RESEARCH REPORT

Institute of Transportation Studies | UNIVERSITY OF CALIFORNIA

Assessing the Economic Impact of Speed Limit Changes on Safety and Mobility in California

Sarder Rafee Musabbir, Ph.D. Student, Civil and Environmental Engineering, University of California, Davis
Michael Zhang, PhD, Professor, Civil and Environmental Engineering, University of California, Davis

June 2023

ITS UCDAVIS Institute of Transportation Studies

Report No.:UC-ITS-2021-36 | DOI:10.7922/G2NK3CCP

Technical Report Documentation Page

1. Report No. UC-ITS-2021-36	**2. Government Accession No.** N/A	**3. Recipient's Catalog No.** N/A

4. Title and Subtitle Assessing the Economic Impact of Speed Limit Changes on Safety and Mobility in California	**5. Report Date** June 2023
	6. Performing Organization Code ITS-Davis
7. Author(s) Sarder Rafee Musabbir, https://orcid.org/0000-0003-2433-8535 Michael Zhang, Ph.D. https://orcid.org/0000-0002-4647-3888	**8. Performing Organization Report No.** UCD-ITS-RR-23-19
9. Performing Organization Name and Address Institute of Transportation Studies, Davis 1605 Tilia Street Davis, CA 95616	**10. Work Unit No.** N/A
	11. Contract or Grant No. UC-ITS-2021-36
12. Sponsoring Agency Name and Address The University of California Institute of Transportation Studies www.ucits.org	**13. Type of Report and Period Covered** Final Research Report (October 2020 – December 2021)
	14. Sponsoring Agency Code UC ITS

15. Supplementary Notes

DOI:10.7922/G2NK3CCP

16. Abstract

This project estimates the safety and mobility impact of changing speed limits on California highways. The safety impact is estimated using statistical models to predict the change in the frequency of all crashes and fatal-or-severe crashes that would result by varying the design speed (85th percentile speed). Statewide crash and traffic data (from the Statewide Integrated Traffic Records System, the Highway Safety Information System, and the Performance Measurement System) were combined to develop a balanced and sampled dataset for the statistical models. Three different increases in differential speed limits (DSLs; whereby trucks and cars have different speed limits) lead to increases in the frequency of all crashes, including fatal and severe crashes, for all of the classified segments (urban, rural, and different design speed segments). The operational condition (speed, travel time, delay) is tested using seven simulation segments with urban-rural classification. Four different DSL scenarios and four uniform speed limit (USL) scenarios are tested for each of the simulation segments. The results show a decrease of travel time but an increase of fuel consumption as the speed limits get higher. The safety cost of crashes and operational costs were also estimated based on the simulation models. In general, as the speed limits are increased, the safety costs increase with the predicted increases in crashes, particularly severe and fatal crashes. The operational costs, on the other hand, generally decrease as the speed limits are increased. However, the amount of operational cost decreases are subject to greater uncertainty than the safety cost estimates are, due to uncertainties in sampling and demand estimation and in negligence of construction costs of roadway and signage changes to accommodate the new speed limits. From the economic perspective in this study, raising speed limits on rural California highways could reduce monetary costs, as savings in operational costs would exceed losses from more crashes.

17. Key Words Traffic safety, variable speed limits, crash data, mathematical models, operating costs, economic analysis	**18. Distribution Statement** No restrictions.

19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 103	**22. Price** N/A

Form Dot F 1700.7 (8-72) Reproduction of completed page authorized

About the UC Institute of Transportation Studies

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

Acknowledgments

This study was made possible through funding received by the University of California Institute of Transportation Studies from the State of California through the Road Repair and Accountability Act of 2017 (Senate Bill 1). The authors would like to thank the State of California for its support of university-based research, and especially for the funding received for this project.

Disclaimer

The contents of this report reflect the views of the author(s), who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the State of California in the interest of information exchange. The State of California assumes no liability for the contents or use thereof. Nor does the content necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

Assessing the Economic Impact of Speed Limit Changes on Safety and Mobility in California

Sarder Rafee Musabbir, Ph.D. Student, Civil and Environmental Engineering, University of California, Davis
Michael Zhang, PhD, Professor, Civil and Environmental Engineering, University of California, Davis

June 2023

UCDAVIS Institute of Transportation Studies

Report No.:UC-ITS-2021-36 | DOI:10.7922/G2NK3CCP

Table of Contents

Table of Contents

List of Tables

List of Figures

Glossary

Acronym	Definition
AADT	annual average daily traffic
BL	binary logit
HSIS	Highway Safety Information System
NB	negative binomial
DSL	differential speed limit
OR	odds ratio
PCF	primary collision factor
PDO	Property Damage Only
PeMS	Performance Measurement System
SWITRS	Statewide Integrated Traffic Records System
TAZ	traffic analysis zone
TIMS	Traffic Injury Mapping System
USL	uniform speed limit
VDS	Vehicle Detecting Station

Operational impact - impact in terms of mobility, i.e., speed, delay, and time of travel.

Operational data - as used in this report, data on the speeds at which vehicles are driven.

The following are definitions of various speeds from Institute of Transportation Engineers[1]

Design Speed - the selected speed used to determine the various geometric design features of the roadway.

Operating Speed - the speeds at which vehicles are observed operating during free flow conditions. Free flow conditions mean that vehicles are unimpeded by other vehicles or by traffic control devices such as traffic signals.

85th Percentile Speed - the speed at or below which 85 percent of vehicles travel.

Posted Speed - the maximum lawful speed for a particular location as displayed on a regulatory sign.

---

[1] https://www.ite.org/technical-resources/topics/speed-management-for-safety/setting-speed-limits/

Speed Limit - the maximum lawful vehicle speed for a specific location.

In this report, the design speed refers to the 85th percentile speed, and is used with speed limit interchangeably in some sections of the report.

Executive Summary

Executive Summary

Background

Speed limits promote highway safety and assist law enforcement to ensure an optimum tradeoff between safety and mobility based on the geometry of the roadway and other relevant factors. A review of studies from California and other states indicates that the findings concerning the impacts of changing speed limits on crashes and operational speeds are not consistent. Notably, some of the studies that analyzed the impact of raising the speed limit found an increase in mean speeds and fatal crashes, whereas others found no significant impact on crash severity or frequency. The direct comparison between the safety effect of differential speed limit (DSL) and uniform speed limit (USL) also reflects conflicting outcomes in several studies. In the case of California, which has adopted DSL, we need to understand the safety impact and potential benefit of increasing the speed limit, specifically the speed limit for trucks. California, with the largest roadway network, different terrain, and high volume of traffic possesses a unique set of traffic and roadway conditions compared to those of other states. Thus, we conducted a study, inspired by previous state-specific approaches in other states (Michigan, Indiana), to understand the safety aspects of increasing the speed limit in California and the potential economic impacts of such an increase.

This study assesses the impact of higher speed limits on safety and operational condition (mobility) to inform policymakers, based on statistical modeling and traffic simulation. The study focuses on two parts; one is safety and the other is mobility. The safety assessment for DSL policies is carried out using the statistical modeling approach. The mobility (operational condition) assessment is carried out by simulating different speed policy scenarios in the Simulation of Urban Mobility (SUMO) for representative roadway segments. As an additional component, we estimate safety costs associated with fatal and severe crashes for different speed limit policies across California. Moreover, we estimate the operational cost of alternative speed limit changes in representative urban and rural locations based on the simulated data (travel time, fuel consumption, etc.).

Data Sources

Data from multiple sources including Highway Safety Information System (HSIS), Statewide Integrated Traffic Records System (SWITRS), Transportation Injury Mapping System (TIMS), and Performance Measurement System (PeMS) have been extracted, used, and tested to develop a balanced dataset and generate statistical models for crashes. The modeling period is limited from 2013 to 2017. Different sources provided different types of data to develop the final modeling dataset. For instance, HSIS provides detailed roadway information supplemented with crash and victim records unlike the raw data from SWITRS, which has many errors in crash observations. TIMS provides a clear overview of statewide crash records with pinpoint location and accurate data encoding over the SWITRS raw data. It also aided in the selection of the simulation segments with the in-built crash visualization tool on county-wise classification.

Statistical Modeling

Two types of statistical models are developed in this study; (a) binary logit model; and (b) negative binomial model. The binary logit models are used to predict crash occurrence (crash or not) and fatal crash (fatal-or-severe or injury); whereas the negative binomial model is used to predict crash frequency on study segments. The primary idea of developing such models is to predict the crash frequency (number of crashes) and crash severity (fatal-severe crashes) by changing the design speed (85th percentile speed), assuming equivalency to the speed limit.

The crash frequency model shows that the odds of crashes in urban areas are higher across all design speed segments compared to the rural areas. For every unit increase in travel in urban areas across all design speed segments the number of crashes increases. This observation is consistent with the actual crash data as the number of crashes is higher on the urban road segments. For urban areas, the variation in design speed also shows an increase in the likelihood of crashes in 60 and 70-mph segments.

The fatal and severe crash model results indicate that the influence of alcohol is statistically significant and has a positive impact on the probability of the crash being fatal and severe. The sampled dataset for the model consists of 18,000 truck-related crashes. The model results indicate that truck-involved crashes are mostly fatal and severe. The lighting of roadway areas plays a critical role in crashes being fatal and severe. The absence of streetlights also increases the likelihood of a crash being fatal and severe. Similarly, the weather also plays a significant role in a crash being fatal and severe. Compared to clear weather fatal crashes are more likely to occur in cloudy weather. In urban and rural locations, the likelihood of a crash being fatal and severe increases with the increase in design speed.

The statistical models are used to estimate the crash frequency and fatal-severe crashes for different speed policy scenarios listed below.

A. Existing differential speeds on interstates with 60, 65, and 70 mph for cars and 55 mph for trucks
B. Raising the existing differential speed on freeways (urban and rural) from 55 to 60 mph for trucks and 65 to 70 mph for cars.
C. Raising the existing differential speed on freeways (urban and rural) from 55 to 65 mph for trucks and 65 to 75 mph for cars.
D. Raising the existing differential speed on freeways (urban and rural) from 55 to 70 mph for trucks and 65 to 80 mph for cars.

For the DSL scenarios, the design speed is raised to maintain the differential between car and truck speeds in the proposed change in the speed limit, unlike USL scenarios, where a uniform speed is required for all. Thus, to analyze a shift from the current DSL speed limit (**Policy A**), for instance, to a uniform speed limit for both cars and trucks at 65 mph, the speed of the trucks on the highway must be increased relative to that of cars. For this reason, separate speed data for cars and trucks are required. However, the study dataset consists of design speed for all traffic, including cars and trucks. Moreover, the PeMS repository with vehicle detecting stations (traffic sensors) contains aggregated traffic speed. Without the disaggregated speed data (car vs. truck), it is difficult to estimate and raise the truck speed limit to generate artificial USL scenarios for crash prediction. Thus, this study focuses on DSL scenarios (**Policy B, C, D**) for accurate crash prediction (safety implication) on California roadways. The results show that for all the scenarios with urban-rural and different design speed classifications, crash frequency and fatal and severe crashes increase with the increase in the speed limit. In urban areas, the increment in fatal-severe crashes is less than 1.31% for 5-, 10-, and 15-mph increments in speed limit.

Traffic Simulation

The simulation models describe the operational behavior of traffic (truck and car) for different speed limit policies. Seven simulation segments are selected from the California network based on the volume of truck traffic and truck-involved crashes. The web interface from the Transportation Injury Mapping System (TIMS) repository provides easy-to-access filters over the California GIS map with SWITRS crash records. The simulation segments are selected around California that attract a high volume of truck traffic (trucks, semi-trailers). The operational condition of traffic is measured using traffic variables including travel time, average speed, flow, vehicle miles traveled, etc. Four DSL scenarios and four USL scenarios are tested for each of the simulation segments.

For urban highways or freeways, the simulated segments exhibited a similar traffic trend. For instance, the travel time for cars gradually decreases as the speed limit is increased both for USL and DSL scenarios, implying that the average speed of cars and trucks increases with the increasing speed limit. The model simulates the off-peak traffic as the effect of speed limit changes diminishes during the peak period. Like cars, the travel time for trucks also decreases gradually with the increase in the speed limit for both USL and DSL scenarios. In the case of USL scenarios, the travel time for trucks is similar to that of cars as the speed limit is the same for both categories of vehicles (Appendix A).

The VMT and traffic throughput (flow) remain about constant for cars and trucks for all the DSL and USL scenarios. The time loss variable also represents a declining trend in the lost time while driving slower than the preferred speed. For the simulated segments, the speed variance is significant for the DSL scenarios, ranging from 5–10 mph. Notably, at higher speed limit scenarios (DSL) the speed variance or the speed difference between cars and trucks decreases. On the other hand, for the USL scenarios, the speed variance is present but small. For instance, the speed variance is around 2-3 mph for all the four USL scenarios ranging from 65 mph to 80 mph.

Cost Estimation

The safety cost is estimated based on the crash costs for different location classifications (urban/rural). Two types of safety costs have been considered in this study: (a) economic and (b) comprehensive; following the guidelines set by the National Safety Council (NSC). Since fatal and severe crashes have a significant impact on the cost component of safety, we estimated these two types for this study. The safety costs are estimated for the DSL scenarios using the estimated crash frequency and fatal-severe crashes. The estimated cost reflects the same trend as the predicted crashes, because the increase in crashes incurs more cost. As with the trend for increasing crashes, the estimated costs increase with the increase in the speed limit, maintaining the speed difference between cars and trucks. Notably, the estimated cost in the urban area shows an increase of about 1% for 5, 10, and 15 mph increments compared to the current speed limit policy. The comprehensive cost for severe injury and fatal crashes at base case is $2.857 billion for urban locations. The highest comprehensive safety cost ($2.891 billion) is observed for the 15 mph increment from the base case (65/55).

The operational costs are estimated for the simulated segments based on the value of time (travel time) costs and vehicle operating costs. Each of the segments shows a decline in travel time cost as increased speed relates to lower travel time. The operational cost analysis on the California highway network exhibits a reduction of approximately $2 billion (2%) from the base case (60/55) when the speed limit is raised to 70/60 (car/truck). Similarly, a 5% reduction in the operational cost from the base case is observed when the speed limit is raised to 75/65 (car/truck).

The estimated difference between combined safety and operational costs indicates a net cost reduction with the increase in speed limit. The combo cost is computed based on the economic and comprehensive safety costs. These costs from different speed limit scenarios are compared to the current speed limit scenario to analyze the possible impact of changing speed limits (Table 21). The estimation results reflect an increase in cost-effectiveness. For instance, changing the current speed limit to 70/60 mph results in an effective increase in benefits for urban and rural networks. This scenario shows a net benefit of approximately $1.8 billion in rural areas for comprehensive safety costs. Similarly, the benefit ranges around $1.4 billion for urban highways using comprehensive safety costs.

The operational cost assessment is limited to vehicle operating cost and travel time cost. It does not factor in other local and statewide costs for signage, training, and infrastructure costs. It provides a general overview of the system with possible uncertainty from seasonal demand, traffic variation, roadway condition, and location sampling. Similarly, the inclusion of Property Damage Only (PDO) and injury crashes will add to the estimation of the safety cost. From the economic perspective in this study, raising speed limits on rural California highways could reduce monetary costs, as savings in operational costs would exceed losses from more crashes.

Contents

Introduction

Speed is a key factor influencing traffic safety and mobility on highways. Speed limit informs motorists of the safe travel speed for standard road-traffic conditions and indicates a trade-off between safety and mobility. For instance, higher traveling speeds relate to longer stopping distances and additional energy, increasing crash likelihood and severity. On the other hand, a higher speed limit relates to shorter travel time (which increases mobility) that has a positive impact on economic well-being (especially for the trucking industry) and quality of life. Thus, it is a critical task for highway management agencies to set an optimum speed limit on freeways for all types of vehicles, including trucks [1].

There have been three major Congressional actions setting speed limits across the United States over the last decades. The first one was the *National Maximum Speed Limit (NMSL)*, which established a national maximum speed limit of *55 mph* as part of the Emergency Highway Conservation Act of 1974. The second was the relaxation of NMSL in 1987, allowing states to selectively increase speed limits up to *65 mph* on rural interstate highways. The third decision came in 1995 when the NMSL was repealed, providing states full authority to determine appropriate speed limits for their roadways. As part of these policy changes, the truck speed limit received major attention as a critical component of commercial development.

In response to these policy changes, several research studies examined the impact of speed limits on traffic crashes and fatalities. Considering the objective and the available data, some study results implied that higher speed limits have a negative impact on traffic safety by increasing the number and/or rate of traffic fatalities [1], [2]. In contrast, others suggested that an increase in the speed limit is not necessarily associated with fatal crashes or safety, and some reported a positive impact from speed limit increases on safety in terms of reduced traffic fatalities [3].

These studies prompted a discussion about whether truck operating speed has a significant influence on the frequency and severity of crashes. Two different schools of thought are followed on setting truck speed limits: (i) uniform speed limit (USL); and (ii) differential speed limit (DSL). USL is a uniform maximum speed limit policy for all classes of vehicles (passenger cars, trucks). DSL consists of different speed limit policies for different classes of vehicles, setting a lower speed limit for trucks than passenger cars [4]. DSL policy recommends lowering the truck speed limit on the assumption that it reduces the potential crash risks for all other surrounding traffic, given the greater size, weight, and limited braking power of trucks during a crash. Moreover, higher speed means more fuel consumption that in turn increases environmental pollution and monetary cost. In contrast, the philosophical argument for a USL policy is that lower truck speeds compared to cars contribute to the formation of randomly moving bottlenecks, causing breakdowns and a greater likelihood of crashes, particularly as cars attempt to overtake slower trucks [3]. Thus, there are economic trade-offs between safety and mobility in setting speed limits. Furthermore, considerable debate exists on the true impacts of speed limit policies on traffic crashes and fatalities. Analysis of a broad range of traffic safety and operational data is a first step to ascertaining these impacts and trade-offs.

The State of California follows the DSL policy for setting different speed limits for cars (65 mph) and trucks (55 mph). The maximum speed limit is set as 70 mph for cars on rural freeways with 55 mph for trucks. On urban freeways, speed limits range from 60 to 65 mph depending on traffic conditions. Overall, 55 mph is a set speed limit for trucks across the truck network in California. The California Department of Transportation (Caltrans) has a guidance manual to set the speed limit on California roadways. The speed limits are set both by following the standard safety guidelines and engineering or empirical analysis of the motorist's behavior, road condition, and crash record. Notably, though the speed limit is set following the motorist behavior, design speed (85th percentile speed), and other criteria; motorists frequently exceed the posted limit in response to their perceived level of safety (crash risk) and enforcement [5].

From the operational perspective, cars traveling at higher speeds will likely navigate around (overtake) a slower moving truck to keep the preferred speed and visibility. Such actions will increase the likelihood of lane changes when trucks are present in the highway or freeway traffic. Notably, unsafe lane change is one of the primary collision factors of the crash incidences on California highways, observed from the statewide crash records. Moreover, the trucks may generate a slowdown while overtaking other trucks on a two-lane highway (e.g., I-5), since the motorists wait behind the trucks initiating the overtaking maneuver. The operational condition also varies with the number and density of vehicles on the roadway since the motorists exhibit different driving behaviors in congested and uncongested traffic conditions. In congested scenarios, motorists cannot drive at their preferred speed and are influenced by the slower speed of other motorists. As such, in congested conditions, the effect of the speed limit on preferred speed diminishes. On the other hand, the driving behavior in an uncongested condition varies as different traffic (cars and trucks) exhibit different conformity to the posted limit. For instance, trucks are more likely to conform to the posted limit than cars as they are heavily enforced due to safety issues, meaning for the same level of the infraction (speeding) a truck driver will face a higher penalty than a car.

Since few states (seven) follow the DSL policy and increasing the speed limit provides an opportunity to improve mobility and increase economic growth, it would be useful to examine the impact of DSL and USL policies in the California context. Investigation of such state-wide speed limit alternatives warrants a careful evaluation of the safety and mobility (travel time) effects [3]. This study aims to provide, through statistical modeling and traffic simulation tools, an understanding of the economic impacts of different speed limit policies (DSL and USL) in the California as they affect safety and operational costs.

Statistical modeling is a necessary component to understand and analyze the crashes or safety (crash occurrence and severity) on California highways, whereas the simulation tool is necessary to investigate the operational condition or mobility (travel time, speed) for different speed limit policies or scenarios. More specifically the goals of the study are: (a) to estimate the safety effect (crash occurrence and severity) of raising speed limits in urban and rural areas; (b) to determine the mobility (travel time) effect of raising speed limits for trucks and cars.

Speed Limit: Policy Direction

Since the repeal of the National Maximum Speed Law, each state has had complete control over its speed limits. A total of 41 States have set speed limits of 70 mph or higher on some portions of their freeways (Figure 1) [1]. Over the years, the popularity of DSL policy has diminished [6] as there are only seven states (California, Idaho, Indiana, Michigan, Montana, Oregon, and Washington) still employing the DSL policy on their freeways (Table 1). Since 2011, 28 states have raised their posted speed limits, and three states—Montana, Texas, and Oregon—have raised speed limits for trucks as well [7]. For instance, the State of Utah passed legislation in 2013, which allowed the state Department of Transportation to increase the speed limit to 80 mph on certain sections of the state highway; Maine passed legislation in 2013 allowing speeds up to 75 mph on interstates and other divided access-controlled highways.

In 2015, several states (Montana, Nevada, South Dakota, Wyoming, Maryland, Oregon, Wisconsin, and Washington) increased their speed limits. Montana, Nevada, South Dakota, and Wyoming increased the speed limit to 80 mph. Montana also increased the truck speed limit to 65 mph. Similarly, Wisconsin increased its overall speed limit to 70 mph, whereas Maryland and Oregon increased the speed limit to 70 mph on some freeway sections. Following the policy direction of these other states and in light of the potential benefits, Washington increased its speed limit to 75 mph.

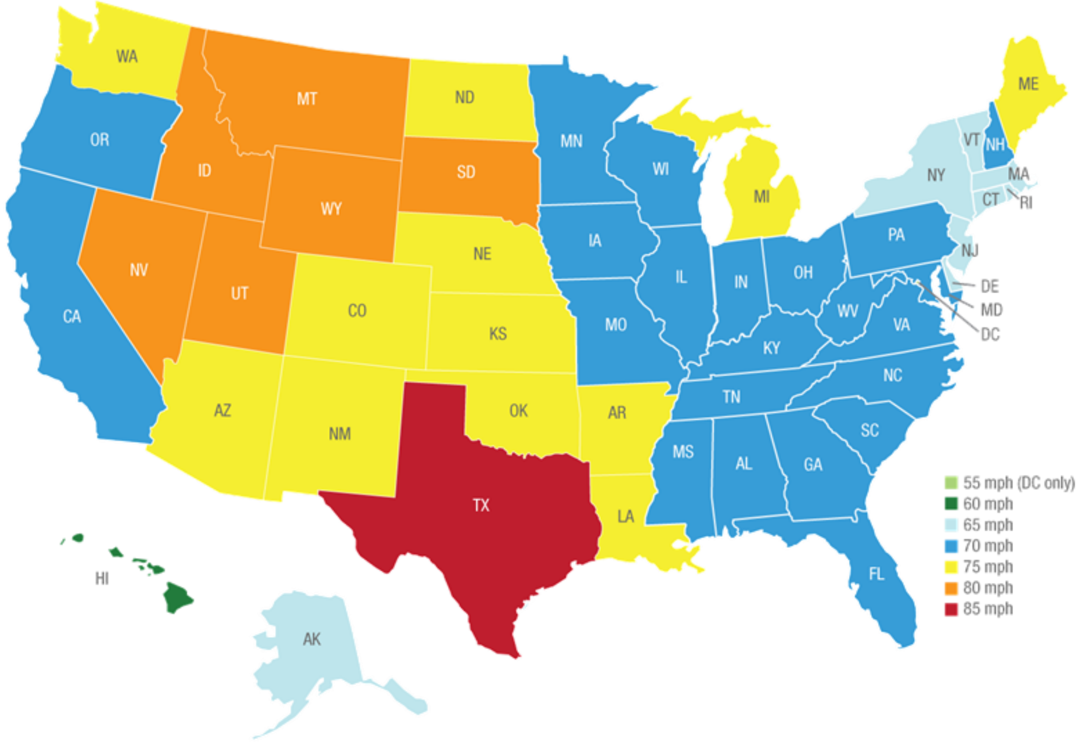


Figure 1. Maximum Interstate Speed Limits Across USA [8]

Table 1. Differential Speed Limit Across USA [8]

State	**Rural Interstates (mph)**			**Urban Interstates (mph)**		
	Car	***Truck***	***Difference***	***Car***	***Truck***	***Difference***
California	70	55	15	65	55	10
Idaho	75	70	5	75	65	10
	80	70	10	80	65	15
Indiana	70	65	5	55	55	0
Michigan	70	65	5	70	70	0
	75	65	10			
Montana	80	65	15	65	65	0
Oregon	65	55	10	55	55	0
	70	65	5			
Washington	70	60	10	60	60	0
	75	60	5			

Related Literature

The relationship between the speed limit and operating speed has been investigated by many using a variety of approaches including before-after studies, cross-sectional studies, and motorists' behavioral studies with a focus on the enforcement perception and reaction to different speed limits. Similarly, researchers have also established the relationship between speed, crash frequency, and severity using a multitude of models and machine learning techniques. These studies have examined the connections between independent variables, including average speed, speed variance, crash frequency, crash severity, and dependent variables consisting of traffic, roadway, and geometry properties. However, the investigation into the direct relationship between safety, mobility, and speed limits has only resulted in inconclusive and conflicting findings. The impact of speed limits on traffic safety and mobility is a critical research topic since a consensus on the balanced relationship between speed, safety, and mobility has yet to be reached [3]. This section reviews the relevant literature discussing the safety and operational effects of raising or lowering speed limits and other secondary impacts of USL and DSL policies. The review highlights several key points, such as the effect of speed on freeway crashes, and factors influencing crash frequency and severity.

