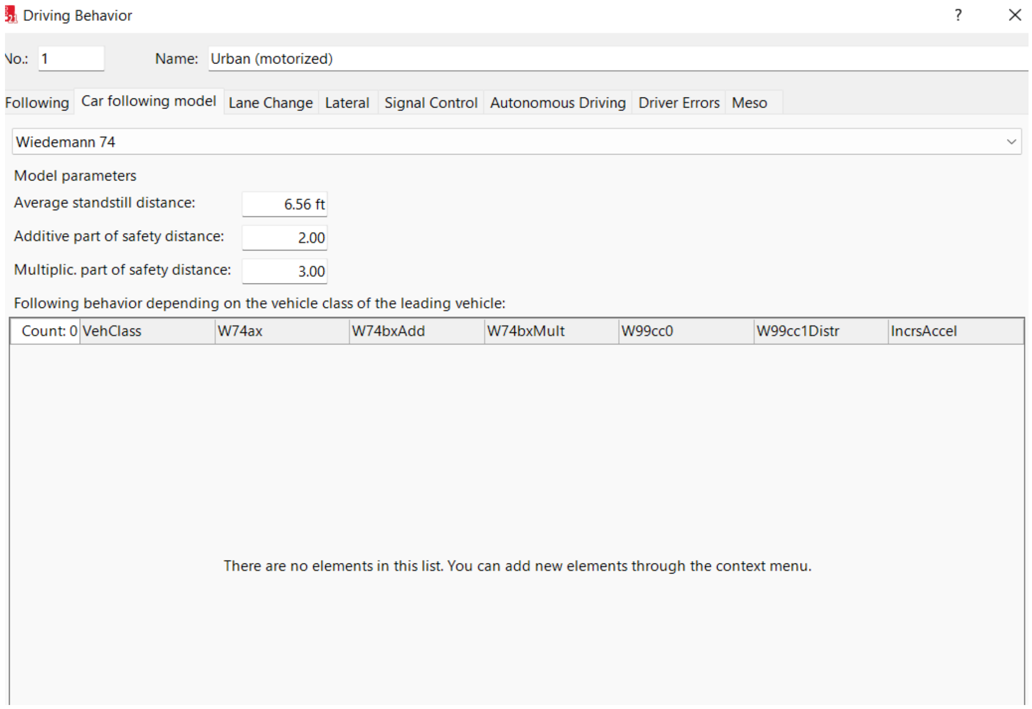
Mainline Freeway (Lane-Change Behavior Modeling Parameters)



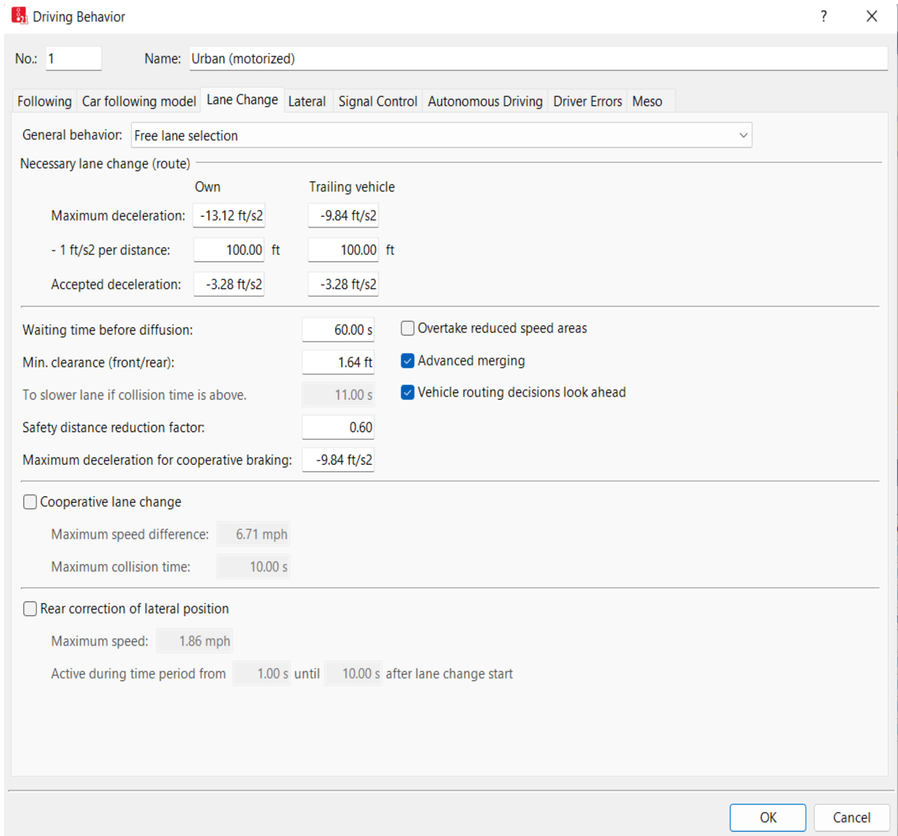
Freeway Ramps (Basic Following Behavior Parameters)



Freeway Ramps (Car-Following Behavior Modeling Parameters)



Freeway Ramps (Lane-change Behavior Modeling Parameters)



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