In general, the studies show that increasing the speed limit typically results in somewhat higher average speeds and increases the probability of fatalities and severe injuries, and that lower speed limits reduce the frequency and severity of crashes. However, increasing speed limits increased the probability of fatal crashes and severe injuries to a lesser degree on highways that are designed for higher speeds than on other roads.

Higher truck speed limits also result in more truck-related fatal crashes but the evidence is mixed on whether differences in car and truck speeds lead to more accidents and some studies show that even with higher truck speed limits average speeds are still lower for trucks than automobiles. There is some support for the idea that lower truck speed limits compared to automobiles result in fewer accidents, but the results are not conclusive.

Regarding California specifically, Haselton et al. [9] assessed the crash patterns on California highways in relation to the posted speed limit. Relevant collision, speed, and traffic volume data were collected at locations where the speed limit was increased from 55 to 65 mph, or from 65 to 70 mph, in early 1996. The study implemented three methodologies for comparison including simple regression, analysis of variance (ANOVA), and an observational before-and-after study. The findings indicated that fatal crashes increased by 35.8% after the speed limit was increased from 55 to 65 mph, and by 33.9% when it was increased from 65 to 70 mph.

Some studies investigated the effect of speed limit reduction on possible safety issues and crash severity. For instance, De Pauw et al. [10] assessed the safety effects of reducing the speed limit from 90 kph (56 mph) to 70 kph (43 mph) on several highways in Belgium. The study incorporated 61 road sections with a total length of 116 km (72 miles) and a control group consisting of 19 road sections with a total length of 53 km (33 miles). The authors estimated the crash modification factor for fatal and injury-related crashes from six years before and after the change in speed limit. The results showed a decrease in fatal and injury-related crashes with the reduced speed limits [10]. Similarly, Islam and El-Basyouny [11] investigated the safety effect of reducing the speed limit from 50 kph (31 mph) to 40 kph (25 mph) for eight urban residential areas in Canada using crash data from four years before and after the change. The study utilized the empirical Bayes and full Bayesian methods; the full Bayesian results showed that lowering the speed limit reduces the frequency and severity of crashes, whereas the empirical Bayes method showed the opposite.

Time series crash data is valuable to study the combined effect of speed limit change on safety. For instance, Farmer [12] examined the combined effect of changes to maximum speed limits across the United States from 1995 to 2013. The author modeled annual traffic fatality rates by states as a function of maximum speed limits. He also accounted for general time trends, unemployment, the percentage of young drivers, and alcohol sales.

The methodology used in Farmer's study was recently updated to include modeling of state-by-state annual traffic fatality rates per mile of travel as a function of time, the unemployment rate, the percentage of the driving population younger than 25-years-old, safety belt use rate, and maximum posted speed limit [1]. The outcomes showed that a 5 mph increase in the speed limit increases the fatality rate by 8.5% on freeways and 2.8% on other roadways. Altogether, the authors estimated that during the 25-year study period approximately 36,760 (13,638 on interstates and 23,122 on other roads) more traffic fatalities occurred than would otherwise have been expected with no change in the maximum speed limit [1]. Prior to the Farmer study [12], Kockelman et al. [13] investigated the impacts of speed limit change with several datasets, including Washington State Highway Safety Information System data from 1993 to 1996. They found that an increase in the speed limit resulted in higher average speeds and that higher speeds increase the probability of fatalities and severe injuries. In another approach, Donnell et al. [14] published an informational guideline for evaluating design speed and setting speed limits. They found that higher vehicle speeds lead to more severe crashes and that the greater the change in speed at the impact the greater the probability of being injured in a crash. Later, Donnell et al. [15] studied the effects of increasing the speed limit from 65 mph to 70 mph on sections of rural interstates in Pennsylvania. They developed a framework for safety performance functions for future before-and-after studies using the empirical Bayes method.

Savolainen et al. [3] conducted a longitudinal analysis of fatal crash data across the United States from 1999 to 2011 and found that higher speed limits led to more single-vehicle crashes, while lower speed limits resulted in more rear-end crashes. The study assessed state-level traffic crash data for Michigan freeways from 2004 to 2012 and showed that crash, injury, and fatality rates on freeways with higher design speeds (> 70 mph) are lower than those where speed limits are raised from 55 to 65 or 70 mph. This study highlights the significance of geometric roadway design and traffic attributes for setting higher speed limit policies. Other approaches based on different datasets (Fatality Analysis Reporting System and Texas Department of Transportation) with similar study objectives also found that increases in speed limits produce more fatal crashes and severe injuries [2], [16].

Investigating truck crash incidents, Davis et al. [17] found that states with a 70 mph speed limit experienced approximately 32% more truck and bus-related fatal crashes than states with 60-65 mph speed limits (see Table 2). They also found that states with 75 mph or higher speed limits have approximately 52% more truck and bus-related fatal crashes. Grant and Lilliard [18] plotted average truck-related fatalities by rural interstate speed limits across the country from 1991 to 2005 and found higher speed limits associated with more truck-related crash fatalities. For DSL policies, Johnson and Pawar [19] analyzed speed data from Arkansas and Illinois rural interstate highways with 70/65 mph (car/truck) and 65/55 mph (car/truck) speed limits and suggested that higher speed variance is associated with a greater risk of a crash (Table 2). Speed variance or differential is the difference in speed between cars and trucks. Notably, the interaction of speed variance with the posted speed limit for trucks and cars is still an open question. Inspired by Monsere et al. [7], we list, in Table 2, the effect of raising USL on vehicle speed measures, including design speed, mean speed, and speed variance. Some of the listed studies [3], [15], [20], [24-26] detail the effect of raising the speed limit, whereas the rest of the studies compare two different speed limits. In this report, the design speed is the 85th percentile speed of the traffic on the roadway.

To investigate the effect of speed limit policies on operational speeds across the country, Johnson and Murray [21] worked with the speed data from 19 rural interstate locations. They found that states with 75 mph truck speed limits had only a 6.3 mph higher mean truck speed than states with 55 mph truck speed limits. Similarly, states with 75 mph truck speed limits had only a 1 mph higher design speed than the states with a 70-mph limit. For passenger cars, the design speed remained somewhat the same across states with 65 and 70 mph speed limits. The mean car speed was 3.5 mph higher than the speed limits of 75 mph compared to 65 mph. Notably, the analysis showed that the speed differential between cars and trucks is evident across different states regardless of speed limit policy (DSL or USL). Furthermore, Garber et al. [22] examined 17 rural interstate highways from 1991 to 2000 and found that average speed, design speed, median speed, and crash rates increased over the 10 years, irrespective of the speed limit policy (USL or DSL).

Table 2. The Effect of Speed Limit Policies on Observed Speed

States [Study Reference]	Speed Policy	Before (mph)	After (mph)	Design Speed Change (mph)	Mean Speed Change (mph)	Compliance Rate Change	Speed Variance (mph)
Texas [23]	USL	70	75	+3	< +5		
Pennsylvania [15]	USL	65	70	< +5	< +5		
Utah [20]	USL	75	80		< +5	Cars (+)	
						Trucks (+)	
Ohio [3]	USL [a]	<65	70				5.4
Michigan [3]	DSL [a] (Car/Truck)	<65	70/60	< +5	< +5		6.9
Indiana [3]	DSL [a] (Car/Truck)	<65	70/65	< +2.5	< +2.5		6.2
Oklahoma vs. Missouri [19]	USL [a] (Trucks)	70	75	+4	+4	+3.1%	1.08
	USL [a] (Cars)	70	75	+3	+2.2	+21.5%	-0.3
Arkansas vs. Illinois [19]	DSL [a] (Trucks)	65/55	70/65	+2	+2.5	32.5%	-0.3
	DSL [a] (Cars)	65/55	70/65	-1	+0.3	14.5%	-1.3
West Texas [24]	USL to DSL (Cars)	75	75/80		+6	-9% (> SL)	
	USL to DSL (Trucks)	75	75/80		+3	-9% (> SL)	
Idaho [25]	USL to DSL (Trucks)	75	75/65	-4.5	- 2.1	+10% (> SL)	
	USL to DSL (Cars)	75	75/65		+1.1		
Montana [26]	USL to DSL	65	70/60	+3.2	+1.6		+1.3

a-Comparing speed limits; SL-Speed Limit

Souleyrette and Olson [27] assessed the effects of changing the speed limit from 65 mph to 70 mph in Iowa and found an increase of 2 mph in the design speed. They also found a reduction in speeding violations by 12%. The study also inferred that an increase in the speed limit is associated with an increase in crash frequency and severity. For instance, night-time fatal crashes increased by 52%, serious injury cross-median crashes increased by 25%, and total crashes increased by 25%. The effect of raising speed limits on crash severity and frequency is listed in Table 3.

Table 3. The Effect of Raising Speed Limits on Crash Frequency and Severity

Reference	Period	Scope	From	To	Fatal Crashes	Truck-Related Fatal Crashes	Frequency
Davis et al.[17]	1999-2011	US (Rural)	60-65	70	+22.2 %	+31.7 %	
			60-65	75+	+84.5 %	+51.1 %	
Kockelman [13]	1993-1996	US	55	65	+24 %		+3%
Savolainen et al. [3]	1999-2011	US	60	70	+31 %		
			65	75	+54 %		
Grant and Lilliard [18]	2005	US	--	55			-561
			--	75			+362
Farmer [12]	1993-2013	US	+5		+8.3 %		-33,000

Hu et.al [20] investigated the impact in Utah between 2010 to 2014 of raising the speed limit on rural interstate freeways from 75 mph to 80 mph. They used a log-linear regression model to estimate percentage changes in speed variance and mean speeds for passenger cars and large trucks associated with the speed limit increase. Results showed that the mean speed change for passenger cars was 8.6% and 5.1% for trucks. For large trucks, the mean speed and probability of exceeding 80 mph were higher than expected within the 80 mph zones. Notably, the results contradict the claim that increasing speed limits reduces speed variance, likely due to the small sample size and the study locations being in different states [20].

Malyshkina and Mannering [28] investigated the effect of speed limit increases (65 mph to 70 mph) in Indiana on crash frequency and severity using a multinomial logit model. A multinomial logit model can relax parameter restrictions, which allows the effect of the speed limit to vary across injury outcomes. The results showed no statistically significant correlation between a change in speed limit and a change in crash severity on interstates. In another approach, Kweon and Kockelman [29] examined the safety effects of speed limit changes on Washington State highways with a posted speed limit greater than 55 mph using random effects negative binomial model. The speed data recorded from the highway segments were used to develop models for average speed and speed variance. These models were used to estimate speed where speed data was not available. The estimated speed data combined with speed limit information and roadway design features were used to estimate crash frequency. The findings showed that none of the speed-related variables had a statistically significant relationship with the frequency of fatal crashes. However, geometric features such as wider shoulders and gentle horizontal curves were associated with fewer fatal and non-fatal crashes.

Table 4. The Effect of Changing Speed Limit Policies on Crash Frequency and Severity

Study	Period	Scope	From	To	Fatal Crashes	Truck-Related Fatal Crashes	Frequency
Davis et al. [17]	1999-2011	USA	USL	DSL	-3.3%	-24.6%	
Savolainen et al. [3]	2004-2012	Michigan (Urban)	USL (55)	DSL (70/60)	-45%		
			DSL (65-70/60)	USL (70)			Decreased
	1999-2011	USA	USL	DSL		-20.5%	
Dixon et al. [25]	1998-2011	Idaho	USL (75)	DSL (75/65)	-26%	-38%	
Korkut et al. [30]	2004-2006	Louisiana	USL (60)	DSL (60/55)	-13%	-79%	
Gates et al. [26]	2005-2014	Montana	DSL (70/60)	USL (65)			NSg
Garber et al. [31]	1991-2000	Idaho	USL	DSL			Increased
		Virginia	DSL	USL	NSg		Increased

NSg – Non-Significant

Davis et al. [17] explored traffic fatalities on rural interstate highways from 1999 to 2011 and found that states with DSL policies had 3.3% fewer total fatal crashes and 24.6% fewer truck- and bus-involved fatal crashes compared to USL states (Table 4). Similarly, Savolainen et al. [3] found that states with USL policies had 20.5% more truck- and bus-involved fatalities than DSL states.

Dixon et al. [25] analyzed the change from a USL policy (75 mph) to a DSL policy (75/65 mph) on rural Idaho interstates and found that crash rates for all-vehicle-involved crashes declined by 26% and truck-involved crashes declined by 38%. They developed a crash prediction model that showed truck-involved crashes decreased by 8.56%, with a standard deviation of 5.06%. Differential speed limits and truck lane restriction policies were implemented on a Louisiana freeway where the results indicated that total crashes decreased by 13% and truck-involved crashes decreased by 79% [32], [30]. Gates et al. [26] found that a change from a DSL (70/60 mph) to a USL (65 mph) on two-lane two-way rural highways in Montana in 2013 did not change the number of non-animal related crashes significantly.

A recent study on the Indiana freeways to predict the impact of changing the speed limit on safety and mobility showed that the conversion from differential (70/65) to uniform (70) speed limit on rural freeways will reduce crash frequency by almost 20% for all forms of crash severity and supplement a $479 million annual benefit.

Whereas for urban freeways the impact of changing to a USL will be the opposite, with increased crash frequency and severity, and net annual loss [5].

Table 5. Safety Impact of USL and DSL

Purpose / Goal	Scope	Results	Reference
Assess the impact of DSL and transition from DSL to USL	Virginia	The results showed differences between the passenger vehicle and truck speeds without any consistent safety differences.	Garber et al. [31]
Assess the speed distributions for both heavy trucks and light vehicles including DSL & USL	19 rural interstate highway sites across the USA	Mean and design speeds were relatively unaffected by the posted speed limits. The 20-mph range for the posted truck speed limits (55 to 75 mph) resulted in only a 7 mph increase in the average speed for trucks (61.7 to 68.8 mph).	Johnson and Murray [21]
Assess the safety impact of DSL	Idaho for DSL	Truck mean speeds were reduced to 65.6 mph and that in turn reduced the speed variance and violation rate. The DSL reduced crashes by 8.56% below the 95% confidence level.	Dixon et al. [25]
Assess the impact of raising speed limits on crash severities	Indiana; Electronic Vehicle Crash Record System (2004-2006)	For crashes in 2006, 5.78% is identified as unsafe speed, compared to 7.28% before the speed limit increase. An increase in the speed limit did not significantly affect crash severity levels.	Malyshkina and Mannering [28]

To summarize, an extensive review of the studies from California and other states indicates that the findings regarding the impacts of changing speed limits on crashes and operational speeds are not consistent. The findings related to safety impact are not conclusive and limited by the studies' scope, data, and locations. Notably, some of the studies that analyzed the impact of raising the speed limit on safety and operational speed (mobility) found an increase in fatal crashes and mean speeds, whereas others found no significant impact on crash severity or traffic attributes. For this reason, a more detailed effort is required to study the safety impact of USL and DSL in the California context. The current study addresses this problem by assessing the effect of speed limits on both safety and mobility. The statistical models used to analyze the safety impact and the simulation models built to check the operational condition (mobility) are the means to improve the realism of evaluating the impact of alternative speed limits policies for California Highways.

Data Description

Statistical Modeling Data

Statewide Integrated Traffic Records System (SWITRS)

The Statewide Integrated Traffic Records System (SWITRS) is a database that collects and processes data gathered from a collision scene. The Internet SWITRS application is a tool that allows the California Highway Patrol, other allied agencies, and members of the public to request various types of statistical reports from this database in an electronic format. The application allows for the creation of custom reports requested by the user, based on different categories, including locations, dates, and collision types.

The preprocessing of the SWITRS data revealed an accuracy issue with numerous data points (longitude and latitude) that mapped to locations in the ocean or outside California (see Figure 5). However, the proportion of accurately mapped data from SWITRS can be identified using the Traffic Injury Mapping System (TIMS), hosted by SafeTREC, UC Berkeley. This study uses both TIMS and SWITRS datasets to divide the entire California dataset into two parts based on different locations: (i) urban; (ii) rural. The SWITRS data consists of more than 200,000 observations per year. However, the dataset is reduced to about 150,000 per year after processing the raw data and updated at TIMS.

The SWITRS data have a hierarchical structure, where the *collision* tables contain information on each collision and the *party* tables contain information from all parties involved in the collisions. Parties are the major players in a traffic collision, including drivers, pedestrians, bicyclists, and parked vehicles. The party information includes personal descriptors and vehicle descriptors. The *victim* tables contain information about the victims associated with each party. For example, in a motorcycle-related crash incident, a motorcyclist and his passenger are each a victim. The victims can be thought of as being nested within parties and parties can be thought of as being nested within crashes.

Combination of SWITRS-TIMS and HSIS Dataset

The Highway Safety Information System (HSIS) is a data source that stores processed data with roadway, victim, and crash information. This data processing and storage system is a cooperative approach funded by Federal Highway Administration (FHWA) for the participating states (8 states including California). The dataset is processed and compiled annually in a common format for further statistical analysis. It contains all sorts of roadway information across California including key traffic information such as average annual daily traffic (AADT) and design speed. The dataset consists of approximately 50,000 roadway segments with roadway information on the median type, pavement width, number of lanes, etc. On the other hand, the SWITRS-TIMS dataset contains crash information on roadway segments. We matched these sources to enrich each crash observation with specific roadway and traffic information. We used two types of combinations for the statistical analysis. One combination includes roadway data and crash data, where each roadway segment is matched with the crash occurrences from the crash observations. The purpose of this combination is to determine the crash occurrence in each California segment. The other combination is based on the crash observation, where each crash observation (SWITRS-TIMS) is matched with specific roadway locations (roadway data-HSIS). The crash dataset is supplemented with roadway information to provide a better understanding of the relation between different design speeds and safety across California segments. Since the study focus was limited to freeway or highway, the design speed limit is observed from 55 mph to 70 mph.

Safety Data for Modeling

This section describes some parts of the data used for modeling purposes. The modeling dataset consists of the combined data from SWITRS or TIMS and HSIS. The merging technique and steps are discussed in the previous section. Table 6 lists the continuous variables involved in the modeling and provides a statistical description consisting of mean, minimum, maximum, and standard deviation. These variables help to identify the breadth and frequency of the variables in the dataset. The crash records are divided into five severity categories ranging from the complaint of pain to fatal crashes. To develop the fatal crash model, the severity category is reorganized into two categories (fatal-severe or injury).

Table 6. Statistical Description of the Continuous Variables

Variable	Number of Observations	Statistical Description				
		Mean	Standard Deviation	Min	Max	Range
Count of severe injuries	262,712	0.07	0.30	0	12	12
Count of visible injuries	262,712	0.34	0.60	0	28	28
Count of Complaint of Pain	262,712	1.02	0.92	0	35	35
Population (in thousands)	262,712	6.62	1.87	1	9	8
Number killed	262,712	0.02	0.18	0	13	13
Number injured	262,712	1.43	0.02	0.18	49	49
Party Count	262,712	2.11	0.89	1	23	22
Segment Length	262,712	780.16	1266.11	1.58	21,790.11	21,789.11
AADT	262,712	136.79	95.35	0.11	461.36	461.25
Distance to nearest intersection (ft)	262,712	1627.99	44,868.11	0.00	88,440	88,440
Lane Width (ft)	258,452	11.97	0.64	9	44	35
Left Shoulder Width (ft)	260,043	5.98	4.19	0	37	37
Right Shoulder Width (ft)	223,523	9.09	2.57	0	48	48
Surface Width (ft)	223,523	45.50	16.99	0	144	144
Median Width (ft)	260,043	27.98	25.8	0	99	99
Pavement Width Left	260,043	5.6	4.3	0	37	37
Pavement Width Right	260,043	8.16	3.16	0	36	36

Simulation Data

Performance Measurement System (PeMS)

PeMS is sponsored by the California Department of Transportation (Caltrans) to offer tools and reports for traffic planners, operators, and engineers via a web interface. It provides an easy-to-access source of historical and real-time traffic data on highways and interstates. It collects real-time traffic data (speed, flow, occupancy) from sensors and estimates performance measures including vehicle miles traveled (VMT), delay, and travel time. PeMS data is a reliable source of traffic information to understand and replicate the operational condition of the freeway or highway. In this study, PeMS data is used to model the operational condition of the urban and rural highways/freeways to determine the impact of changing speed limits on mobility. The dataset consists of time-series records of traffic information from vehicle detecting stations (VDS) on the mainline and ramps along the freeway or highway segment.

Simulation Segments

The simulation segments are selected from the TIMS query interface based on several criteria including frequency of truck crashes, adjacent city, urban and rural location, state route, etc. The segments are sampled across California based on the truck traffic volume and crashes. Each simulation of a freeway or highway route covers a segment more than 3 miles in length whether in a rural or urban area. There are a total of 7 simulation models with 3 locations in rural areas and 4 locations in urban areas to test the impact of speed limit changes on traffic operation (travel time, speed, etc.). The demand (traffic flow) in the simulation models is generated from the VDS data collected from PeMS for both mainline and ramps. The simulation models serve as a template for urban and rural areas with high truck volumes that can be adapted for other locations across California with lower truck volumes. Each simulation model is run for different scenarios or speed limit policies. A detailed description is provided in the methodology section.

Study Methodology

The study is divided into two parts. The first part describes the safety impact of speed limit changes using statistical modeling analysis. The second part involves traffic simulation analysis, where the operational condition, or mobility, of the roadway with different speed limits is examined for cars and trucks.

The impact of speed limit changes is considered separately for cars and trucks because of the vehicle dynamics (acceleration, deceleration), gross weight, axle size, length, turning radius, etc. In general, trucks move more slowly than cars due to differences in dynamics, and the presence of speed limiters, irrespective of the posted speed limit on the highway [33], [34]. Moreover, perception of enforcement plays a key role in different driving behavior. For example, truck drivers are more likely to be ticketed or penalized for speeding compared to cars due to the level of severity involving truck crashes. Lastly, the cost component for cars and trucks varies with the fuel consumption and value of time. For example, in 2014 the average hourly cost of truck operation was $46.10; whereas the cost for cars was half at $21.31 [35].

In the study, urban and rural roads are classified separately due to the difference in speed limit settings, driving behavior, trip purpose, and enforcement level. In California, many rural interstates or highways have a speed limit of 70 mph for cars and 55 mph for trucks, whereas the urban freeways are mostly limited to 65 mph for cars and 55 mph for trucks. The driving pattern on urban and rural highways differ as urban roads mostly cater to the daily commuters who are familiar with the road and often drive aggressively to maintain preferred speeds. Moreover, enforcement in urban areas also differs as more police officers patrol the roads for deviant driving, moderating motorists' tendency to drive over the posted speed limit.

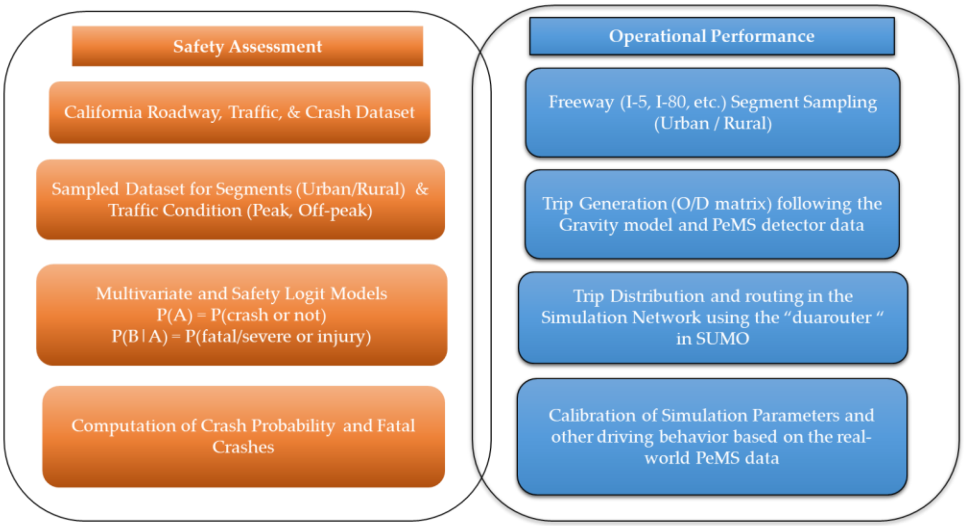


Figure 2. Description of the study Methodology

Statistical Modeling

Two types of statistical models are developed in this study: a binary logit model and a negative binomial model. The binary logit models are used to predict crash occurrence (crash or not) and fatal crash (fatal-severe or injury); whereas the negative binomial model is used to predict crash frequency on study segments. This section highlights the scope of the two binary logit models and one negative binomial model, which are applied to different types of roadway segments (urban and rural) and design speeds (60, 65, and 70). The primary idea of developing such models is to predict the crash frequency (number of crashes) and crash severity (fatal-severe crashes) by changing the design speed, assuming equivalency of the speed limit.

The negative binomial model represents the crash frequency on a particular segment, based on the roadway information (lane width, median width, etc.). Generally, this type of model is used for over-dispersed count data [36]. For instance, about 11,000 segments out of 50,000 do not have any crash observation for the study period of 2013-2017. Whereas the crash frequency on other segments varies widely (1 to 100 or more). The model can be interpreted as an extension of the regular count model (Poisson distribution) with an added parameter to handle the overdispersion of the count data (crash frequency).

The logit models are used sequentially to estimate the probability of a crash and the conditional probability of a crash being fatal or severe. First, the probability of a crash is computed from the roadway segment data. Second, the crash severity is modeled as the probability of a minor injury vs. a severe or fatal injury based on the crash data. A similar modeling technique is applied to all different models including rural-urban classification and different design speed segments. Since fatal crashes are small compared to the entire sampled dataset, we grouped the fatal and severe crashes to form a representative sample for the statistical model. This technique is a common practice in modeling crash severity on highways ([36], [37]).

Based on various input variables, two binary logit models determine whether the incident was more or less likely to involve a 1) crash or not crash and 2) fatal-severe or injury. Each model is developed (trained) based on a sample set and then tested on a separate sample to determine the model fitness for all classifications (urban, rural, and design speeds). Part of the modeling effort is focused on binary logit models, mainly due to the dichotomous (yes/no) nature of the dependent or response variables. For instance, the “fatal crash” logit model simply predicts the probability of a crash as being fatal-severe or not. On the other hand, the crash occurrence model predicts whether a crash will occur or not. The models are designed to overestimate the number of such crashes to ensure a margin of safety in setting the speed limit policy.

Table 7. Details of the Modeling Segments for the Study

Dependent or Response Variable (Y)	Model Type	Modeling Scope				
		Urban	Rural	Design Speed (mph)		
				70	65	60
Cash Frequency	Negative Binomial	x	x	x	x	x
Crash Occurrence	Binary Logit (BL)	x	x	x	x	x
Fatal and Severe Crashes	Binary Logit (BL)	x	x	x	x	x

This study builds on two sequential logit models to investigate and infer the relationships between various predictor variables (design speed, AADT, alcohol influence, etc.) and response variables (crash occurrence, fatal and severe crash). Thus, it is possible to compare the effects of different predictor variables on the response variables across models. For instance, in the fatal crash model, crashes involving trucks have a greater probability of being fatal-severe than passenger car-related crashes. This relationship is visible for all the models (urban, rural, and design speed).

The methodological approach is to develop the logit models with a portion of the historic crash data (2013-2017) and use them to predict (on the complete dataset) the number of crashes being fatal-severe or not. Once validated, the models are used to estimate changes in the response variables for the different speed limits (design speed). More details on the prediction part of the modeling are discussed in the results section. The framework of the logit model used in this study is defined as follows.

$$P(y_n) = \frac{e^x}{1+e^x} \tag{1}$$

$$X = \beta_0 + \beta_1 x_1 + \beta_x x_2 + \ldots + \beta_N x_N \tag{2}$$

Where, $P(y_n)$ is the probability of n, x denotes the predictive variables which determine the probability of a discrete outcome for n, β_N denote estimating parameters, N defines the number of independent parameters and X represents the linear function of multiple explanatory variables. The odds ratio (OR) is obtained from the exponential of the logit model coefficients. It denotes the odds that an outcome will occur given an exposure, compared with the odds of the outcome happening in the absence of that exposure.

For example, let's say that among the accidents that involve a truck (i.e., are positive for the outcome "truck-related crash") the number **with** and the number **without** an "unsafe lane change" (i.e., the *exposure* or *predictor variable*) are *p* and *q*, respectively. Also, among the causes of accidents that do **not** involve a truck (i.e., are negative for the outcome), the number with and the number without an “unsafe lane change” (exposure) are *r* and *s*, respectively. The OR is calculated as follows:

$$OR = \frac{p/r}{q/s} = \frac{ps}{qr} \tag{3}$$

If the OR is greater than 1, the presence of the exposure (for instance, an unsafe lane change) is associated with higher odds of the crash being truck related. On the other hand, if the OR is less than 1, the presence of an unsafe lane change is associated with a lower probability of a truck being involved in the crash. In other words, an OR greater than 1 indicates that the predictor variable has a positive impact on the probability of the outcome (response variable). On the other hand, an OR lower than 1 indicates that the predictor variable has a negative impact on the outcome.

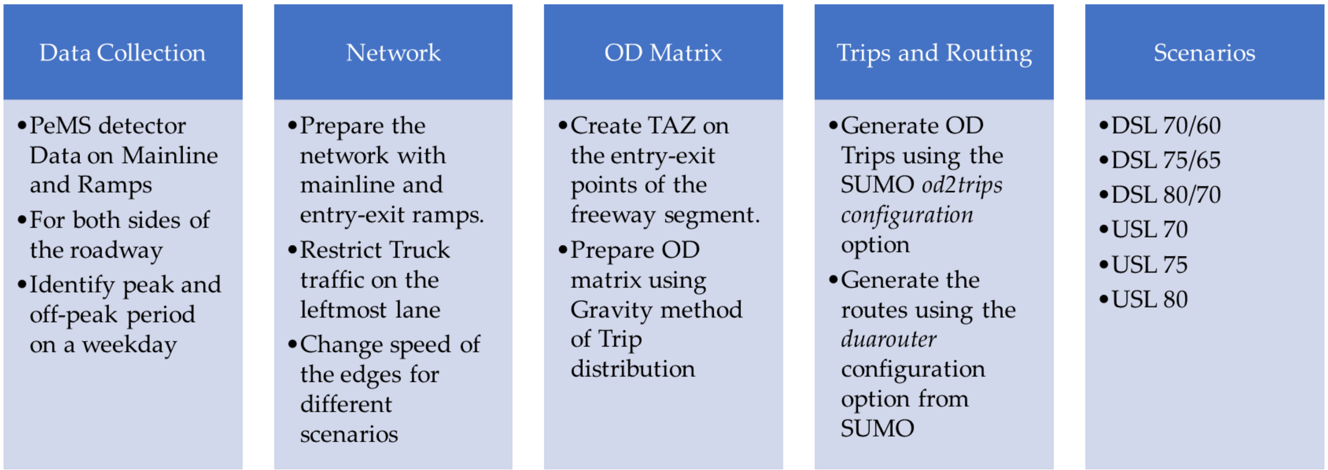
The result section describes the outcome of each of these statistical models and how some of the key predictor variables are related to the response variables, specifically whether they are more or less likely to be present in crashes, and in those involving fatalities. The final section of this study reports on what the models can infer about the likelihood of fatal or severe crashes from increasing speed limits consistent with the various scenarios presented above.

Traffic Simulation

The simulation models describe the operational behavior of traffic (truck and car) for different speed limit policies. Seven simulation segments are selected from the California network based on the volume of truck traffic and truck-involved crashes. The web interface from the TIMS (Traffic Injury Mapping System) repository provides easy-to-access filters over the California GIS map with SWITRS crash records. We selected simulation segments from across California that attract a high volume of car and truck traffic. The operational condition of traffic is measured using traffic variables including travel time, average speed, flow, vehicle miles traveled, etc.

Trip Generation and Routing

The simulation models are calibrated and validated using the traffic information from the PeMS detectors located at the mainline and ramps along with the freeway segments. The trips are generated considering the detectors as the origin (source) and destination (sink). For trip generation, different traffic analysis zones (TAZs) are created on the open ends of the simulation network. For instance, the origin-destination points on the mainline (freeway) and the exit-entry points on the ramps are selected as TAZs. Then the traffic flow recorded at the PeMS detectors (mainline and ramps) is distributed among the TAZs following the gravity model for trip distribution. Based on the gravity model distribution, the origin-destination trips are generated using the “od2trips” function in the SUMO simulation. Two separate trip files for cars and trucks are generated for each network or simulation model. Afterward, the routes are generated from these trips using the “duarouter” function in SUMO.



Data Collection

- PeMS detector Data on Mainline and Ramps
- For both sides of the roadway
- Identify peak and off-peak period on a weekday

Network

- Prepare the network with mainline and entry-exit ramps.
- Restrict Truck traffic on the leftmost lane
- Change speed of the edges for different scenarios

OD Matrix

- Create TAZ on the entry-exit points of the freeway segment.
- Prepare OD matrix using Gravity method of Trip distribution

Trips and Routing

- Generate OD Trips using the SUMO *od2trips configuration* option
- Generate the routes using the *duarouter* configuration option from SUMO

Scenarios

- DSL 70/60
- DSL 75/65
- DSL 80/70
- USL 70
- USL 75
- USL 80

Figure 3. Traffic Simulation Steps

Simulation Period

The simulation period for each simulated segment is based on the intermediate traffic demand between peak and off-peak periods. We recorded traffic data from the PeMS for one week in May 2019 to understand the peak, off-peak, and intermediate traffic patterns. Afterward, the simulation period is set up, varying from 4 to 6 hours on a weekday (Monday) based on the intermediate traffic demand. Previous studies have used intermediate traffic demand to analyze the impact of different speed limit policies on a simulated segment [5]. This is because the peak period caters to the highest volume of traffic on the highway, affecting the operational condition. The peak period traffic operates at a nearly congested volume and reduced speed. Thus, it becomes difficult to assess any possible impact of alternative speed limits on the overall traffic speed. On the other hand, the off-peak period caters to the least amount of traffic on the highway. Thus, any change in speed limit is directly proportional to the average traffic speed as the traffic moves without any impedance. However, for real-world consideration, intermediate traffic demand serves as an adequate threshold to reflect any possible impact of the changing speed limit [5].

Scenario Generation

Multiple scenarios are tested using the simulation models for both urban and rural areas. Several uniform and differential speed limit policies are tested to determine the operational conditions along with the study segments. The DSL scenarios include 70/60, 75/65, and 80/70 mph speed limits for cars and trucks, respectively. The USL scenarios include 65, 70, 75, and 80 mph uniform speeds for all types of traffic.

Calibration and Validation

Most of the freeway or highway segments are covered by traffic detectors (PeMS) on both mainline and ramps. The real-time detector data is used for trip generation and calibration of the simulation models. Since the demand (traffic flow) is generated directly from the real-time traffic data, secondary validation is not warranted. To replicate the real-time operational condition on the simulated segments, the leftmost lane is restricted to car traffic only when there are more than two lanes. Also, the speed limit difference between trucks and cars is maintained in the base condition and DSL scenarios, whereas for the USL scenarios the speed limit remains the same for cars and trucks.

Statistical Modeling Results

Crash Frequency Model

The crash frequency model describes the relationship between the number of crashes on the road segments and the roadway variables, including design speed and AADT. In other words, the model estimates the number of crashes on the road segments based on the association of the predictor variables (roadway and traffic characteristics). The model coefficient represents the change in the outcome variable for a unit change in the predictor variable, keeping all the other predictor variables constant. The model coefficients are placed in a natural log scale due to the log link function in the negative binomial model. Thus the exponential of the model coefficients or estimates denoted as the odds ratio (OR) describes the outcome variable on its original scale. Although the urban and rural segments are the primary classifications used to describe the spatial and temporal effect of similar predictor variables on crash occurrence, the classification of different design speeds provides insight into existing different speed limits.

Table 8. Negative Binomial Model for Crash Frequency

Predictor Variable	**Model Coefficients (Car speed limit / Truck Speed Limit)**				
	Urban	***Rural***	***Design Speed (70/55)***	***Design Speed (65/55)***	***Design Speed (60/55)***
CONTINUOUS VARIABLES					
Annual Average Daily Traffic (AADT)	1.008***	1.027***	1.008***	1.013***	1.015***
Segment Length	1.003***	1.001***	1.002***	1.001***	1.001***
Number of Lanes	1.038***	0.981***	1.033***	1.125***	1.077***
Lane Width	0.963***	1.013***	0.956***	1.027***	1.085***
Surface Width	0.996***	0.986***	0.996***	0.979***	0.986***
Pavement Width Right	0.988***	1.074***	0.970***	1.072***	1.048***
Right Shoulder Width	0.976***	0.942***	0.991***	0.931***	0.942***
Median Width	0.998***	1.001***	0.996***	1.001***	0.996***
CATEGORICAL VARIABLES					
Design Speed					
55 mph	-	-			
60 mph	1.236	1.146			
65 mph	1.104	0.861			
70 mph	1.388	0.923			
Urban-Rural Classification					
Rural			-	-	-
Urban			2.174***	2.049***	2.101***

Predictor Variable	**Model Coefficients (Car speed limit / Truck Speed Limit)**				
	Urban	***Rural***	***Design Speed (70/55)***	***Design Speed (65/55)***	***Design Speed (60/55)***
Road Surface Type					
Dry	-	-	-	-	-
Wet	2.742***	5.897***	3.358***	3.856***	7.272***
Snowy	2.433***	6.243***	2.881***	4.311***	7.716***
Slippery	2.057***	4.393***	2.825***	4.213***	5.585***
Observations	*20,204*	*17,786*	*21,966*	*8,317*	*5,103*
McFadden R-square	0.681	0.555	0.664	0.451	0.467

In the crash frequency model, the AADT has a positive impact on the number of crashes on the California road segments. This implies that roadways with higher AADT values tend to have more crashes than roads with lower AADT values. From the exact modeling description, we can interpret the model coefficients as odds ratios, where for every unit increase in the AADT value, the odds of a crash frequency in a segment increase by a factor of 1.008, 1.027, 1.008, 1.013, and 1.015, respectively, for urban, rural, design speed 70 mph, 65 mph, and 60 mph segments.

In the design speed segments, the odds of crashes in urban areas are higher across all design speed segments compared to the rural areas. For every unit increase in travel in urban areas, the odds of crash frequency increase by a factor of 2.174, 2.049, and 2.101, across all design speed segments. This observation is consistent with the actual crash data as the number of crashes is higher in the urban road segments.

For urban and rural areas, the variation in design speed shows an increase in the likelihood of crashes in 60 and 70 mph urban segments, when 55 mph segments are used as the reference. On the other hand, using the same reference design speed of 55 mph, the rural segments with 65 mph and 70 mph design speeds show a decrease in the likelihood of crashes.

Crash Occurrence Model

The crash occurrence model describes the probability of a crash on California road segments based on the design speed, AADT, and other roadway information. This model does not have any crash information (e.g., severity, crash type, etc.). This model is a binary logit model with different locations (urban, rural) and design speed classifications (70, 65, 60). Although the urban and rural segments are the primary classifications used to describe the spatial and temporal effect of similar predictor variables on crash occurrence, the classification of different design speeds provides insight into different existing speed limits. The exponential form of the model estimates denoted as the odds ratio (OR) are reported in Table 9.

In the crash occurrence model, the AADT has a positive impact on the probability of a crash occurring on California road segments. This implies that roadways with higher AADT values tend to have more crashes than roads with lower AADT values. From the exact modeling description, we can interpret the model coefficients as odds ratios, where for every unit increase in the AADT value, the odds of a crash occurring in a segment increase by a factor of 1.010, 1.027, 1.010, 1.021, and 1.027, respectively for urban, rural, design speed 70 mph, 65 mph, and 60 mph segments.

Table 9. Logit Model Related to Crash Occurrence on California Segments

Predictor Variable	**Odds Ratio (Car speed limit / Truck Speed Limit)**				
	Urban	***Rural***	***Design Speed (70/55)***	***Design Speed (65/55)***	***Design Speed (60/55)***
CONTINUOUS VARIABLES					
Annual Average Daily Traffic (AADT) in thousand	1.010***	1.027***	1.012***	1.026***	1.033***
Segment Length (m)	1.031***	1.003***	1.021***	1.003***	1.003***
Lane Width (ft)	0.986***	1.009***	1.008***	1.072***	0.985***
No. of Lanes (1-10)	1.098***	1.031***	1.057***	1.145***	1.139***
Surface Width (ft)	0.985***	0.985***	0.990***	0.984***	0.984***
Pavement Width Left (ft)	0.947***	1.016***	0.984***	0.964***	1.006***
Left Shoulder Width (ft)	1.048***	0.965***	1.029***	0.996***	0.979***
Pavement Width Right (ft)	1.020***	1.103***	0.988***	1.118***	1.085***
Right Shoulder Width (ft)	0.958***	0.939***	0.980***	0.923***	0.945***
Median Width (ft)	0.999***	0.999***	0.997***	0.998***	0.993***
CATEGORICAL VARIABLES					
Design Speed					
55 mph	-	-			
60 mph	1.495[a]	1.294[a]			
65 mph	0.971[a]	0.834[a]			
70 mph	1.170[a]	0.958[a]			
Rural-Urban Classification					
Rural			-	-	-
Urban			2.163[a]	1.789[a]	1.845[a]
Road Surface Type					
Dry	-	-	-	-	-
Wet	1.279[a]	3.409[a]	1.336[a]	3.247[a]	4.392[a]
Snowy	1.119[a]	3.591[a]	0.993[a]	3.691[a]	3.984[a]
Slippery	0.688[a]	1.900[a]	0.925[a]	2.326[a]	3.171[a]

a: $p < 0.01$; b: $p < 0.05$; c: $p < 0.1$.

For the urban-rural classification in the design speed models, the odds of crash occurrence in urban areas are higher across all design speed segments. We can interpret the model coefficients as odds ratios, were for traveling from a rural to an urban location, the odds of a crash occurring increase by a factor of 2.163, 1.789, and 1.845, across all design speed segments. This observation is consistent with the real-world measurement since more crashes occur in the urban road segments.

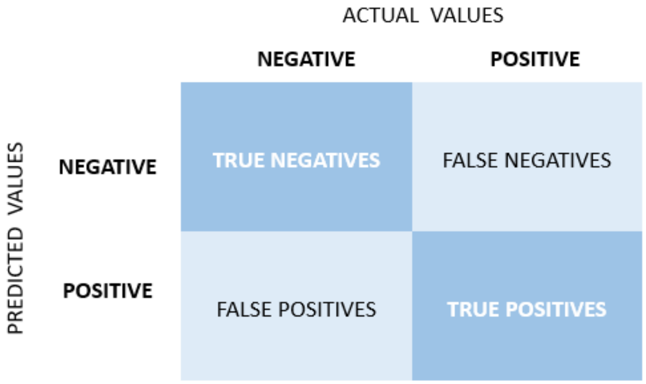
For urban and rural location models, the variation in design speed shows an increase in the probability of crash occurrence in 60 and 70 mph urban segments, when 55 mph segments are used as the reference. On the other hand, using the same reference design speed of 55 mph, the rural segments with 65 mph and 70 mph design speeds show a decrease in the probability or likelihood of a crash occurrence.

The model diagnostics of the crash occurrence for different road types (urban, rural, and design speeds) include pseudo-rho-square (McFadden R-square), Akaike information criteria (AIC), true positive rate (TPR), and area under receiver operating curve (AUROC) are reported in Table 10.

Table 10. Model Diagnostics for Crash Occurrence

Model Diagnostics	***Urban***	***Rural***	***Design Speed (70/55)***	***Design Speed (65/55)***	***Design Speed (60/55)***
Training Sample	75	75 %	75	75 %	75 %
Testing Sample	25 %	25 %	25 %	25 %	25 %
Misclassification Error	0.1126	0.2046	0.118	0.2207	0.201
Sensitivity (True Positive Rate)	0.8593251	0.5736249	0.84375	0.5495751	0.6496273
Specificity	0.4033413	0.6266164	0.4868173	0.5948905	0.4677804
Model Precision	0.90195	0.80397	0.90084	0.80654	0.805025
Area Under Receiver Operating Curve (AUROC)	0.8414	0.7931	0.8481	0.7515	0.8052
Akaike Information Criteria (AIC)	10975.749	16979.290	12679.450	8350.074	4643.264
McFadden R-square	0.36623	0.280815	0.395957	0.247679	0.273356
Total Observations	20204	17786	21966	8317	5103

The models' accuracy is tested based on a separate testing dataset. The confusion matrix (Figure 4) provides a clear concept of modeling accuracy. Here, for example, the number of crashes accurately classified can be expressed as the proportion of true positives relative to the number of predicted (true and false) positives. A higher precision value is associated with a better model. The predictive power of the crash occurrence model is satisfactory according to the precision value in Table 10 for each of the different road types.



		ACTUAL VALUES	
		NEGATIVE	POSITIVE
PREDICTED VALUES	NEGATIVE	TRUE NEGATIVES	FALSE NEGATIVES
	POSITIVE	FALSE POSITIVES	TRUE POSITIVES

Figure 4. Confusion Matrix for the Binary Logit Model

$$\text{Precision} = {}^{TP}\!/_{(TP + FP)}$$

Fatal Crash Model

The fatal crash model is a combination of crashes with fatal and severe injuries. The fatal crash model is also divided into four different parts reflecting the different types of roadway segments (urban, rural, classified design speed locations) with several continuous and categorical predictor variables. Although the urban and rural segments are the primary classifications used to describe the spatial and temporal effect of similar predictor variables on fatal crashes, the design speed classifications also provide an insight into where the speed difference between cars and trucks varies. For instance, in a 65-mph design speed segment, the truck speed is limited to 55 mph with a speed difference of 10 mph. However, for a 70-mph design speed segment the truck speed is limited to 55 mph with a speed difference of 15 mph. The model data is sampled from a pool of about 700,000 observations (HSIS) and matched with the statewide dataset (TIMS-SWITRS) to add more information on each crash observation. A total of 170,000 crash observations are used to train and test the fatal crash model. The exponential form of the model estimates denoted as the odds ratio (OR) are reported in Table 11.

Truck-involved crashes are an important consideration for this study. The sampled dataset for the model consists of 18,000 truck-related crashes. The model variable "vehicle at fault" or responsible for a crash consists of 7,000 trucks compared to 150,000 observations where passenger cars are at fault. The model estimates or coefficients show that the crashes where the truck and motorbike are at fault have an increasing likelihood or probability of the crashes being fatal compared to passenger cars. For example, the model coefficients or odds ratios show that for a unit increase in the crashes with trucks at fault, the odds of the crash being fatal increases by a factor of 3.029, 1.543, 2.381, 1.692, and 2.053, respectively for urban, rural, and design speed segments (70 mph, 65 mph, and 60 mph); where the reference for comparison is the passenger cars at fault.

Alcohol influence is an important predictor variable for the fatal crash model. The model results show that the influence of alcohol is statistically significant and has a positive impact on the probability of the crash being fatal. From modeling estimates, this indicates that for a unit increase in alcohol influenced crashes, the odds of the crash being fatal increase by factors of 2.133, 1.515, 1.927, 1.562, and 2.061 for urban, rural, and design speed segments (70 mph, 65 mph, and 60 mph), respectively.

For the "collision types" predictor variable in the fatal crash model, the reference level for comparison is the "rear-end" type collision. The odds ratios of model estimates show that among different types of collisions, "head-on," "broad-side," and "vehicle-related" crashes are significant and have a considerable impact on the probability of a crash being fatal in all model scopes (urban, rural, and design speed locations). The results show that for a unit increase in "head-on" collisions, the odds of the crash being fatal increase by factors of 6.806, 7.471, 5.791, 9.653, and 8.272 on urban, rural, speed zone, and truck network roads, respectively.

A crash occurring in "cloudy weather" compared to regular "clear weather," increases the odds of the crash being fatal by factors of 1.307, 1.046, 1.189, 1.121, and 1.659, respectively, in urban, rural, and different design speed segments. The lighting of roadway areas plays a critical role in crashes being fatal. Except for the "streetlight not functioning" case, all other lighting conditions are statistically significant and have a higher likelihood of a crash being fatal for all the model scopes or segments.

Table 11. Logit Model Related to Fatal and Severe Crash

Predictor Variable	**Model Coefficients or Odds Ratio (Car speed limit / Truck Speed Limit)**				
	Urban	***Rural***	***Design Speed (70/55)***	***Design Speed (65/55)***	***Design Speed (60/55)***
CONTINUOUS VARIABLES					
Annual Average Daily Traffic (AADT)	0.998***	0.993***	0.998***	0.997***	0.998***
Complaint of Injury Count	0.059	0.289***	0.090	0.343***	0.317***
Visible Injury Count [a]	0.111	0.487***	0.176**	0.554***	0.510***
Number of Vehicles involved	1.678***	1.752***	2.058***	1.783***	1.627***
Number of Lanes	0.978***	0.973***	0.916***	0.897***	0.994***
Lane Width	0.936***	0.968***	0.930***	0.992***	1.015***
Surface Width	1.004***	1.002***	1.002***	1.011***	0.993***
Pavement Width Left	0.965***	1.021***	0.981***	1.020***	1.017***
Median Width	1.000***	1.005***	1.004***	1.002***	0.992***
Left Shoulder Width	1.038***	1.005***	1.015***	1.008***	0.979***
CATEGORICAL VARIABLES					
Location Classification					
Urban			0.611***	0.502***	0.398***
Rural			-	-	-

Predictor Variable	Model Coefficients or Odds Ratio (Car speed limit / Truck Speed Limit)				
	Urban	*Rural*	*Design Speed (70/55)*	*Design Speed (65/55)*	*Design Speed (60/55)*
Design Speed					
55 mph	-	-			
60 mph	0.947***	0.899***			
65 mph	1.099***	0.976***			
70 mph	1.013***	0.968***			
Primary Collision Factors					
Alcohol Influence [a]	2.133***	1.515***	1.927***	1.562***	2.061***
Truck Related Crash					
Yes	3.053***	1.999***	2.699***	2.699***	2.901***
Weather Condition					
Weather - Clear	-	-	-	-	-
Weather - Cloudy [a]	1.307***	1.046***	1.189***	1.121***	1.659***
Weather - Raining [a]	0.961***	0.884***	0.814***	2.224***	1.050**
Road Surface					
Regular A	-	-	-	-	-
Dry Surface B	0.743***	0.696***	0.684***	0.523**	0.873***
Wet Surface [a] C	0.0003	0.569	0.268	0.708	0.617
Collision Type					
A - Head-On [a]	6.806***	7.471***	5.791***	9.653***	8.272***
B - Sideswipe	0.981***	0.902***	0.945***	1.456***	0.966***
C - Rear End	-	-	-	-	-
D - Broadside [a]	2.399***	2.327***	2.135***	2.792***	2.632***
E - Hit Object [a]	1.664***	1.259***	1.622***	1.672***	1.362***
F – Overturned [a]	1.041***	0.963***	1.183***	1.152***	0.904***
G – Vehicle [a]	5.522***	5.414***	6.797***	5.788***	5.338***
H - Other	1.134***	1.233***	1.042***	2.228***	1.134*
Lighting					
A - Daylight	-	-	-	-	-
B - Dusk – Dawn [a]	1.506***	1.333***	1.601***	1.399***	1.182***
C - Dark - Street Lights [a]	1.889***	1.059***	1.809***	1.289***	1.179***
D - Dark - No Street Lights [a]	2.333***	1.433***	2.064***	1.565***	1.697***
E - Dark - Street Lights Not Functioning	2.979***	0.270	2.586***	0.00001	2.867***
Observations	*148,875*	*28,992*	*147,406*	*13,563*	*12,531*
Akaike Information Criteria (AIC)	*15,067.170*	*9,450.756*	*17,092.730*	*3,713.841*	*2,830.209*
McFadden R-square	0.221736	0.164423	0.217475	0.1900400	0.22853

a: $p < 0.01$; b: $p < 0.05$; c: $p < 0.1$.

The diagnostics of the fatal crash logit model for different segments including pseudo-rho-square (McFadden R-square), AIC, TPR, FPR, and AUROC are reported in Table 12. The model predicts a smaller number of fatal crashes than the actual number of fatal crashes recorded in the database segments. According to the model precision values noted in Table 12, the fatal crash model performs well in predicting whether a crash is fatal or not.

Table 12. Model Diagnostic of Fatal Crash Logit Model

Model Diagnostics	Urban	Rural	Design Speed (70/55)	Design Speed (65/55)	Design Speed (60/55)
Training Sample	75%	75%	75%	75%	75%
Testing Sample	25%	25%	25%	25%	25%
Misclassification Error	0.0264	0.0503	0.0318	0.0608	0.056
Sensitivity (True Positive Rate, TPR)	0.5307	0.3134	0.4651	0.3369	0.4963
Model Precision	0.9721	0.8765	0.9635	0.8538	0.913
Area Under Receiver Operating Curve (AUROC)	0.8379	0.7752	0.8385	0.7942	0.8125
Akaike Information Criteria (AIC)	54,032.38	24,986.72	57,845.87	10,677.66	8,316.51
McFadden R-square	0.3587	0.2252	0.3318	0.2519	0.3231
Total Observations (Sample)	*185,384*	*37,750*	*182,260*	*18,403*	*16,615*

Speed Limit Effect on Safety

This section describes the results of using the statistical models to estimate the safety implications of changing the speed limit based on the crash frequency and crash severity (fatal-severe) for urban, rural, and combinations of design speed segments. As noted in the literature review, for a 5 mph increment in the speed limit the design speed of the traffic tends to increase within a range of 2-5 mph (Table 2). To be conservative, we modeled the safety implication of changing the speed limit by assuming it would result in the same increment or decrement in design speed (for instance, a 5 mph change in the speed limit is assumed to produce a 5 mph change in the design speed on the highway). The speed policy analysis discusses the safety implications of raising the speed limit by varying the current differential speed limit (Table 13). The prediction is extended for a combination of design speed sections. For instance, California roadway segments with 55 and 60 mph design speeds are combined in one category, and the segments with 65 and 70 mph design speeds are combined in another. These categories along with the urban and classification describe the safety impact of speed limit changes in different locations. The 55 mph design speed segments are included in the aggregation or combination because quite a few truck crashes (about 350) were observed in such segments over the study period (2013–2017).

The crash frequency model is used to estimate or predict the number of crashes and the crash models (crash occurrence and fatal-severe crash) are used to predict the number of fatal and severe crashes by varying the design speeds. For this purpose, we used 70% of the crash records for model development and used the models to predict the specific crash probability on the entire crash dataset. This section estimates the increase or decrease in the number of crashes (crash frequency) and the crashes being fatal and severe. For example, if we count all crashes where there is a chance that a fatality will result under the existing speed level **Policy A** (55/65 mph), then there could be as many as 2343 fatal-severe crashes. Table 13 reflects the estimated number of crashes and fatalities (fatal and severe injuries) for the urban, rural, freeway, and highway segments across California for speed policy alternatives.

This study uses the design speed as a proxy for changing the speed limit to provide an estimate of crash frequency and fatal-severe crashes. This is because raising the speed limit (design speed in this case) typically results in a smaller actual increase in average traffic speed (so a 5 mph increase in the posted speed limit, for instance, will result in a smaller increase in actual traffic speed and thus likely result in fewer actual crashes). In other words, as we know from the previous studies that the average traffic speed is less than that of the design speed (Table-2), considering design speed as the speed limit provides a conservative estimate.

The policy alternatives used for analysis in this section are listed below.

A. Existing differential speeds on interstates with 60, 65, and 70 mph for cars and 55 mph for trucks
B. Raising the existing differential speed on freeways (urban and rural) from 55 to 60 mph for trucks and 65 to 70 mph for cars.

C. Raising the existing differential speed on freeways (urban and rural) from 55 to 65 mph for trucks and 65 to 75 mph for cars.

D. Raising the existing differential speed on freeways (urban and rural) from 55 to 70 mph for trucks and 65 to 80 mph for cars.

Policy A is the current speed policy (DSL) scenario, which is used as a base case for comparison with the alternatives. **Policy B** and **Policy C** reflect changing the speed limit (design speed) policy for differential speed or DSL alternatives (Table 13). The changes (+/-) in the crash frequency and fatal-severe crashes resulting from the change in design speed for different policy scenarios are estimated concerning the current differential speed **Policy A**. The results are presented in the following table along with the associated percentage changes (+/- n%).

Table 13. Speed Limit Policy Alternatives for DSL. The percentage change is the comparison with the base case (Policy A).

Location	Estimated Values	Number of Estimated Crashes and Fatal Crashes			
		A: Base Case DSL 65/55	B: DSL 70/60	C: DSL 75/65	D: DSL 80/70
Urban	Crash Frequency 2013	126,222	127,816	132,286	135,356
	Crash Frequency 2014	132,306	134,773	138,472	140,531
	Crash Frequency 2015	135,193	138,166	140,370	142,642
	Crash Frequency 2016	155,095	158,794	161,649	163,950
	Crash Frequency 2017	154,754	157,148	160,116	164,178
	Average Crash Frequency	140,714	143,339	146,579	149,331
	Comparison with Base Case	0	+1.866%	+4.168%	+6.124%
	Fatal Crashes 2013	2371	2470	2428	2415
	Fatal Crashes 2014	2175	2182	2186	2195
	Fatal Crashes 2015	2286	2292	2314	2327
	Fatal Crashes 2016	2296	2305	2320	2319
	Fatal Crashes 2017	2587	2590	2602	2612
	Average Crash Frequency	2343	2368	2370	2374
	Comparison with Base Case	0	+1.058%	+1.152%	+1.306%

Location	Estimated Values	Number of Estimated Crashes and Fatal Crashes			
		A: Base Case DSL 65/55	B: DSL 70/60	C: DSL 75/65	D: DSL 80/70
Rural	Crash Frequency 2013	21,267	21,468	21,519	21,775
	Crash Frequency 2014	23,001	23,071	23,164	23,278
	Crash Frequency 2015	29,221	29,275	29,251	29,466
	Crash Frequency 2016	34,894	34,926	34,832	34,958
	Crash Frequency 2017	35,236	35,284	35,695	35,786
	Average Crash Frequency	28,724	28,805	28,892	29,053
	Comparison with Base Case	0	+0.282%	+0.586%	+1.145%
	Fatal Crashes 2013	1128	1185	1195	1226
	Fatal Crashes 2014	1175	1176	1178	1181
	Fatal Crashes 2015	1228	1230	1232	1235
	Fatal Crashes 2016	1315	1321	1317	1322
	Fatal Crashes 2017	1393	1415	1450	1464
	Average Fatal Crashes	1248	1265	1274	1286
	Comparison with Base Case	0	+1.410%	+2.132%	+3.029%
Design Speed 55 mph and 60 mph	Crash Frequency 2013	13,707	13,861	14,033	14,466
	Crash Frequency 2014	13,807	14,163	14,353	14,674
	Crash Frequency 2015	16,936	17,147	17,238	17,615
	Crash Frequency 2016	20,619	20,732	20,934	21,425
	Crash Frequency 2017	19,403	19,423	19,883	20,440
	Average Crash Frequency	16,894	17,065	17,288	17,724
	Comparison with Base Case	0	+1.011%	+2.331%	+4.911%
	Fatal Crashes 2013	595	598	603	610
	Fatal Crashes 2014	591	605	598	618
	Fatal Crashes 2015	640	643	645	656
	Fatal Crashes 2016	608	612	620	638
	Fatal Crashes 2017	642	650	665	675
	Average Fatal Crashes	615	622	626	639
	Comparison with Base Case	0	+1.040%	+1.788%	+3.934%

Location	Estimated Values	Number of Estimated Crashes and Fatal Crashes			
		A: Base Case DSL 65/55	B: DSL 70/60	C: DSL 75/65	D: DSL 80/70
Design Speed 65 mph and 70 mph	Crash Frequency 2013	122,470	126,825	132,766	138,427
	Crash Frequency 2014	127,350	134,240	136,276	140,379
	Crash Frequency 2015	139,379	142,788	148,936	152,135
	Crash Frequency 2016	167,129	170,882	179,775	182,466
	Crash Frequency 2017	168,806	173,077	180,672	183,560
	Average Crash Frequency	145,027	149,562	155,685	159,393
	Comparison with Base Case	0	+3.127%	+7.349%	+9.906%
	Fatal Crashes 2013	2764	2774	2784	2796
	Fatal Crashes 2014	2763	2773	2785	2802
	Fatal Crashes 2015	2864	2866	2882	2892
	Fatal Crashes 2016	2970	2975	2982	3008
	Fatal Crashes 2017	3334	3373	3394	3386
	Average Fatal Crashes	2939	2952	2965	2977
	Comparison with Base Case	0	+0.449%	+0.898%	+1.286%

DSL Policy Alternatives

For DSL policy alternatives (Table 13), **Policy B** raises the current truck speed limit (55 mph) by 5 mph to 60 mph for trucks. However, for cars, the 5-mph increment changes the posted speed limit to different values in different design speed sections of the California network. For instance, the car speed limit for the 60, 65, and 70 mph design speed sections shift to 65, 70, and 75 mph, respectively. **Policy C** raises the current speed limit from 55 to 65 mph for trucks. In this policy, the car speed limit for the 65 and 70 mph design speed sections shifts to 75 and 80 mph, respectively. **Policy D** raises the current speed limit from 55 to 70 mph for trucks, a 15-mph increment. In this policy scenario, the car speed limit for the 60, 65, and 70 mph design speed sections shift to 75, 80, and 85 mph, respectively. The model estimates are obtained by increasing the design speed values for the road segments in the crash database and rerunning the crash frequency and severity (fatal and severe) models to estimate the change in the number of crashes and crash severity (fatal-severe) under new conditions. In this study, the fatal and severe crashes are combined as a representative dataset to develop the fatal crash model. The primary goal of this analysis is to determine the impact of speed limit changes on safety through the percentage change in crash frequency and fatal-severe crashes.

Results

For **Policy B** (5 mph increment), in urban areas, the frequency of crashes increases by about 2% (1.866%) and the frequency of fatal-severe crashes, by 1%. For rural areas, the frequency of crashes and of fatal-severe crashes both increase by 1.4%. When subject to a 5 mph increase in car and truck design speed, California roadway segments with 55 and 60 mph design speeds also show an increase in crash frequency and fatal-severe crashes by 1.01% and 1.04%, respectively. Similarly, segments with 65 and 70 mph design speeds show an increase in crash frequency (or number of crashes) and fatal-severe crashes by 3.127% and 0.5%, respectively.

For **Policy C** (10 mph increment), in urban areas, the frequency of crashes increases by 4.168% and the frequency of fatal-severe crashes increases by 1.15%. For rural areas, the crash frequency increased by 0.586% and the fatal-severe crash frequency, by 2.123%. California roadway segments with 55 and 60 mph design speeds also show an increase in crash frequency and fatal-severe crashes by 2.33% and 1.79%, respectively. Similarly, segments with 65 and 70 mph design speeds show an increase in crash frequency and fatal-severe crashes by 7.35% and 0.898%, respectively.

For **Policy D** (15 mph increment), in urban areas, crash frequency increases by 6.12% and fatal-severe crash frequency increases by 1.31%. For rural areas, the crash frequency increases by 1.14% and the fatal-severe crash frequency increases by 3.02%. California roadway segments with 55 and 60 mph design speeds also show an increase in crash frequency and fatal-severe crashes by 4.91% and 3.93%, respectively. Similarly, segments with 65 and 70 mph design speeds show an increase in crash occurrence and fatal-severe crashes by 9.90% and 1.28%, respectively.

Across the country, speed limits are increasing. However, the impacts of this trend are unclear as studies differ based on the datasets and methodology used. In some of the direct comparisons between DSL and USL scenarios, previous studies have used the data from two states with comparable roadway networks (e.g., Indiana, and Illinois) to understand the safety impact and rationalize the transferability of the results from one state to the other [5]. Others have used the state-specific data and carried out a before-after study to understand the safety implications of adopting USL or DSL speed limit policies (see literature review section). In the case of California, the length of the roadway network and varied landscape (flat, mountainous) makes the comparison with other states complicated. Moreover, the California roadway network caters to the highest number of commuters, travelers, and commercial vehicles (trucks, semi-trailers, etc.) in the United States, warranting an approach that differs from that in other studies.

One of the primary goals of this study is to compare the safety impacts of different speed limit changes on California roadways. For the DSL scenarios, the design speed is raised to maintain the differential between car and truck speeds, unlike USL scenarios, where a uniform speed is required for all. Thus, to analyze a shift from the current DSL speed limit (**Policy A**), for instance, to a uniform speed limit for both cars and trucks at 65 mph, the speed of the trucks on the highway must be increased relative to that of cars. For this reason, separate speed data for cars and trucks are required. However, the study dataset consists of design speed for all traffic, including cars and trucks. Moreover, the PeMS dataset with vehicle detecting stations and sensors also contains aggregated traffic speed. Without the disaggregated speed data (car vs. truck) it is difficult to estimate and raise the truck speed limit to generate artificial USL scenarios for crash prediction. Thus, this study focuses on DSL scenarios for accurate crash prediction (safety implication) on California roadways. The results show that for all the scenarios with urban-rural and different design speed classifications, the crash frequency and the number of fatal and severe crashes increase with the increase in the speed limit.

Simulation and Cost Estimation

Speed Limit Impact on Mobility

The operational condition (mobility) of the simulation segments is assessed on the traffic variables (speed, travel time, flow, delay) for different speed limit policies. Each scenario describes one type of speed limit policy (USL or DSL) on the mainline of the freeway segments. For instance, the speed limit for the USL 70 mph scenario is maintained at 70 mph for both cars and trucks on the freeway mainline. For this study, four urban segments and three rural segments are simulated to determine the change in operational conditions that occur with different speed limit policies (DSL and USL). Eight alternative speed scenarios are considered including DSL and USL, for each simulated segment for this study (Table 13).

The average traffic speed reflects the speed averaged over the segment of each simulation model for the simulation period. Each freeway or highway simulation model consists of multiple edges joined via connectors. The traffic speed is measured and averaged over each of these edges of the simulation models.

Traffic flow is also measured on the edges of the simulation models. The flow is a measurement of the hourly rate of cars or trucks passing over each of the edges (segments) in the simulation model. In the simulation model, the flow is computed as the number of vehicles that have left the edge or segment within the hour.

The time loss variable represents the amount of lost time in seconds for all the vehicles over an hour of the simulation period while driving slower than the desired speed. The idea of this variable is to determine the delay that will be incurred for different speed policy scenarios.

Travel time is an important measure to understand the operational impact of the speed limit for trucks and cars. For instance, trucks with the same speed as cars (65 mph) in the USL scenario should have less travel time than that of the DSL and Base scenarios. We have computed travel time for cars and trucks separately over the simulation segments to understand the shift in speed variation and travel time for different speed limit scenarios.

Vehicle miles traveled (VMT) is an important criterion to understand the operation condition of the simulation network. For the same network, the VMT remains almost constant for cars and trucks across different simulation scenarios.

The expected simulation results from the intermediate traffic should reflect an increase in the traffic speed and reduced travel time with a similar VMT and flow for all the speed policy scenarios. Intermediate traffic refers to a volume of traffic that is 10-20% lower than the peak hour volume.

A. Urban Segment: Merced SR-99 North-South

The simulation model developed for Merced SR-99 NS (Table 14) is a representative model for a growing urban area. The simulation results show that the travel time for cars gradually decreases as the speed limit is increased both for USL and DSL scenarios. This implies that the average speed of cars and trucks increases with the increasing speed limit. The model simulates the off-peak traffic as the effect of speed limit changes diminishes during the peak period. To understand the direction-wise variation in traffic parameters (speed, travel time, time loss) both sides of the highway and freeway are studied and reported. Like cars, the travel time for trucks also decreases gradually with the increase in the speed limit for both USL and DSL scenarios. The VMT and traffic throughput (flow) remain about constant for cars and trucks for all the DSL and USL scenarios. The time loss variable also represents a declining trend in the lost time while driving slower than the preferred speed. Speed variance or the difference in speed between cars and trucks is also an important consideration for this study. The speed variance is significant for the DSL scenarios, ranging from 5 (63 vs. 58) to 7 (74 vs. 67) mph for 70/60 and 80/70 policy scenarios. Interestingly, the speed difference varies as the speed limit is increased for the DSL scenarios. Thus, at higher speed limit scenarios (DSL) the speed variance decreases. On the other hand, for the USL scenarios, the speed variance is present in a small magnitude. For instance, the speed variance is about 1 mph for all the four USL scenarios ranging from 65 mph to 80 mph.

Table 14. Merced SR-99 North-South Urban Simulation Results

Merced	Base Scenario (Car 65 / Truck 55)	DSL Scenarios				USL Scenarios			
		Car 70 /Truck 60	Car 70 /Truck 65	Car 75 /Truck 65	Car 80 /Truck 70	Car - Truck 65	Car - Truck 70	Car- Truck 75	Car - Truck 80
Average Travel Time Car (North)	*541*	*505*	*498*	*457*	*429*	*526*	*496*	*457*	*430*
Average Travel Time Car (South)	*544*	*503*	*501*	*461*	*431*	*535*	*495*	*463*	*431*
Average Travel Time Truck (North)	*605*	*557*	*515*	*511*	*486*	*517*	*488*	*450*	*429*
Average Travel Time Truck (south)	*604*	*556*	*517*	*512*	*484*	*523*	*485*	*453*	*427*
Car Vehicle Miles Traveled	*95437*	*95377*	*95175*	*95253*	*95280*	*95086*	*95167*	*95253*	*95288*
Truck Vehicle Miles Traveled	*18667*	*18780*	*18720*	*18697*	*18631*	*18790*	*18574*	*18806*	*18791*
Average Car Speed (North)	*59*	*63*	*64*	*70*	*74*	*62*	*65*	*71*	*76*
Average Car Speed (South)	*60*	*64*	*64*	*69*	*74*	*61*	*66*	*70*	*75*
Average Truck Speed (North)	*53*	*58*	*62*	*62*	*66*	*61*	*64*	*70*	*75*
Average Truck Speed (South)	*54*	*58*	*63*	*61*	*66*	*60*	*65*	*69*	*74*
Time Loss (North)	*38681*	*37853*	*27620*	*21917*	*21143*	*24242*	*27311*	*22296*	*22253*
Time Loss (South)	*36942*	*31845*	*29333*	*22061*	*19385*	*27567*	*24148*	*23406*	*18909*
Traffic Flow or Throughput	*2070*	*2077*	*2080*	*2075*	*2075*	*2071*	*2075*	*2075*	*2071*
Simulation Period	*18600 sec (5 hour 10 minutes)*								

For urban highways, the simulated segments exhibited a similar traffic trend as that of the Merced segment. For instance, the simulated result for the Fresno I-5 NS segment shows that the travel time for cars gradually decreases as the speed limit is increased both for USL and DSL scenarios. This implies that the average speed of cars and trucks increases with the increasing speed limit. The model simulates the off-peak traffic as the effect of speed limit changes diminishes during the peak period. As with cars, the travel time for trucks decreases gradually with the increase in the speed limit for both USL and DSL scenarios. Notably, because trucks are slower moving vehicles than cars as per the DSL scenarios, their travel time is higher than that of cars. In the case of the USL scenarios, the travel time is similar to the trucks as the speed limit is the same for cars and trucks (Appendix A).

B. Rural Segment: Fresno I-5 North-South

The simulation model developed for Fresno I-5 North-South (Table 15) is a representative model for a rural area. The simulation results show that the travel time for cars gradually decreases as the speed limit is increased both for USL and DSL scenarios. This implies that the average speed of cars increases with the increasing speed limit. The model simulates the off-peak traffic as the effect of speed limit changes diminishes during the peak period. To understand the direction-wise variation in traffic parameters (speed, travel time, time loss) both sides of the highway and freeway are studied and reported. Like cars, the travel time for trucks also decreases gradually with the increase in the speed limit for both USL and DSL scenarios.

Table 15. Coalinga, Fresno I-5 North-South Rural Simulation Results

Coalinga, Fresno	Base Scenario (Car 70 /Truck 55)	DSL Scenarios				USL Scenarios			
		Car 70 / Truck 60	Car 70 / Truck 65	Car 75 / Truck 65	Car 80 / Truck 70	Car - Truck 65	Car - Truck 70	Car- Truck 75	Car - Truck 80
Car Travel Time (North)	573	566	556	524	478	576	552	523	500
Car Travel Time (South)	570	566	554	521	481	570	550	520	498
Truck Travel Time (North)	658	608	573	570	541	596	565	545	510
Truck Travel Time (South)	657	605	570	568	539	595	564	542	509
Car VMT	158557	158617	158623	158595	158657	158589	158612	158612	158614
Truck VMT	16521	16498	16492	16521	16512	16495	16512	16495	16516
Car Speed (North)	62	62	62	66	73	63	68	73	77
Car Speed (South)	63	63	63	68	72	63	67	72	76
Truck Speed (North)	53	57	61	62	65	59	64	70	74
Truck Speed (South)	53	58	61	61	66	60	64	69	72
Time Loss (North)	70102	69214	64714	59231	51785	72725	68356	59238	49185
Time Loss (South)	69854	68242	63815	58612	52236	71812	68125	60856	49215
Total Flow or Throughput	4547	4555	4554	4565	4566	4564	4544	4559	4556
Simulation Period (sec)	18500								

The VMT and traffic throughput (flow) remain about constant for cars and trucks for all the DSL and USL scenarios. The time loss variable also represents a declining trend in the lost time while driving slower than the preferred speed. Speed variance or the difference in speed between cars and trucks is also an important consideration. The speed variance is significant for the DSL scenarios, ranging from 5 (63 vs. 58) to 7 (72 vs. 65) mph for 70/60 and 80/70 policy scenarios. Interestingly, the speed difference varies as the speed limit is increased for the DSL scenarios. Thus, at higher speed limit scenarios (DSL), the speed variance decreases. On the other hand, for the USL scenarios, the speed variance is small, at about 3 mph for all the four USL scenarios ranging from 65 mph to 80 mph.

All the other urban and rural segments show a similar trend as noted for these segments. The results are listed in Appendix A.

Cost Estimation

In this study, we estimated operational costs for the simulation segments and safety costs for the predicted crashes across California. Since the crash cost does not vary significantly for roadway segments apart from urban and rural classification, we can provide an estimate of the overall crash costs (economic and comprehensive) for the state of California using the predicted total number of crashes (fatal, severe, etc.). However, the operational cost depends on the travel time, fuel consumption, and other details that are location- or segment-specific. For instance, the travel time along the "Alameda I-80 EW" corridor through Berkeley has a different operational condition (travel time, speed, fuel consumption, etc.) due to the number of lanes, road geometry, design speed, number of ramps, the volume of traffic, etc. Thus, we want to showcase a possible way to estimate operational costs in urban and rural locations for simulated scenarios with different speed limits.

Safety Cost

The safety cost is estimated based on the crash costs for different location classifications (urban/rural). Two types of safety costs have been implemented in this study: (a) economic and (b) comprehensive; following the guidelines set by the National Safety Council (NSC). A similar methodology has been followed for predicting the impact of changing the speed limit on Indiana highways [5]. The average crash cost for California is estimated based on the 2017 crash records and unit crash cost estimates from the NSC. Separate costs are calculated for different severity levels (fatal and severe injury). Since fatal crash and severe crash costs are much higher than other crashes with injuries, we estimated the crash cost related to fatality and severe injuries. Using the crash data (number of vehicles involved, fatality number, etc.) we computed the economic and comprehensive cost of a crash for different severity levels (fatal, severe) and locations (urban, rural). Since fatal and severe crashes have a significant impact on the cost component of safety, we estimated these two types for this study. The safety costs are estimated for the DSL scenarios using the predicted crash occurrences and predicted fatal-severe crashes from the statistical modeling results section. The cost of fatal crashes in urban areas is estimated at $1.89 million.

Table 16. Crash cost for severe and fatal crashes with urban-rural classification

Road Type	Economic Cost		Comprehensive Cost	
	Fatal (K)	Severe(A)	Fatal (K)	Severe(A)
Urban	$1,897,343	$98,438	$12,412,902	$1,219,477
Rural	$1,967,074	$98,343	$12,869,095	$ 1,218,293

The estimated cost reflects the same trend as the predicted crashes as the increase in crashes incurs more cost. The estimated costs also show the same increasing trend with the increase in the speed limit, maintaining the speed difference between cars and trucks. Notably, the estimated cost in the urban area shows an increase of about 1% for 5, 10, and 15 mph increments compared to the current speed limit policy. The comprehensive cost for severe injury and fatal crashes at base case is $2.857 billion for urban locations. The highest comprehensive safety cost ($2.891 billion) is observed for the 15 mph increment from the base case (65/55).

Table 17. Estimated Safety Costs of DSL Policies on California Urban Highways

Safety Cost Assessment	A: Base Case (65/55)	B: DSL (70/60)	C: DSL (75/65)	D: DSL (80/70)
Safety Economic Cost	$98,438	$98,438	$98,438	$98,438
Predicted injury and fatal Crashes	2343	2368	2370	2371
Cost of Injury and Fatal Crashes	$230,640,234	$233,081,496	$233,298,060	$233,376,810
Difference in Cost from Base Case	0	+1%	+1%	+1%
Safety Comprehensive Cost	$1,219,477	$1,219,477	$1,219,477	$1,219,477
Predicted injury and fatal Crashes	2343	2367.8	2370	2370.8
Cost of Injury and Fatal Crashes	$2,857,234,611	$2,887,477,641	$2,890,160,490	$2,891,136,072
Difference in Cost from Base Case	0	+1%	+1%	+1%

For rural areas, the estimated economic and comprehensive safety costs exhibit a similar increasing trend for the DSL scenarios with 5, 10, and 15 mph increments. The comprehensive cost for severe injury and fatal crashes at base case is $1.52 billion. The highest comprehensive safety cost ($1.57 billion) is observed for the 15-mph increment from the base case (60/55). The safety cost does not consider general injury estimates for economic and comprehensive costs.

Table 18. Estimated Safety Costs of DSL Policies on California Rural Highways

Safety Cost Assessment	A: Base Case (65/55)	B: DSL (70/60)	C: DSL (75/65)	D: DSL (80/70)
Safety Economic Cost	$98,343	$98,343	$98,343	$98,343
Predicted Injury and Fatal Crashes	1248	1265	1274	1286
Cost of Injury and Fatal Crashes	$122,712,395	$124,443,232	$125,328,319	$126,429,761
Difference in Cost from Base Case	0	+1%	+2%	+3%
Safety Comprehensive Cost	$1,218,293	$1,218,293	$1,218,293	$1,218,293
Predicted Injury and Fatal Crashes	1248	1265	1274	1286
Cost of Injury and Fatal Crashes	$1,520,186,005	$1,541,627,962	$1,552,592,599	$1,566,237,481
Difference in Cost from Base Case	0	+1%	+2%	+3%

Operational Cost

The operational cost includes value of time (VoT) costs, and vehicle operating costs (VOC), for current and alternative speed limit scenarios. We estimated the travel time cost (VoT) and VOC for the simulated segments in urban and rural areas. We simulated three urban segments and four rural segments for this study. After computing the VoT and VOC for the simulated segments for different speed limit scenarios, we estimated the weighted average operational cost for each mile in urban and rural areas. Finally, based on the urban and rural roadway classification of California (HSIS), we extended the average operational cost for 2703 miles of urban and 7770 miles of rural highway. Notably, the urban and rural roadways consisted of different design speed miles, ranging from 55 mph to 70 mph.

The non-fuel vehicle operating costs for cars and trucks is $0.619/mile [38] and $1.61/mile [39], respectively. The value of delay time for passenger vehicle travel is estimated at $19.64 per person [39]. On the other hand, the value of travel time for commercial vehicle travel is estimated at $55.24 per vehicle per hour by the American Transportation Research Institute (ATRI) [39]. The fuel consumption cost is $3.6 per gallon for cars and $3.9 per gallon for trucks from 2019 figures. The estimated cost for each simulated segment is detailed in Appendix B. Each of the segments shows a decline in travel time cost as increased speed relates to lower travel time. On other hand, the cost of fuel consumption increases with the increase in the speed limit for both cars and trucks for all the simulated locations (urban and rural).

The simulation segments are selected from the TIMS query interface based on several criteria including frequency of truck crashes, adjacent city, urban and rural location, state route, etc. The segments are sampled across California based on the truck traffic volume and crashes. Each simulation of a highway route covers a segment more than 3 miles in length whether in a rural or urban area. The demand (traffic flow) in the simulation models is generated from the VDS data collected from PeMS for both mainline and ramps. After observing the AADT and weekly traffic pattern on each of the selected segments, intermediate traffic demand (in between the peak and off-peak) was adopted to analyze the effect of alternative speed limits on urban and rural highway segments.

For urban areas, the average weighted cost per mile is estimated based on the three urban simulation segments, which are extended over the 2703 miles of urban highway across California. The length of the urban network is estimated from the Highway Safety Information System (HSIS) data. To compare the safety costs the specific highway segments with design speeds of 55, 60, 65, and 70 mph are selected to measure the network length.

Computation of the total operational costs indicates a gradual reduction with the increase in the speed limit. A reduction of approximately 4% ($1 billion) is observed from the base case when the speed limit is raised to 70/60 (car/truck). Similarly, a maximum reduction of approximately $3 billion (9%) is observed from the base case when the speed limit is raised to 80/70 (car/truck) (Table 19). For a DSL speed limit of 75/65 mph, a 7% ($1.8 billion) reduction from the base case is observed.

Table 19. Estimated Operational Costs of DSL Policies on Urban Highways across California

Operational Cost for Urban Areas	Base Case (70 / 55)	DSL 70 / 60	DSL 70 / 65	DSL 75 / 65	DSL 80 / 70
I-5 North Orange (3 mile)	$72,630,438	$69,857,082	$70,381,838	$68,981,474	$67,678,057
SR 99 North South Merced (9 mile)	$70,085,292	$66,681,286	$65,641,179	$63,339,041	$61,174,397
I 80 East West Alameda (5 mile)	$89,103,671	$86,077,908	$84,068,031	$84,028,564	$82,219,543
Weighted per Mile Operational Cost	$13,636,435	$13,095,075	$12,946,532	$12,726,416	$12,416,000
Urban Miles	2703	2703	2703	2703	2703
Total Operational Cost	$36,859,284,688	$35,395,987,892	$34,994,476,735	$34,399,503,613	$33,560,447,507
Percentage Change from Base Case	0%	-4%	-5%	-7%	-9%

For rural areas, the weighted operational cost per mile is estimated based on the four rural simulation segments, which are extended over the 7770 miles of rural highway across California. The length of the network is estimated from the Highway Safety Information System (HSIS) data. To compare the safety costs the specific highway segments with design speeds of 55, 60, 65, and 70 mph are selected to measure the network length.

For rural areas, the operational cost estimation reflects the actual weighted cost incurred over the urban simulation segments, which is extended over the entire rural highway network across California (Table 20). The estimations indicate an improvement in the operational cost. For instance, a reduction of approximately $2 billion (2%) from the base case (60/55) is observed when the speed limit is raised to 70/60 (car/truck). Similarly, a 5% reduction ($5 billion) in the operational cost from the base case is observed when the speed limit is raised to 75/65.

Table 20. Estimated Operational Costs of DSL Policies on Rural Highways across California

Operational Cost for Rural Areas	Base Case (70/55)	DSL 70 / 60	DSL 70 / 65	DSL 75 / 65	DSL 80 / 70
I-5 North South Fresno (9 mile)	$151,179,276	$150,997,629	$149,128,673	$144,863,540	$137,742,945
I-5 North South Kern (17 mile)	$183,546,373	$177,037,372	$177,250,393	$169,453,495	$164,800,771
I-15 North South San Bernardino (10 mile)	$199,235,394	$199,301,055	$198,469,755	$193,117,593	$187,065,488
I-5 North South San Diego (11 mile)	$129,763,147	$125,017,952	$126,434,051	$121,510,439	$117,390,626
Rural Miles (Design Speed 55, 60, 65, 70)	7770	7770	7770	7770	7770
Weighted per mile Operational Cost	$14,121,791	$13,879,873	$13,857,082	$13,381,810	$12,914,890
Total Operational Cost	$109,726,318,306	$107,846,609,425	$107,669,530,223	$103,976,663,261	$100,348,695,246
Percentage Change from Base Case	0%	-2%	-2%	-5%	-9%

The estimated difference between combined safety and operational costs indicates a net cost reduction with the increase in speed limit. The combo cost is computed based on the economic and comprehensive safety costs. These costs from different speed limit scenarios are compared to the current speed limit scenario to analyze the possible impact of changing speed limits (Table 21). The estimation results reflect an increase in cost-effectiveness. For instance, changing the current speed limit to 70/60 mph results in an effective increase in benefits for urban and rural networks. This scenario shows a net benefit of approximately $1.8 billion in rural areas for comprehensive safety costs. Similarly, the benefit ranges around $1.4 billion for urban highways using comprehensive safety costs.

For economic costs in the 75/65 scenario, the difference in combo costs also indicates a benefit of $2.4 billion and $5.5 billion for urban and rural areas, respectively. The overall estimates indicate that the travel time savings on urban and rural highways outweigh the safety and other associated costs of increasing the speed limit.

Table 21. Estimated Difference in Costs for Alternative DSL Policies

Urban	**Base Case (65 / 55)**	**DSL 70 / 60**	**DSL 75 / 65**	**DSL 80 / 70**
Total Operational Cost (Urban)	$36,859,284,688	$35,395,987,892	$34,399,503,613	$33,560,447,507
Safety Economic Cost	$230,640,234	$233,081,496	$233,298,060	$233,376,810
Total Difference using Safety Economic cost	$0	$1,460,855,534	$2,457,123,249	$3,296,100,605
Safety Comprehensive Cost	$2,857,234,611	$2,887,477,641	$2,890,160,490	$2,891,136,072
Total Difference using Safety Comprehensive Cost	$0	$1,433,053,766	$2,426,855,196	$3,264,935,720
Rural				
Total Operational Cost (Rural)	$109,726,318,306	$107,846,609,425	$103,976,663,261	$100,348,695,246
Safety Economic Cost	$122,712,395	$124,443,232	$125,328,319	$126,429,761
Total Difference using Safety Economic Cost	$0	$1,632,553,254	$5,501,614,331	$9,128,480,904
Safety Comprehensive Cost	$1,520,186,005	$1,541,627,962	$1,552,592,599	$1,566,237,481
Total Difference using Safety Comprehensive Cost	$0	$1,858,266,924	$5,717,248,451	$9,331,571,584

The operational cost estimation considers the cost relating to vehicle operation and maintenance, and travel time savings. It does not consider the substantial investment required for road signage and alignment modification to facilitate higher speeds. Moreover, the simulated segments are sampled over the urban network with varied traffic and roadway conditions. We have tried to incorporate a generic estimation process for the operational cost for urban and rural highway segments. However, the operational cost depends on the travel time, fuel consumption, and other details that are location-specific. For instance, the travel time along the “I-80 EW” corridor through Davis has a different operational condition (travel time, speed, fuel consumption, etc.) than other urban highways due to the number of lanes, road geometry, design speed, number of ramps, the volume of traffic, etc. In other words, the operational costs could vary with different highway segments.

The unit cost per mile is estimated for the simulated environment over a short period of a weekday (4-5 hours) to reflect an intermediate traffic condition (between peak and off-peak hours). The inclusion of the seasonal, weekly, and daily patterns of traffic will also have an impact on the estimation of the operational costs. The fuel price is also a limiting factor, as higher fuel prices will affect the cost benefits of raising the speed limit. Thus, the operational cost estimates provide a generic overview of the system with possible uncertainty from seasonal demand, traffic variation, roadway condition, and location sampling.

The safety cost estimates do not incorporate the property damage crash and injury crash category for different speed limit scenarios. The crash prediction analysis in the study shows that the PDO and injury crashes increase with the increment in the speed limit. The safety costs associated with this crash category are smaller than the severe and fatal crashes. Thus, the overall safety costs, including all the crash categories, would add to the estimation.

Conclusion

Speed limits promote highway safety and assist law enforcement to ensure an optimum tradeoff between safety and mobility based on the geometry of the roadway and other relevant factors. The review of studies from California and other states indicated that the findings concerning the impacts of changing speed limits on crashes and operational speeds are not consistent. Notably, some of the studies that analyzed the impact of raising the speed limit found an increase in mean speeds and fatal crashes, whereas others found no significant impact on crash severity or frequency. The direct comparison between the safety effect of DSL and USL also reflects conflicting outcomes in several studies. In the case of California, which assigns a DSL that prioritizes safety, we need to understand the safety impact and potential benefit of increasing the speed limit, specifically the speed of trucks. California, with the largest roadway network, different terrain, and high volume of traffic possesses a unique traffic and roadway condition compared to other states. Thus, a study inspired by previous state-specific approaches is carried out to understand the safety aspects of raising the speed limit and the potential benefit it may translate to the quality of life (less travel time).

This study assesses the impact of higher speed limits on safety and operational condition (mobility) to inform policymakers, based on a data-driven statistical modeling and traffic simulation. The study focuses on two parts; one is safety, and the other is mobility. The safety assessment for DSL policies is carried out using the statistical modeling approach. Whereas the mobility (operational condition) assessment is carried out by simulating different speed policy scenarios in SUMO.

The crash frequency model shows that the odds of crashes in urban areas are higher across all design speed segments compared to the rural areas. For every unit increase in travel in urban areas, the odds of crash frequency increase by a factor of 2.174, 2.049, and 2.101, across all design speed segments. This observation is consistent with the actual crash data as the number of crashes is higher in the urban road segments. For urban and rural areas, the variation in design speed also shows an increase in the likelihood of crashes in 60 and 70-mph urban segments, when 55 mph segments are used as the reference. On the other hand, using the same reference design speed of 55 mph, the rural segments with 65 mph and 70 mph design speeds show a decrease in the likelihood of crashes.

Two sets of binary logit models are developed to understand the impact of roadway and traffic variables on safety. One model describes the crash occurrence on the roadway segment and the other describes whether the crash is fatal and severe. The crash occurrence model coefficients show that the AADT has a positive impact on the probability of a crash occurring in California road segments, implying that roadways with higher AADT values tend to have more crashes than roads with lower AADT values. For the urban-rural classification in the design speed models, the odds of crash occurrence in urban areas are higher across all design speed segments. The fatal and severe crash model results indicate that influence of alcohol is statistically significant and has a positive impact on the probability of a crash being fatal and severe. The sampled dataset for the model consists of 18,000 truck-related crashes. The model results indicate that truck-involved crashes are mostly fatal and severe. The lighting of roadway areas plays a critical role in crashes being fatal and severe. The absence of streetlights also increases the likelihood of a crash being fatal and severe. Similarly, the weather also plays a significant role in a crash being fatal and severe. Compared to clear weather fatal crashes are more likely to occur in cloudy weather. In urban and rural locations, the likelihood of a crash being fatal and severe increases with the increase in design speed.

One of the primary goals of this study is to compare the safety impacts of speed limit changes on California roadways. DSL policy alternatives are tested by predicting the increase or decrease of crash occurrences and fatal-severe crashes using the historic data. The primary assumption for this methodology is that the design speed of the traffic is directly linked with the posted speed limit of the roadway. The policies are then tested based on the predicted crash occurrences and fatal-severe crashes in urban, rural, and design speed areas. For the DSL scenarios, the design speed is raised to maintain the differential between car and truck speeds in the proposed change in the speed limit, unlike USL scenarios, where a uniform speed is required for all. Thus, to analyze a shift from the current DSL speed limit (**Policy A**), for instance, to a uniform speed limit for both cars and trucks at 65 mph, the speed of the trucks on the highway must be increased relative to that of cars. For this reason, separate speed data for cars and trucks are required. However, the study dataset consists of design speed for all traffic, including cars and trucks. Moreover, the PeMS repository with vehicle detecting stations (traffic sensors) contains aggregated traffic speed. Without the disaggregated speed data (car vs. truck) it is difficult to estimate and raise the truck speed limit to generate artificial USL scenarios for crash prediction. Thus, this study focuses on DSL scenarios (**Policy B, C, D**) for accurate crash prediction (safety implication) on California roadways. The results show that in case of crash occurrences, except in rural areas all other areas (urban and design speed segments) show an increase in crashes with the increase in speed limit. Moreover, for all the scenarios with urban-rural and different design speed classifications, fatal and severe crashes show an increase with the increase in the speed limit. In urban areas, the increment in fatal-severe crashes is less than 1.31% for 5, 10, and 15 mph increments in speed limit.

The safety cost is estimated based on the crash costs for different location classifications (urban/rural). Two types of safety costs have been implemented in this study: (a) economic and (b) comprehensive; following the guidelines set by the National Safety Council (NSC). Since fatal and severe crashes have a significant impact on the cost component of safety, we estimated these two types for this study. The safety costs are estimated for the DSL scenarios using the predicted crash occurrences and predicted fatal-severe crashes from the statistical modeling results section. The estimated cost reflects the same trend as the predicted crashes as the increase in crashes incurs more cost. The estimated costs also show the same increasing trend with the increase in the speed limit, maintaining the speed difference between cars and trucks. Notably, the estimated cost in the urban area shows an increase of about 1% for 5, 10, and 15 mph increments compared to the current speed limit policy. The comprehensive cost for severe injury and fatal crashes at base case is $2.857 billion for urban locations. The highest comprehensive safety cost ($2.891 billion) is observed for the 15-mph increment (80/70) from the base case (65/55).

The operational costs are estimated for the simulated segments based on the value of time (travel time) costs and vehicle operating costs. Each of the segments shows a decline in travel time cost as increased speed relates to lower travel time. The minimum cost is observed for the USL 80 scenario, where the speed limit is the highest among the tested scenarios. On other hand, the cost of fuel consumption increases with the increase in the speed limit for both cars and trucks for all the simulated locations (urban and rural). The operational cost analysis on the California highway network exhibits a reduction of approximately $2 billion (2%) from the base case (60/55) when the speed limit is raised to 70/60 (car/truck). Similarly, a 5% reduction in the operational cost from the base case is observed when the speed limit is raised to 75/65 (car/truck).

The estimated difference between combined safety and operational costs indicates a net cost reduction with the increase in speed limit. The combo cost is computed based on the economic and comprehensive safety costs. These costs from different speed limit scenarios are compared to the current speed limit scenario to analyze the possible impact of changing speed limits (Table 21). The estimation results reflect an increase in cost-effectiveness. For instance, changing the current speed limit to 70/60 mph results in an effective increase in benefits for urban and rural networks. This scenario shows a net benefit of approximately $1.8 billion in rural areas for comprehensive safety costs. Similarly, the benefit ranges around $1.4 billion for urban highways using comprehensive safety costs.

The operational cost assessment is limited to vehicle operating cost and travel time cost. It does not factor in other local and statewide costs for signage, training, and infrastructure costs. Also, the cost estimates provide a generic overview of the system with possible uncertainty from seasonal demand, traffic variation, roadway condition, and location sampling. Similarly, the inclusion of PDO and injury crashes will add to the estimation of the safety cost. From the economic perspective, raising speed limits on rural California highways could reduce monetary costs, as savings in operational costs would exceed the costs from more crashes.

References

[1] C. M. Farmer, "The effects of higher speed limits on traffic fatalities in the United States , 1993 – 2017," 2019.

[2] L. S. Friedman, D. Hedeker, and E. D. Richter, "Long-term effects of repealing the national maximum speed limit in the United States," *American Journal of Public Health*, vol. 99, no. 9, pp. 1626–1631, Sep. 2009.

[3] P. Savolainen *et al.*, "Evaluating the Impacts of Speed Limit Policy Alternatives," 2014.

[4] N. J. Garber, J. S. Miller, B. Yuan, and X. Sun, "Safety Effects of Differential Speed Limits on Rural Interstate Highways," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1830, no. 1, pp. 56–62, Jan. 2003.

[5] A. P. Tarko, R. Pineda-Mendez, and Q. Guo, "Predicting the Impact of Changing Speed Limits on Traffic Safety and Mobility on Indiana Freeways," Joint Transportation Research Program, West Lafayette, IN, Jan. 2019.

[6] T. J. Gates and P. T. Savolainen, "Economic analysis of freeway speed limit policy alternatives," *Transportation Research Record*, vol. 2597, pp. 108–115, 2016.

[7] C. Monsere, S. Kothuri, and A. Razmpa, "Update to Issues Report for Interstate Speed Changes," no. June, 2017.

[8] Insurance Institute for Highway Safety (IIHS), "Speed." [Online]. Available: https://www.iihs.org/topics/speed. [Accessed: 30-Dec-2019].

[9] C. B. Haselton, A. R. Gibby, and T. C. Ferrara, "Methodologies Used to Analyze Collision Experience Associated with Speed Limit Changes on Selected California Highways."

[10] E. De Pauw, S. Daniels, M. Thierie, and T. Brijs, "Safety effects of reducing the speed limit from 90 km/h to 70 km/h," *Accident Analysis and Prevention*, vol. 62, pp. 426–431, Jan. 2014.

[11] M. T. Islam and K. El-Basyouny, "Full Bayesian evaluation of the safety effects of reducing the posted speed limit in urban residential area," *Accident Analysis and Prevention*, vol. 80, pp. 18–25, Jul. 2015.

[12] C. M. Farmer, "Relationship of traffic fatality rates to maximum state speed limits," *Traffic Injury Prevention*, vol. 18, no. 4, pp. 375–380, May 2017.

[13] K. Kockelman, "Safety Impacts and Other Implications of Raised Speed Limits on High-Speed Roads

Final Report," 2006.

[14] E. T. Donnell, S. C. Himes, K. M. Mahoney, R. J. Porter, and H. McGee, "Speed Concepts : Informational Guide," no. September, p. 59, 2009.

[15] E. T. Donnell, B. Hamadeh, L. Li, and J. Wood, "70 mph Study," 2016.

[16] R. E. Goodwin and U. Anderson, *Analysis of Texas Speed Limit Laws and Fatality Accident Rates*, no. 2. 2005.

[17] A. Davis, E. Hacker, P. T. Savolainen, and T. J. Gates, "Longitudinal Analysis of Rural Interstate Fatalities in Relation to Speed Limit Policies," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2514, no. 1, pp. 21–31, Jan. 2015.

[18] G. W. Neeley and L. E. Richardson, "The effect of state regulations on truck-crash fatalities," *American Journal of Public Health*, vol. 99, no. 3, pp. 408–415, Mar. 2009.

[19] S. L. Johnson and N. Pawar, "Cost-Benefit Evaluation of Large Truck-Automobile Speed Limit Differentials on Rural Interstate Highways," 2005.

[20] W. Hu, "Raising the speed limit from 75 to 80 mph on Utah rural interstates: Effects on vehicle speeds and speed variance," *Journal of Safety Research*, vol. 61, pp. 83–92, Jun. 2017.

[21] S. L. Johnson and D. Murray, "Empirical Analysis of Truck and Automobile Speeds on Rural Interstates: Impact of Posted Speed Limits," 2010.

[22] N. J. Garber, J. S. Miller, B. Yuan, and X. Sun, "Safety effects of differential speed limits on rural interstate highways," *Transportation Research Record*, no. 1830, pp. 56–62, Oct. 2003.

[23] N. Alemazkoor and G. Hawkins, "Examining Impacts of Increasing the Speed Limit on Speed Distribution : A Case Study," in *TRB 2014 Annual Meeting*, 2014.

[24] R. A. Retting and E. R. Teoh, "Traffic speeds on interstates and freeways 10 years after repeal of national maximum speed limit," *Traffic Injury Prevention*, vol. 9, no. 2, pp. 119–124, Apr. 2008.

[25] M. P. Dixon, A. Abdel-Rahim, S. Elbassuoni, M. University of Idaho, I. T. Department, and F. H. Administration, "Evaluation of the Impacts of Differential Speed Limits on Interstate Highways in Idaho," no. October, p. 44p, 2012.

[26] T. J. Gates *et al.*, "Safety and Operational Impacts of Differential Speed Limits on Two-Lane Rural Highways in Montana." p. 133p, 2016.

[27] R. R. Souleyrette Gerald and A. Olson Professor of Civil Engineering, "Evaluation of Iowa's 70 mph

Speed Limit-2.5 Year Update," 2009.

[28] N. V Malyshkina and F. Mannering, "Effect of Increases in Speed Limits on Severities of Injuries in Accidents," *Transportation Research Board of the National Academies, 2083*, pp. 122–127, 2008.

[29] Y. J. Kweon and K. M. Kockelmam, "Safety effects of speed limit changes use of panel models, including speed, use, and design variables," in *Transportation Research Record*, 2005, no. 1908, pp. 148–158.

[30] M. Korkut, S. Ishak, and B. Wolshon, "Freeway truck lane restriction and differential speed limits: Crash analysis and traffic characteristics," *Transportation Research Record*, vol. 2194, no. 2194, pp. 11–20, Jan. 2010.

[31] B. Y. and X. S. Nicholas J. Garber, John S. Miller, "Safety Effects of Differential Speed Limits on Rural Interstate Highways," 2005.

[32] S. Ishak, B. Wolshon, M. Korkut, Y. Qi, and X. Sun, "Evaluation of the Traffic Safety Benefits of a Lower Speed Limit and Restriction of Trucks to Use of Right Lane Only on I-10 Over the Atchafalaya Basin," no. 5, 2008.

[33] J. S. Hickman, F. Guo, R. J. Hanowski, R. Bishop, G. Bergoffen, and D. Murray, "Safety benefits of speed limiters in commercial motor vehicles using carrier-collected crash data," *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, vol. 16, no. 4, pp. 177–183, Nov. 2012.

[34] S. L. Johnson, N. Pawar, and J. Pawar, "ANALYSIS OF HEAVY TRUCK AND AUTOMOBILE SPEED DISTRIBUTIONS FOR UNIFORM AND DIFFERENTIAL SPEED LIMIT CONFIGURATIONS ON RURAL INTERSTATE HIGHWAYS," 2006.

[35] K. C. Sinha and S. Labi, *Transportation Decision Making: Principles of Project Evaluation and Programming*. John Wiley, 2007.

[36] D. Lord, X. Qin, and S. R. Geedipally, *Highway Safety Analytics and Modeling*. 2021.

[37] D. Lord and F. Mannering, "The statistical analysis of crash-frequency data: A review and assessment of methodological alternatives," *Transportation Research Part A: Policy and Practice*, vol. 44, no. 5, pp. 291–305, Jun. 2010.

[38] "Average Cost of Owning and Operating an Automobile | Bureau of Transportation Statistics." [Online]. Available: https://www.bts.gov/content/average-cost-owning-and-operating-automobilea-assuming-15000-vehicle-miles-year. [Accessed: 30-Nov-2021].

[39] N. Williams and D. Murray, "An Analysis of the Operational Costs of Trucking: 2020 Update," Nov. 2020.

Appendix A

Simulated Segments and Results

The simulation results for all the segments show that the travel time for cars gradually decreases as the speed limit is increased both for USL and DSL scenarios. This implies that the average speed of cars increases with the increasing speed limit. The model simulates the off-peak traffic as the effect of speed limit changes diminishes during the peak period. To understand the direction-wise variation in traffic parameters (speed, travel time, time loss) both sides of the highway and freeway are studied and reported. As with cars, the travel time for trucks decreases gradually with the increase in the speed limit for both USL and DSL scenarios. The VMT and traffic throughput (flow) remain about a constant value for cars and trucks for all the DSL and USL scenarios. The time loss variable also represents a declining trend in the lost time while driving slower than the preferred speed.

Location - 1: I-5 NS Coalinga, Fresno

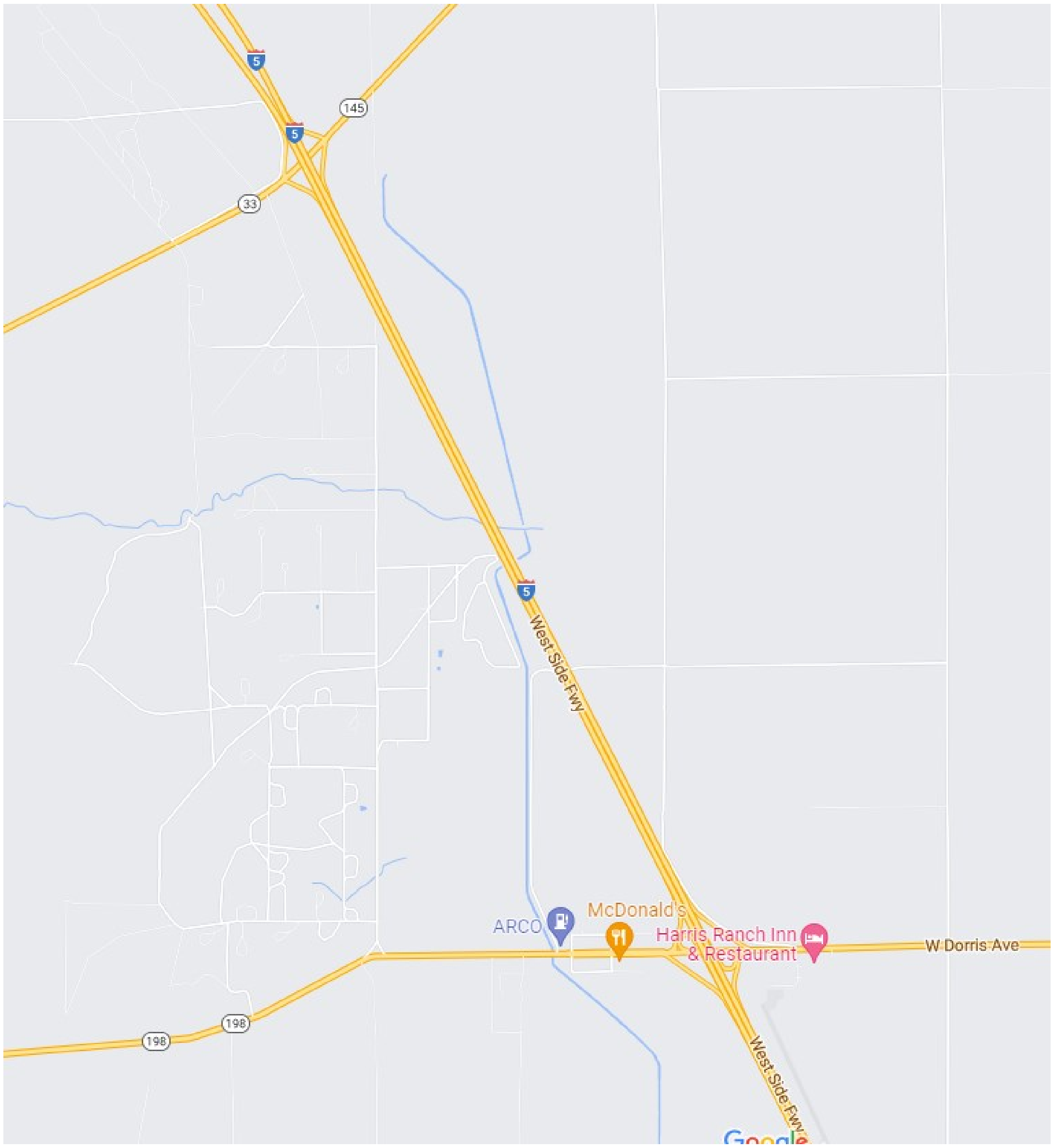


Figure 5. Map of the Simulated Segment I-5 NS Coalinga, Fresno, CA

Table 22. Operational Performance of Alternative Speed Limit Policies on California Rural Highway (I-5 North-South Coalinga, CA)

Coalinga, Fresno	Base Scenario (Car 70 / Truck 55)	DSL Scenarios				USL Scenarios			
		Car 70 / Truck 60	Car 70 / Truck 65	Car 75 / Truck 65	Car 80 / Truck 70	Car - Truck 65	Car - Truck 70	Car- Truck 75	Car - Truck 80
Car Travel Time (North)	573	566	556	524	480	576	552	523	500
Car Travel Time (South)	570	566	554	521	478	570	550	520	498
Truck Travel Time (North)	658	608	573	570	541	596	565	545	510
Truck Travel Time (South)	657	605	570	568	539	595	564	542	509
Car VMT	158557	158617	158623	158595	158657	158589	158612	158612	158614
Truck VMT	16521	16498	16492	16521	16512	16495	16512	16495	16516
Car Speed (North)	62	62	62	66	73	63	68	73	77
Car Speed (South)	63	63	63	68	72	63	67	72	76
Truck Speed (North)	53	57	61	62	65	59	64	70	74
Truck Speed (South)	53	58	61	62	66	60	64	69	72
Time Loss (North)	70102	69214	64714	59231	51785	72725	68356	59238	49185
Time Loss (South)	69854	68242	63815	58612	52236	71812	68125	60856	49215
Total Flow or Throughput	4547	4555	4554	4565	4566	4564	4544	4559	4556
Simulation Period (sec)	18500								
Segment Length (mile)	9								

Location - 2: I-5 NS Grapevine, Kern

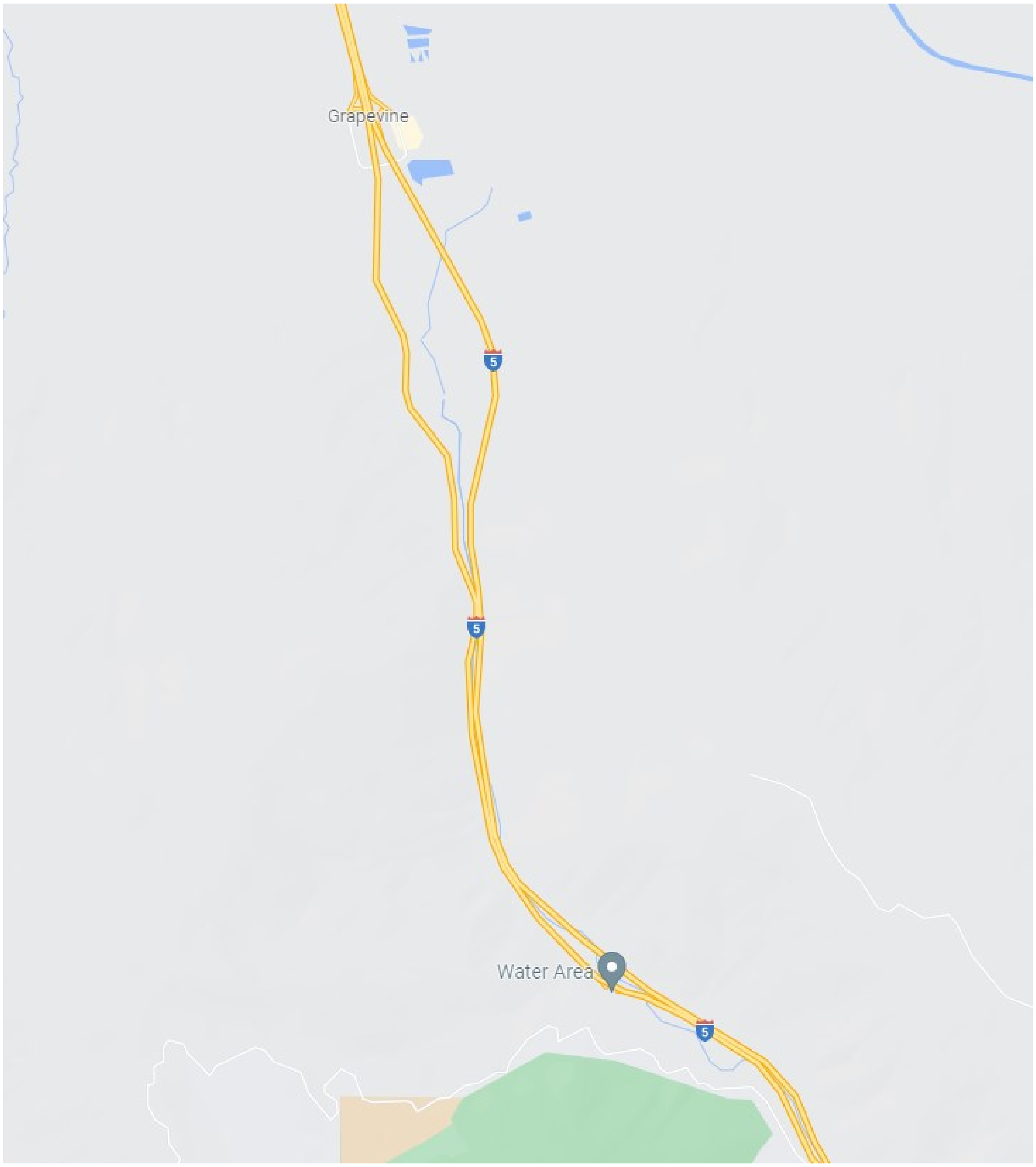


Figure 6. Map of the Simulated Segment I-5 NS Grapevine, Kern, CA

The simulation model developed for Kern I-5 North-South (Table 23) is a representative model for a rural area.

Speed variance or the difference in speed between cars and trucks is also an important consideration for this study. The speed variance is significant for the DSL scenarios, ranging from 7 (60 vs. 53) to 8 (74 vs. 66) mph for 70/60 and 80/70 policy scenarios. Interestingly, the speed difference varies as the speed limit is increased for the DSL scenarios. Thus, at higher speed limit scenarios (DSL) the speed variance or the speed difference between cars and trucks decreases. On the other hand, for the USL scenarios, the speed variance is present in a small magnitude. For instance, the highest speed variance is about 1 mph among all the four USL scenarios ranging from 65 mph to 80 mph.

Table 23. Operational Performance of Alternative Speed Limit Policies on California Rural Freeway (I-5 North-South Grapevine, Kern, CA)

Grapevine, Kern	Base Scenario (Car 65 / Truck 55)	DSL Scenarios				USL Scenarios			
		Car 70 / Truck 60	Car 70 / Truck 65	Car 75 / Truck 65	Car 80 / Truck 70	Car - Truck 65	Car - Truck 70	Car- Truck 75	Car - Truck 80
Travel Time Car (South)	*435*	*408*	*409*	*374*	*350*	*434*	*403*	*375*	*351*
Travel Time Car (North)	*437*	*411*	*409*	*376*	*353*	*435*	*404*	*376*	*353*
Travel Time Truck (South)	*491*	*450*	*426*	*425*	*394*	*439*	*406*	*378*	*356*
Travel Time Truck (North)	*490*	*452*	*429*	*427*	*396*	*440*	*407*	*379*	*359*
Car VMT	*284905*	*284910*	*284875*	*284984*	*284820*	*284886*	*284781*	*284854*	*284789*
Truck VMT	*28786*	*27598*	*27460*	*27431*	*27566*	*27656*	*27675*	*27511*	*27651*
Car Speed (North)	*60*	*65*	*65*	*70*	*74*	*61*	*65*	*71*	*74*
Car Speed (South)	*60*	*64*	*64*	*70*	*74*	*61*	*65*	*70*	*74*
Truck Speed (North)	*53*	*58*	*62*	*62*	*66*	*60*	*65*	*69*	*73*
Truck Speed (South)	*53*	*58*	*62*	*61*	*65*	*60*	*65*	*70*	*73*
Time Loss (North)	*96258*	*86122*	*86158*	*75818*	*68353*	*94514*	*82408*	*76743*	*68629*
Time Loss (South)	*97325*	*87215*	*86859*	*76215*	*69322*	*95125*	*82915*	*77156*	*69215*
Total Flow or Throughput	*7037*	*7053*	*7043*	*7058*	*7048*	*7058*	*7034*	*7045*	*7053*
Simulation Period (s)	*18600*								
Freeway Segment Length (mile)	*15*								

Location - 3: I-5 NS Oceanside, San Diego

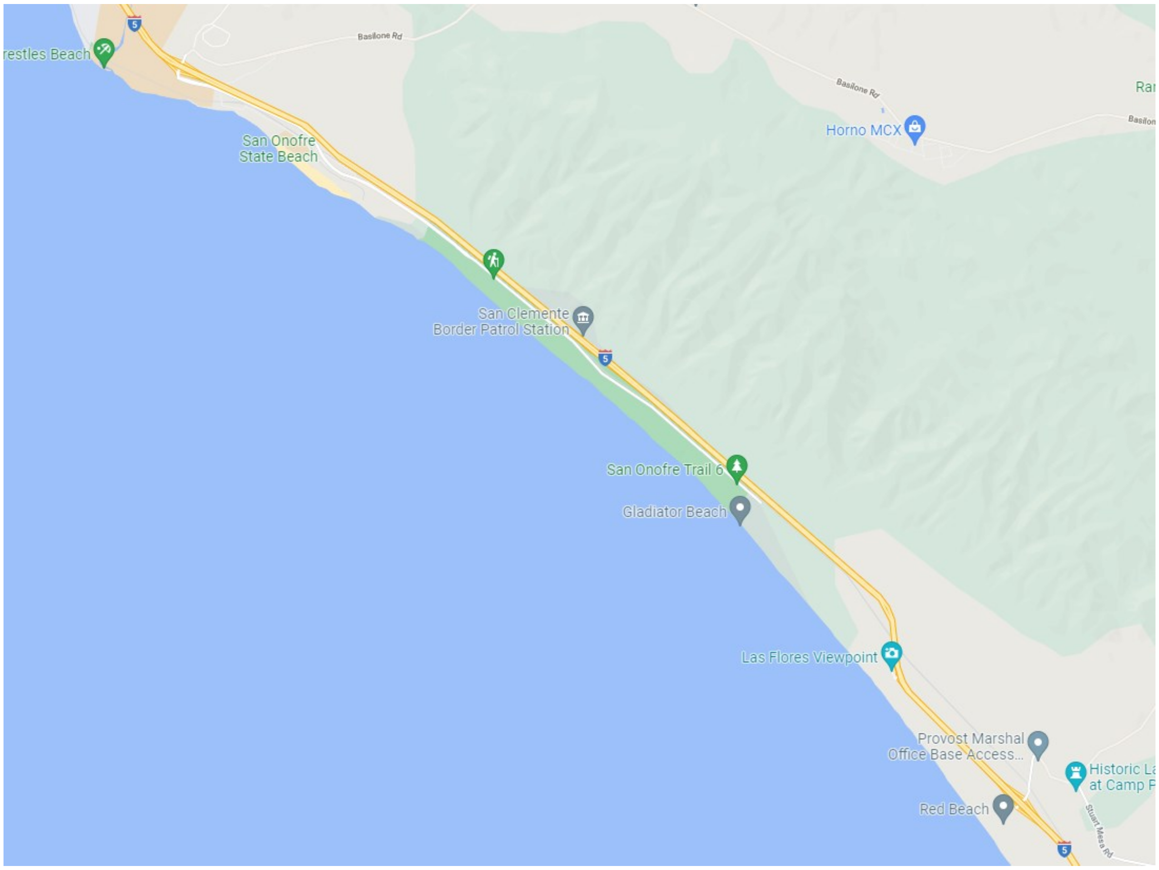


Figure 7. Map of the Simulated Segment I-5 NS Oceanside, San Diego, CA

The simulation model developed for San Diego I-5 North-South (Table 24) is a representative model for a rural area.

The speed variance is significant for the DSL scenarios, ranging from 7 (61 vs. 54) to 8 (74 vs. 66) mph for 70/60 and 80/70 policy scenarios. Interestingly, the speed difference varies as the speed limit is increased for the DSL scenarios. Thus, at higher speed limit scenarios (DSL) the speed variance decreases. On the other hand, for the USL scenarios, the speed variance is small. For instance, the highest speed variance is about 2 mph (62 vs 60) among all the four USL scenarios ranging from 65 mph to 80 mph.

Table 24. Operational Performance of Alternative Speed Limit Policies on California Rural Freeway (I-5 North-South Oceanside, San Diego, CA)

Oceanside, San Diego	Base Scenario (Car 65 / Truck 55)	DSL Scenarios				USL Scenarios			
		Car 70 / Truck 60	Car 70 / Truck 65	Car 75 / Truck 65	Car 80 / Truck 70	Car - Truck 65	Car - Truck 70	Car- Truck 75	Car - Truck 80
Travel Time Car (North)	*695*	*645*	*643*	*599*	*563*	*692*	*645*	*602*	*563*
Travel Time Car (South)	*693*	*646*	*645*	*599*	*562*	*693*	*645*	*600*	*562*
Travel Time Truck (North)	*799*	*735*	*676*	*678*	*634*	*799*	*636*	*595*	*563*
Travel Time Truck (south)	*804*	*737*	*685*	*681*	*633*	*804*	*641*	*596*	*565*
Car VMT	*229259*	*229911*	*229828*	*230348*	*230585*	*229197*	*229841*	*230350*	*230675*
Truck VMT	*8670*	*7612*	*7780*	*7763*	*7829*	*7811*	*7494*	*7682*	*7690*
Car Speed (North)	*61*	*65*	*65*	*70*	*74*	*62*	*67*	*72*	*76*
Car Speed (South)	*61*	*65*	*65*	*70*	*74*	*61*	*67*	*71*	*75*
Truck Speed (North)	*54*	*58*	*62*	*62*	*66*	*60*	*66*	*70*	*75*
Truck Speed (South)	*53*	*58*	*62*	*61*	*66*	*59*	*66*	*71*	*74*
Time Loss (North)	*46188*	*42769*	*41574*	*39108*	*36882*	*48947*	*42323*	*38670*	*35425*
Time Loss (South)	*51596*	*48215*	*47197*	*42238*	*38721*	*50569*	*45011*	*42875*	*37713*
Traffic Flow or Throughput	*3525*	*3531*	*3533*	*3530*	*3533*	*3528*	*3533*	*3541*	*3538*
Simulation Period	*15000 (4 hour 10 minutes)*								
Freeway Segment Length (mile)	*10*								

Location - 4: I-5 NS San Clemente, Orange

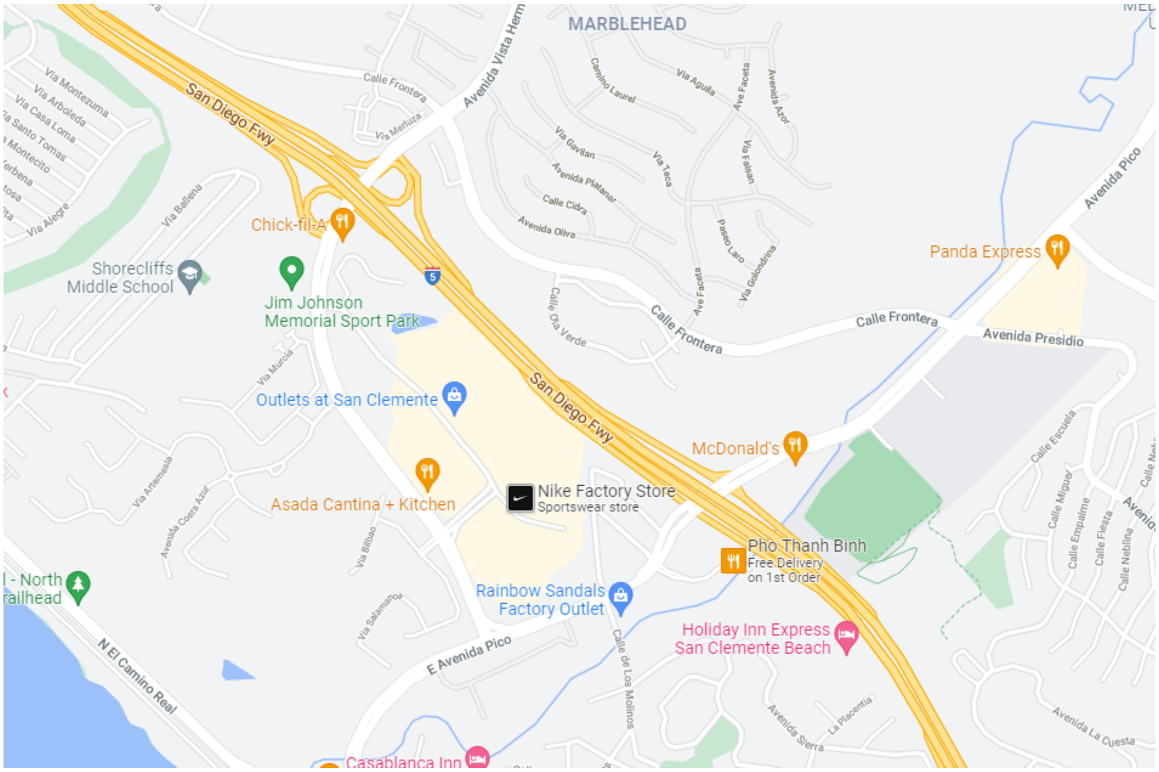


Figure 8. Map of the Simulated Segment I-5 NS San Clemente, Orange, CA

The simulation model developed for San Clemente, Orange I-5 North-South (Table 25) is a representative model for an urban area. The speed variance is significant for the DSL scenarios, ranging from 8 (61 vs. 53) to 8 (74 vs. 66) mph for 70/60 and 80/70 policy scenarios. The speed difference varies as the speed limit is increased for the DSL scenarios. Thus, at higher speed limit scenarios (DSL) the speed variance decreases. On the other hand, for the USL scenarios, the speed variance is small. For instance, the highest speed variance is about 2 mph (75 vs 73) among all the four USL scenarios ranging from 65 mph to 80 mph.

Table 25. Operational Performance of Alternative Speed Limit Policies on California Urban Highway / Freeway (I-5 North-South San Clemente, Orange, CA)

San Clemente, Orange	Base Scenario	DSL Scenarios				USL Scenarios			
		Car 70 / Truck 60	Car 70 / Truck 65	Car 75 / Truck 65	Car 80 / Truck 70	Car - Truck 65	Car - Truck 70	Car- Truck 75	Car - Truck 80
Speed Car (North)	61	65	66	70	75	62	66	71	75
Speed Car (South)	62	66	65	71	74	62	67	71	75
Speed Truck (North)	53	58	62	62	66	60	66	70	74
Speed Truck (south)	53	58	62	62	66	61	65	70	73
Car VMT	119555	119558	119557	119553	119557	119557	119557	119557	119558
Truck VMT	7385	7378	7391	7381	7375	7389	7378	7386	7380
Travel Time Car (North)	161	150	151	140	133	162	150	141	132
Travel Time Car (South)	165	153	153	142	134	165	153	143	134
Travel Time Truck (North)	186	171	159	158	147	161	149	138	134
Travel Time Truck (South)	187	172	161	160	149	163	152	142	136
Time Loss (North)	29448	27627	26535	25132	23612	28026	26632	24142	23788
Time Loss (South)	29342	27458	26813	25214	23425	27895	26451	24265	23654
Traffic Flow or Throughput	6528	6577	6585	6581	6580	6578	6571	6588	6582
Simulation Period	***21960 second (6 hours 6 minutes)***								
Segment Length (mile)	***4***								

Location - 5: SR-99 NS Merced

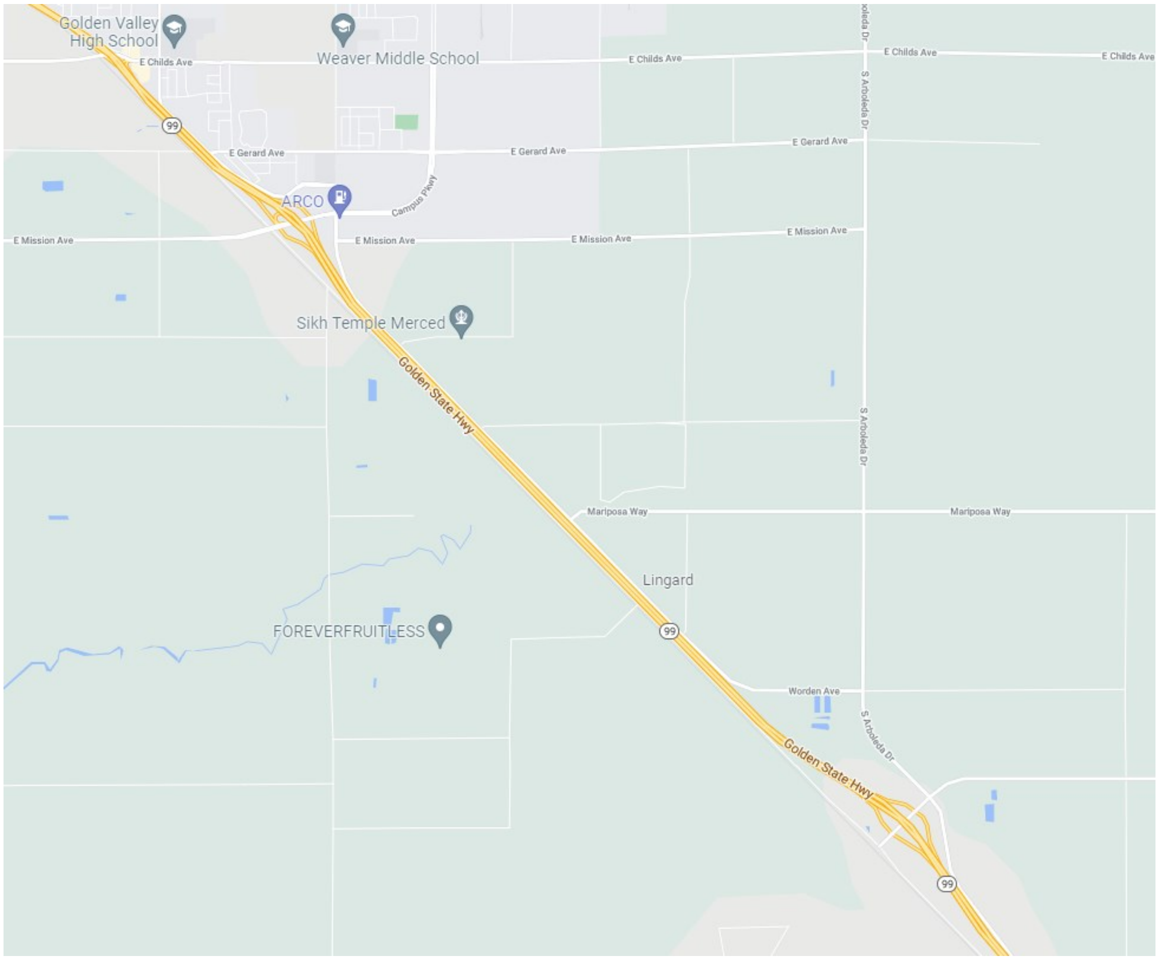


Figure 9. Map of the Simulated Segment SR-99 NS Merced, CA

The simulation model developed for Merced, SR-99 North-South (Table 26) is a representative model for an urban area.

The speed variance is significant for the DSL scenarios, ranging from 7 (60 vs. 53) to 7 (74 vs. 67) mph for 70/60 and 80/70 policy scenarios. The speed difference varies as the speed limit is increased for the DSL scenarios. Thus, at higher speed limit scenarios (DSL) the speed variance decreases. On the other hand, for the USL scenarios, the speed variance is present in a small magnitude. For instance, the highest speed variance is about 2 mph (72 vs 70) among all the four USL scenarios ranging from 65 mph to 80 mph.

Table 26. Operational Performance of Alternative Speed Limit Policies on California Urban Highway (SR-99 North-South Merced, CA)

Merced	Base Scenario (Car 65 / Truck 55)	DSL Scenarios				USL Scenarios			
		Car 70 / Truck 60	Car 70 / Truck 65	Car 75 / Truck 65	Car 80 / Truck 70	Car - Truck 65	Car - Truck 70	Car- Truck 75	Car - Truck 80
Travel Time Car (North)	*541*	*505*	*498*	*457*	*429*	*526*	*496*	*457*	*430*
Travel Time Car (South)	*544*	*503*	*501*	*461*	*431*	*535*	*495*	*463*	*431*
Travel Time Truck (North)	*605*	*557*	*515*	*511*	*486*	*517*	*488*	*450*	*429*
Travel Time Truck (south)	*604*	*556*	*517*	*512*	*484*	*523*	*485*	*453*	*427*
Car VMT	*95437*	*95377*	*95175*	*95253*	*95280*	*95086*	*95167*	*95253*	*95288*
Truck VMT	*18667*	*18780*	*18720*	*18697*	*18631*	*18790*	*18574*	*18806*	*18791*
Car Speed (North)	*60*	*63*	*64*	*71*	*74*	*62*	*66*	*72*	*76*
Car Speed (South)	*60*	*64*	*64*	*70*	*74*	*62*	*67*	*70*	*75*
Truck Speed (North)	*53*	*59*	*62*	*62*	*67*	*61*	*66*	*70*	*75*
Truck Speed (South)	*53*	*59*	*62*	*61*	*66*	*61*	*65*	*70*	*74*
Time Loss (North)	*38681*	*37853*	*27620*	*21917*	*21143*	*24242*	*27311*	*22296*	*22253*
Time Loss (South)	*36942*	*31845*	*29333*	*22061*	*19385*	*27567*	*24148*	*23406*	*18909*
Traffic Flow or Throughput	*2070*	*2077*	*2080*	*2075*	*2075*	*2071*	*2075*	*2075*	*2071*
Simulation Period	*18600 (5 hour 10 minutes)*								
Segment Length (mile)	*10*								

Location - 6: I-15 NS San Bernardino

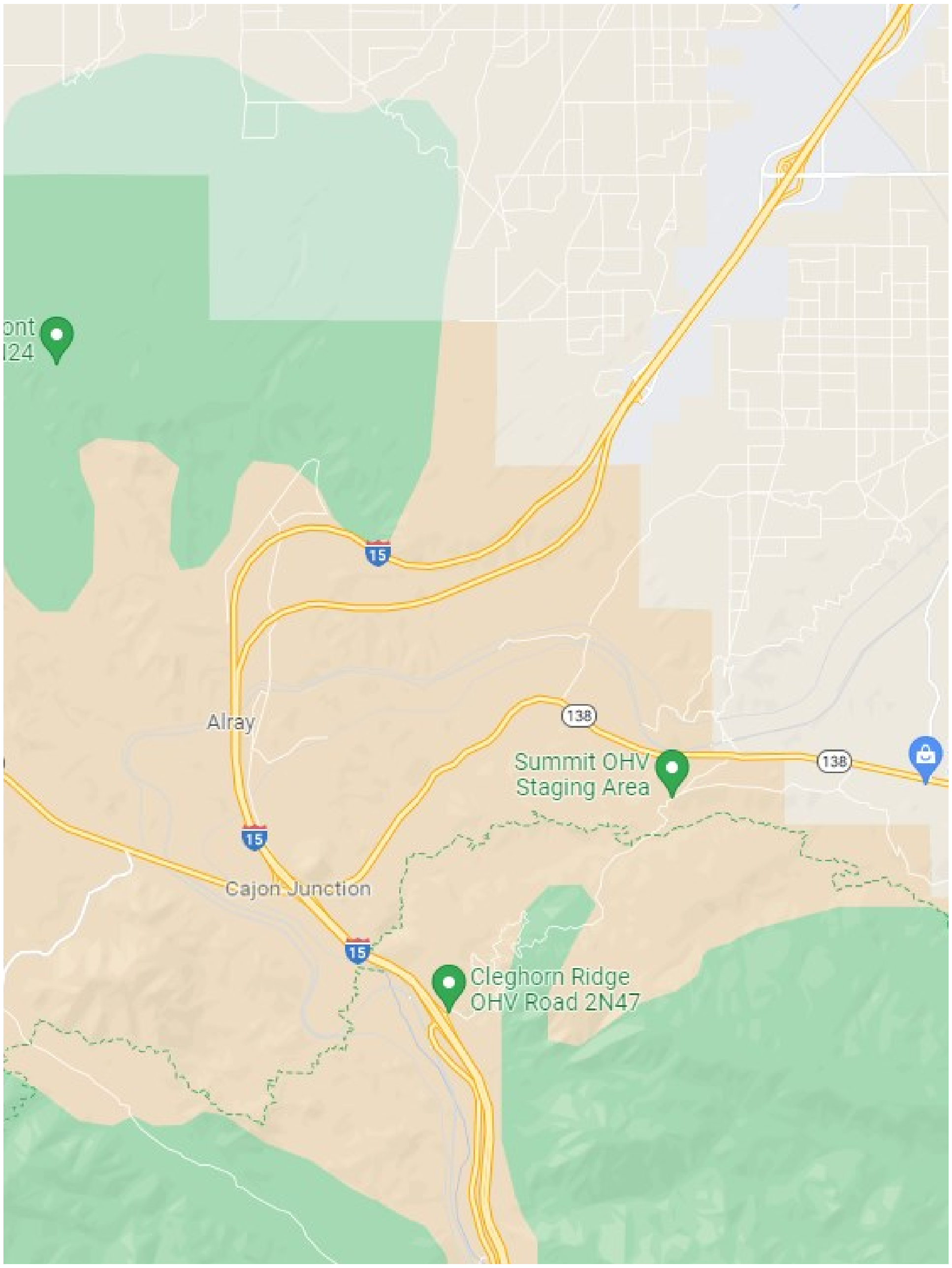


Figure 10. Map of the Simulated Segment I-15 NS San Bernardino, CA

The simulation model developed for San Bernardino, I-15 North-South (Table 27) is a representative model for a rural area with a 70-mph speed limit. The speed variance is significant for the DSL scenarios, ranging from 9 (65 vs. 54) to 7 (74 vs. 67) mph for 70/60 and 80/70 policy scenarios. The speed difference varies as the speed limit is increased for the DSL scenarios. Thus, at higher speed limit scenarios (DSL) the speed variance decreases. On the other hand, for the USL scenarios, the speed variance is small. For instance, the highest speed variance is about 2 mph (75 vs 73) among all the four USL scenarios ranging from 65 mph to 80 mph.

Table 27. Operational Performance of Alternative Speed Limit Policies on California Rural Freeway (I-15 North-South San Bernardino, CA)

San Bernardino I-15 North-South	Base Scenario (Car 70 / Truck 55)	DSL Scenarios				USL Scenarios			
		Car 70 / Truck 60	Car 70 / Truck 65	Car 75 / Truck 65	Car 80 / Truck 70	Car - Truck 65	Car - Truck 70	Car-Truck 75	Car - Truck 80
Travel Time Car (North)	*523*	*522*	*520*	*487*	*459*	*572*	*523*	*486*	*457*
Travel Time Car (South)	*521*	*520*	*518*	*485*	*457*	*570*	*522*	*484*	*455*
Travel Time Truck (North)	*643*	*592*	*552*	*550*	*515*	*570*	*520*	*486*	*460*
Travel Time Truck (South)	*595*	*552*	*549*	*551*	*511*	*572*	*516*	*484*	*459*
Car VMT	*399818*	*399833*	*399828*	*399851*	*399853*	*399853*	*399866*	*399841*	*399821*
Truck VMT	*15241*	*15251*	*15238*	*15247*	*15240*	*15250*	*15254*	*15252*	*15244*
Car Speed (North)	*65*	*67*	*66*	*72*	*74*	*63*	*66*	*72*	*75*
Car Speed (South)	*65*	*66*	*67*	*71*	*74*	*63*	*67*	*72*	*75*
Truck Speed (North)	*54*	*58*	*62*	*62*	*67*	*62*	*65*	*70*	*74*
Truck Speed (South)	*54*	*57*	*62*	*61*	*66*	*61*	*65*	*70*	*73*
Traffic Flow or Throughput	*6715*	*6749*	*6761*	*6734*	*6763*	*6752*	*6763*	*6782*	*6767*
Car Time Loss (North)	*85877*	*83617*	*83168*	*74096*	*71264*	*96074*	*86515*	*75653*	*71273*
Truck Time Loss (South)	*86153*	*84123*	*83675*	*74621*	*71854*	*96175*	*86931*	*76123*	*71483*
Simulation Period	*18600 seconds (5 hour 10 minutes)*								
Freeway Segment Length (mile)	*10*								

Location - 7: I-80 EW Alameda

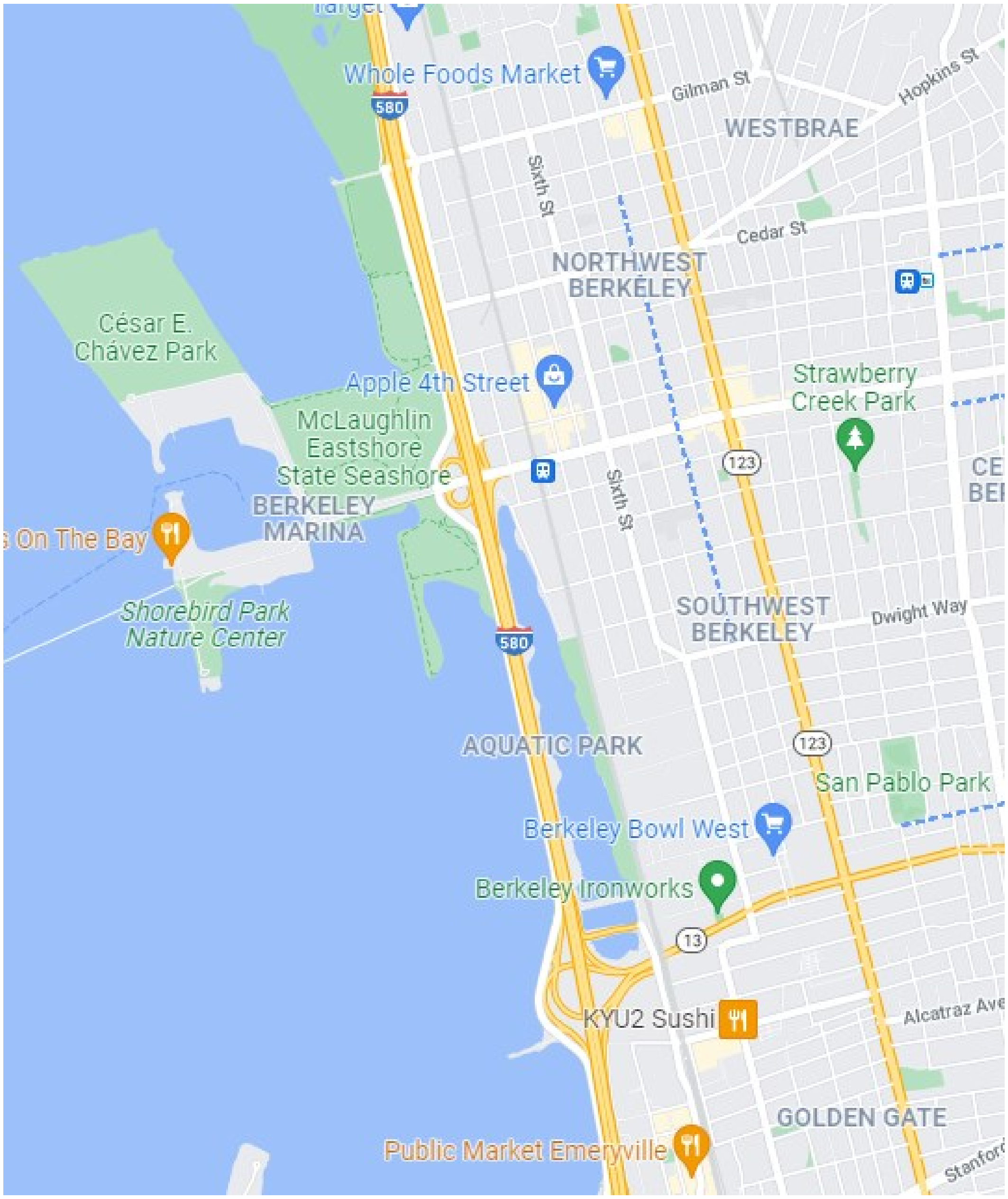


Figure 11. Map of the Simulated Segment I-80 East-West Berkeley, Alameda, CA

The simulation model developed for Berkeley, Alameda, I-80 East-West (Table 28) is a representative model for an urban area with a 65-mph speed limit. Speed variance or the difference in speed between cars and trucks is also an important consideration for this study. The speed variance is significant for the DSL scenarios, ranging from 9 (61 vs. 52) to 9 (74 vs. 65) mph for 70/60 and 80/70 policy scenarios. Interestingly, the speed difference varies as the speed limit is increased for the DSL scenarios. Thus, at higher speed limit scenarios

(DSL) the speed variance or the speed difference between cars and trucks decreases. On the other hand, for the USL scenarios, the speed variance is present in a small magnitude. For instance, the highest speed variance is about 2 mph (74 vs 72) among all the four USL scenarios ranging from 65 mph to 80 mph.

Table 28. Operational Performance of Alternative Speed Limit Policies on California Urban Freeway (I-80 East-West Berkeley, Alameda, CA)

Berkeley I-80 East-West	Base Scenario (Car 65 / truck 55)	DSL Scenarios				USL Scenarios			
		Car 70 / Truck 60	Car 70 / Truck 65	Car 75 / Truck 65	Car 80 / Truck 70	Car - Truck 65	Car - Truck 70	Car- Truck 75	Car - Truck 80
Travel Time Car (West)	*197*	*184*	*185*	*171*	*162*	*199*	*185*	*172*	*164*
Travel Time Car (East)	*200*	*184*	*184*	*172*	*162*	*198*	*184*	*173*	*163*
Travel Time Truck (West)	*225*	*207*	*199*	*198*	*186*	*195*	*187*	*177*	*168*
Travel Time Truck (East)	*230*	*210*	*197*	*196*	*185*	*196*	*187*	*175*	*166*
Car VMT	*171520*	*171546*	*171524*	*171510*	*171518*	*171505*	*171515*	*171527*	*171510*
Truck VMT	*8124*	*8128*	*8122*	*8126*	*8124*	*8138*	*8136*	*8117*	*8120*
Car Speed (West)	*62*	*65*	*67*	*67*	*74*	*62*	*66*	*72*	*74*
Car Speed (East)	*61*	*66*	*67*	*67*	*73*	*62*	*66*	*71*	*74*
Truck Speed (West)	*53*	*57*	*61*	*61*	*65*	*61*	*64*	*70*	*72*
Truck Speed (East)	*52*	*56*	*62*	*62*	*65*	*61*	*65*	*70*	*73*
Time Loss (West)	*65107*	*61352*	*61452*	*57866*	*55823*	*64512*	*61769*	*58320*	*52320*
Time Loss (East)	*62679*	*59895*	*59082*	*56916*	*53826*	*64874*	*62361*	*57908*	*51973*
Traffic Flow or Throughput	*9150*	*9171*	*9157*	*9160*	*9168*	*9177*	*9175*	*9182*	*9184*
Simulation Period	*18600 seconds (4 hours 10 minutes)*								
Segment Length (mile)	*5 Miles*								

Appendix B

Cost Estimation of Simulated Segments

Table 29. Estimated Annual Effects of Alternative Speed Limit Policies on California Rural Highway (I-5 North-South Coalinga, Fresno, CA)

Value of Time	Base Case (70/55)	DSL 70 / 60	DSL 70 / 65	DSL 75/65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
Travel Time for Passenger Car (seconds)	572	566	555	523	479	573	551	522	499
Annual Travel Time for Passenger Car	1392	1377	1350	1271	1166	1394	1342	1269	1215
Travel Time for trucks	657	607	572	572	540	595	565	544	509
Annual Travel Time for Trucks	1599	1476	1391	1392	1314	1449	1374	1323	1240
Car VoT (2020)	30	30	30	30	30	30	30	30	30
Truck VoT (2020, ATRI)	55	55	55	55	55	55	55	55	55
Cost of Travel Time for Passenger Cars	$42,109	$41,679	$40,865	$38,476	$35,288	$42,171	$40,598	$38,414	$36,768
Cost of Travel Time for Truck	$88,354	$81,530	$76,825	$76,887	$72,585	$80,038	$75,920	$73,100	$68,485
Car Flow	2000	2005	2010	2003	2010	2007	1990	2011	2005
Truck Flow	262	272	274	275	271	268	275	270	267
Total Cost of Travel Time	$107,366,144	$105,741,802	$103,188,793	$98,210,417	$90,600,428	$106,086,532	$101,668,470	$96,986,496	$92,005,309
Difference in Cost from Base Case	0	-2%	-4%	-9%	-16%	-1%	-5%	-10%	-14%

Value of Time	**Base Case (70/55)**	**DSL 70 / 60**	**DSL 70 / 65**	**DSL 75/65**	**DSL 80 / 70**	**USL 65**	**USL 70**	**USL 75**	**USL 80**
Vehicle Operating Cost									
Fuel Consumption for Passenger Cars (gallon/hr)	599	608	602	616	622	584	599	612	624
Annual Fuel Consumption for Cars	5248376	5323623	5275780	5398770	5445093	5111765	5249456	5364256	5469376
Fuel Consumption for Trucks (gallon/hr)	308	338	361	370	380	365	373	383	395
Annual Fuel Consumption for Trucks	2701701	2959151	3164628	3239956	3327556	3193651	3269582	3351077	3462081
Other Non Fuel Costs cars	$10,687,200	$10,713,918	$10,740,636	$10,703,231	$10,740,636	$10,724,605	$10,633,764	$10,745,980	$10,713,918
Other Non Fuel Costs Trucks	$3,695,143	$3,836,179	$3,864,386	$3,878,490	$3,822,076	$3,779,765	$3,878,490	$3,807,972	$3,765,661
Vehicle Operating Cost for cars ($3.6 per gallon)	$18,894,154	$19,165,042	$18,992,808	$19,435,574	$19,602,336	$18,402,353	$18,898,043	$19,311,322	$19,689,754
Vehicle Operating Cost for trucks ($3.9 per gallon)	$10,536,635	$11,540,688	$12,342,049	$12,635,829	$12,977,469	$12,455,238	$12,751,371	$13,069,199	$13,502,115
Total VOC	$43,813,133	$45,255,827	$45,939,880	$46,653,123	$47,142,516	$45,361,961	$46,161,668	$46,934,473	$47,671,448
Difference in Cost from Base Case	0	3%	5%	6%	8%	4%	5%	7%	9%
Total Operating Cost	$151,179,276	$150,997,629	$149,128,673	$144,863,540	$137,742,945	$151,448,493	$147,830,138	$143,920,968	$139,676,757
Difference in Cost from Base Case		0%	-1%	-4%	-9%	0%	-2%	-5%	-8%

Table 30. Estimated Annual Effects of Alternative Speed Limit Policies on California Rural Highway (I-5 North-South Grapevine, Kern, CA)

Value of Time	Base Case (65/55)	DSL 70 / 60	DSL 70 / 65	DSL 75/65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
Travel Time for Passenger Car (seconds)	435.865	409.175	409.005	375.114	351.603	434.92	403.2	375.854	352.019
Annual Travel Time for Passenger Car	1060.604833	995.6591667	995.2455	912.7774	855.5673	1058.305333	981.12	914.5780667	856.5795667
Travel Time for trucks	490	451	427	426	395	439	407	379	358
Annual Travel Time for Trucks	1193.326133	1098.333667	1039.6295	1036.6	961.1666667	1068.939	989.3811667	921.7345	870.233
Car VoT (2020)	30.26	30.26	30.26	30.26	30.26	30.26	30.26	30.26	30.26
Truck VoT (2020, ATRI)	55.24	55.24	55.24	55.24	55.24	55.24	55.24	55.24	55.24
Cost of Travel Time for Passenger Cars	$32,094	$30,129	$30,116	$27,621	$25,889	$32,024	$29,689	$27,675	$25,920
Cost of Travel Time for Truck	$65,919	$60,672	$57,429	$57,262	$53,095	$59,048	$54,653	$50,917	$48,072
Car Flow	3228	3234	3238	3224	3235	3228	3230	3226	3231
Truck Flow	272	274	270	271	275	272	272	274	275
Total Cost of Travel Time	$121,529,176	$114,060,157	$113,021,891	$104,566,900	$98,353,507	$119,435,611	$110,760,202	$103,231,129	$96,967,545
Difference in Cost from Base Case	0	-6%	-7%	-14%	-19%	-2%	-9%	-15%	-20%

Value of Time	**Base Case (65/55)**	**DSL 70 / 60**	**DSL 70 / 65**	**DSL 75/65**	**DSL 80 / 70**	**USL 65**	**USL 70**	**USL 75**	**USL 80**
Vehicle Operating Cost									
Fuel Consumption for Passenger Cars	853.3424	876.215	887.9795	895.8214	927.5521	843.6146	868.589	892.935	921.189
Annual Fuel Consumption for Cars	7475279.424	7675643.4	7778700.42	7847395.464	8125356.396	7390063.896	7608839.64	7822110.6	8069615.64
Fuel Consumption for Trucks	410.399	415.622	442.414	456.215	469.235	449.1193	463.152	475.289	492.521
Annual Fuel Consumption for Trucks	3595095.24	3640848.72	3875546.64	3996443.4	4110498.6	3934285.068	4057211.52	4163531.64	4314483.96
Other Non-Fuel Costs cars	$17,249,141	$17,281,202	$17,302,577	$17,227,766	$17,286,546	$17,249,141	$17,259,828	$17,238,454	$17,265,172
Other Non-Fuel Costs Trucks	$3,836,179	$3,864,386	$3,807,972	$3,822,076	$3,878,490	$3,836,179	$3,836,179	$3,864,386	$3,878,490
Vehicle Operating Cost for cars ($3.6 per gallon)	$26,911,006	$27,632,316	$28,003,322	$28,250,624	$29,251,283	$26,604,230	$27,391,823	$28,159,598	$29,050,616
Vehicle Operating Cost for trucks ($3.9 per gallon)	$14,020,871	$14,199,310	$15,114,632	$15,586,129	$16,030,945	$15,343,712	$15,823,125	$16,237,773	$16,826,487
Total VOC	$62,017,197	$62,977,215	$64,228,502	$64,886,595	$66,447,264	$63,033,262	$64,310,955	$65,500,212	$67,020,765
Difference in Cost from Base Case	0	2%	4%	5%	7%	2%	4%	6%	8%
Total Operating Cost	$183,546,373	$177,037,372	$177,250,393	$169,453,495	$164,800,771	$182,468,873	$175,071,156	$168,731,341	$163,988,310
Difference in Cost from Base Case	0	-4%	-3%	-8%	-10%	-1%	-5%	-8%	-11%

Table 31. Estimated Annual Effects of Alternative Speed Limit Policies on California Urban Highway (I-5 North-South Orange, CA)

Value of Time	Base Case	DSL 70 / 60	DSL 70 / 65	DSL 75 / 65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
Travel Time for Passenger Car (seconds)	163	152	152	141	134	164	152	142	133
Annual Travel Time for Passenger Car	397	369	370	343	325	398	369	346	324
Travel Time for trucks	187	172	160	159	148	162	151	140	135
Annual Travel Time for Trucks	454	417	389	387	360	394	366	341	329
Car VoT (2020)	30	30	30	30	30	30	30	30	30
Truck VoT (2020, ATRI)	55	55	55	55	55	55	55	55	55
Cost of Travel Time for Passenger Cars	$12,002	$11,155	$11,192	$10,382	$9,830	$12,039	$11,155	$10,456	$9,793
Cost of Travel Time for Truck	$25,069	$23,053	$21,507	$21,372	$19,894	$21,776	$20,230	$18,818	$18,146
Car Flow	3070	3050	3065	3072	3080	3064	3075	3068	3074
Truck Flow	180	176	182	185	180	184	178	186	182
Total Cost of Travel Time	$41,358,913	$38,081,067	$38,218,219	$35,848,023	$33,857,158	$40,894,027	$37,903,604	$35,578,740	$33,406,761
Difference in Cost from Base Case	0	-8%	-8%	-13%	-18%	-1%	-8%	-14%	-19%

Value of Time	Base Case	DSL 70 / 60	DSL 70 / 65	DSL 75 / 65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
Vehicle Operating Cost									
Fuel Consumption for Passenger Cars (gallons)	298	309	310	319	331	297	309	320	335
Annual Fuel Consumption for Cars	2608728	2703213	2714339	2790612	2901007	2597892	2704116	2801939	2936816
Fuel Consumption for Trucks	86	96	101	119	128	96	108	121	135
Annual Fuel Consumption for Trucks	752975	836983	883849	1041678	1123163	843176	942269	1056132	1179552
Other Non Fuel Costs cars	$16,404,852	$16,297,980	$16,378,134	$16,415,539	$16,458,288	$16,372,790	$16,431,570	$16,394,165	$16,426,226
Other Non Fuel Costs Trucks	$2,538,648	$2,482,234	$2,566,855	$2,609,166	$2,538,648	$2,595,062	$2,510,441	$2,623,270	$2,566,855
Vehicle Operating Cost for cars ($3.6 per gallon)	$9,391,421	$9,731,568	$9,771,619	$10,046,203	$10,443,626	$9,352,411	$9,734,816	$10,086,979	$10,572,539
Vehicle Operating Cost for trucks ($3.9 per gallon)	$2,936,604	$3,264,234	$3,447,011	$4,062,544	$4,380,337	$3,288,387	$3,674,851	$4,118,914	$4,600,251
Total VOC	$31,271,525	$31,776,015	$32,163,619	$33,133,452	$33,820,899	$31,608,651	$32,351,678	$33,223,328	$34,165,871
Difference in Cost from Base Case	0	2%	3%	6%	8%	1%	3%	6%	9%
Total Operating Cost	$72,630,438	$69,857,082	$70,381,838	$68,981,474	$67,678,057	$72,502,678	$70,255,282	$68,802,068	$67,572,632
Difference in Cost from Base Case	0%	-4%	-3%	-5%	-7%	0%	-3%	-5%	-7%

Table 32. Estimated Annual Effects of Alternative Speed Limit Policies on California Urban Highway/Freeway (I-15 North-South San Bernardino, CA)

Value of Time	Base Case (70/55)	DSL 70 / 60	DSL 70 / 65	DSL 75 / 65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
Travel Time for Passenger Car (seconds)	522	521	519	486	458	571	523	485	456
Annual Travel Time for Passenger Car	1270	1268	1263	1183	1114	1389	1271	1180	1110
Travel Time for trucks	619	572	551	551	513	571	518	485	460
Annual Travel Time for Trucks	1506	1392	1340	1341	1248	1389	1260	1180	1118
Car VoT (2020)	30	30	30	30	30	30	30	30	30
Truck VoT (2020, ATRI)	55	55	55	55	55	55	55	55	55
Cost of Travel Time for Passenger Cars	$38,436	$38,363	$38,215	$35,785	$33,724	$42,044	$38,473	$35,712	$33,576
Cost of Travel Time for Truck	$83,204	$76,887	$73,997	$74,064	$68,956	$76,752	$69,628	$65,192	$61,765
Car Flow	3295	3300	3314	3301	3305	3301	3311	3312	3306
Truck Flow	76	80	72	81	79	82	75	78	82
Total Cost of Travel Time	$132,970,979	$132,747,581	$131,973,449	$124,127,036	$116,904,562	$145,081,766	$132,606,443	$123,362,633	$116,068,606
Difference in Cost from Base Case	0	0%	-1%	-7%	-12%	9%	0%	-7%	-13%

Value of Time	Base Case (70/55)	DSL 70 / 60	DSL 70 / 65	DSL 75 / 65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
Vehicle Operating Cost									
Fuel Consumption for Passenger Cars (gallons)	1389	1385	1374	1442	1470	1335	1379	1432	1447
Annual Fuel Consumption for Cars	12163943	12136326	12038299	12628644	12876858	11696440	12082283	12547404	12673837
Fuel Consumption for Trucks	111	120	130	139	147	141	142	145	149
Annual Fuel Consumption for Trucks	973124	1051419	1136995	1216878	1289603	1238025	1241511	1273047	1307456
Other Non Fuel Costs cars	$17,607,162	$17,633,880	$17,708,690	$17,639,224	$17,660,598	$17,639,224	$17,692,660	$17,698,003	$17,665,942
Other Non Fuel Costs Trucks	$1,071,874	$1,128,288	$1,015,459	$1,142,392	$1,114,184	$1,156,495	$1,057,770	$1,100,081	$1,156,495
Vehicle Operating Cost for cars ($3.6 per gallon)	$43,790,196	$43,690,772	$43,337,875	$45,463,118	$46,356,690	$42,107,183	$43,496,217	$45,170,653	$45,625,812
Vehicle Operating Cost for trucks ($3.9 per gallon)	$3,795,183	$4,100,534	$4,434,282	$4,745,824	$5,029,453	$4,828,296	$4,841,893	$4,964,883	$5,099,079
Total VOC	$66,264,415	$66,553,474	$66,496,307	$68,990,556	$70,160,926	$65,731,197	$67,088,540	$68,933,620	$69,547,328
Difference in Cost from Base Case	0	0%	0%	4%	6%	-1%	1%	4%	5%
Total Operating Cost	$199,235,394	$199,301,055	$198,469,755	$193,117,593	$187,065,488	$210,812,963	$199,694,982	$192,296,253	$185,615,935
Difference in Cost from Base Case	0%	0%	0%	-3%	-6%	6%	0%	-3%	-7%

Table 33. Estimated Annual Effects of Alternative Speed Limit Policies on California Rural Highway/Freeway (I-5 North-South San Diego, CA)

Value of Time	Base Case (65/55)	DSL 70 / 60	DSL 70 / 65	DSL 75/65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
Travel Time for Passenger Car (seconds)	694	645.5	644	599	562.43	692.27	645.16	600.62	562.645
Annual Travel Time for Passenger Car	1688.733333	1570.716667	1567.066667	1457.566667	1368.579667	1684.523667	1569.889333	1461.508667	1369.102833
Travel Time for trucks	801	736	681	680	634	801	638	596	564
Annual Travel Time for Trucks	1950.3045	1791.067167	1656.005	1654.666667	1542.733333	1950.3045	1553.354833	1449.256833	1371.937667
Car VoT (2020)	$30.26	$30.26	$30.26	$30.26	$30.26	$30.26	$30.26	$30.26	$30.26
Truck VoT (2020, ATRI)	$55.24	$55.24	$55.24	$55.24	$55.24	$55.24	$55.24	$55.24	$55.24
Cost of Travel Time for Passenger Cars	$51,101	$47,530	$47,419	$44,106	$41,413	$50,974	$47,505	$44,225	$41,429
Cost of Travel Time for Truck	$107,735	$98,939	$91,478	$91,404	$85,221	$107,735	$85,807	$80,057	$75,786
Car Flow	1720	1715	1716	1718	1710	1716	1708	1721	1719
Truck Flow	68	72	75	72	75	74	76	72	75
Total Cost of Travel Time	$95,219,809	$88,637,331	$88,232,583	$82,355,125	$77,208,152	$95,443,222	$87,659,642	$81,875,759	$76,900,478
Difference in Cost from Base Case	0	-7%	-7%	-14%	-19%	0%	-8%	-14%	-19%

Value of Time	**Base Case (65/55)**	**DSL 70 / 60**	**DSL 70 / 65**	**DSL 75/65**	**DSL 80 / 70**	**USL 65**	**USL 70**	**USL 75**	**USL 80**
Vehicle Operating Cost									
Fuel Consumption for Passenger Cars (gallons)	663.611	722.757	778.24	804.521	830.386	676.211	757.3825	800.57	836.253
Annual Fuel Consumption for Cars	5813232.36	6331351.32	6817382.4	7047603.96	7274181.36	5923608.36	6634670.7	7012993.2	7325576.28
Fuel Consumption for Trucks	101.442	99.7548	100.4421	105.028	111.231	101.523	102.534	109.65	117.235
Annual Fuel Consumption for Trucks	888631.92	873852.048	879872.796	920045.28	974383.56	889341.48	898197.84	960534	1026978.6
Other Non Fuel Costs cars	$9,190,992	$9,164,274	$9,169,618	$9,180,305	$9,137,556	$9,169,618	$9,126,869	$9,196,336	$9,185,648
Other Non Fuel Costs Trucks	$959,045	$1,015,459	$1,057,770	$1,015,459	$1,057,770	$1,043,666	$1,071,874	$1,015,459	$1,057,770
Vehicle Operating Cost for cars ($3.6 per gallon)	$20,927,636	$22,792,865	$24,542,577	$25,371,374	$26,187,053	$21,324,990	$23,884,815	$25,246,776	$26,372,075
Vehicle Operating Cost for trucks ($3.9 per gallon)	$3,465,664	$3,408,023	$3,431,504	$3,588,177	$3,800,096	$3,468,432	$3,502,972	$3,746,083	$4,005,217
Total VOC	$34,543,338	$36,380,621	$38,201,468	$39,155,315	$40,182,475	$35,006,706	$37,586,528	$39,204,653	$40,620,710
Difference in Cost from Base Case	0	5%	11%	13%	16%	1%	9%	13%	18%
Total Operating Cost	$129,763,147	$125,017,952	$126,434,051	$121,510,439	$117,390,626	$130,449,928	$125,246,171	$121,080,412	$117,521,187
Difference in Cost from Base Case	0	-4%	-3%	-6%	-10%	1%	-3%	-7%	-9%

Table 34. Estimated Annual Effects of Alternative Speed Limit Policies on California Urban Highway (SR-99 North-South Merced, CA)

Value of Time	Base Case	DSL 70 / 60	DSL 70 / 65	DSL 75/65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
Travel Time for Passenger Car (seconds)	543	503.94	499.6	459.075	430.19	530.31	495.405	460.035	430.505
Annual Travel Time for Passenger Car	1321	1226	1216	1117	1047	1290	1205	1119	1048
Travel Time for trucks	605	557	516	512	486	520	487	451	428
Annual Travel Time for Trucks	1471	1355	1255	1246	1183	1265	1184	1098	1042
Car VoT (2020)	$30.26	$30.26	$30.26	$30.26	$30.26	$30.26	$30.26	$30.26	$30.26
Truck VoT (2020, ATRI)	$55.24	$55.24	$55.24	$55.24	$55.24	$55.24	$55.24	$55.24	$55.24
Cost of Travel Time for Passenger Cars	$39,961	$37,106	$36,787	$33,803	$31,676	$39,048	$36,478	$33,874	$31,699
Cost of Travel Time for Truck	$81,261	$74,847	$69,327	$68,822	$65,327	$69,893	$65,399	$60,647	$57,539
Car Flow	872	874	876	875	872	878	880	874	878
Truck Flow	164	162	163	164	161	165	162	170	168
Total Cost of Travel Time	$48,172,689	$44,556,237	$43,525,622	$40,864,307	$38,139,123	$45,816,608	$42,695,228	$39,915,534	$37,498,537
Difference in Cost from Base Case	0	-8%	-10%	-15%	-21%	-5%	-11%	-17%	-22%

Value of Time	**Base Case**	**DSL 70 / 60**	**DSL 70 / 65**	**DSL 75/65**	**DSL 80 / 70**	**USL 65**	**USL 70**	**USL 75**	**USL 80**
Vehicle Operating Cost									
Fuel Consumption for Passenger Cars (gallons)	266.5038	275.711	268.45	272	285	255	267	274	285
Annual Fuel Consumption for Cars	2334573	2415228	2351622	2382720	2496600	2233800	2338920	2400240	2496600
Fuel Consumption for Trucks	191.2987	189.531	195.23	202.21	208.325	196	202	211	220
Annual Fuel Consumption for Trucks	1675777	1660292	1710215	1771360	1824927	1716960	1769520	1848360	1927200
Other Non-Fuel Costs cars	$4,659,619	$4,670,306	$4,680,994	$4,675,650	$4,659,619	$4,691,681	$4,702,368	$4,670,306	$4,691,681
Other Non-Fuel Costs Trucks	$2,312,990	$2,284,783	$2,298,887	$2,312,990	$2,270,680	$2,327,094	$2,284,783	$2,397,612	$2,369,405
Vehicle Operating Cost for cars ($3.6 per gallon)	$8,404,464	$8,694,822	$8,465,839	$8,577,792	$8,987,760	$8,041,680	$8,420,112	$8,640,864	$8,987,760
Vehicle Operating Cost for trucks ($3.9 per gallon)	$6,535,529	$6,475,137	$6,669,838	$6,908,302	$7,117,215	$6,696,144	$6,901,128	$7,208,604	$7,516,080
Total VOC	$21,912,602	$22,125,049	$22,115,557	$22,474,735	$23,035,274	$21,756,599	$22,308,391	$22,917,386	$23,564,926
Difference in Cost from Base Case	0%	1%	1%	3%	5%	-1%	2%	5%	8%
Total Operating Cost	$70,085,292	$66,681,286	$65,641,179	$63,339,041	$61,174,397	$67,573,207	$65,003,619	$62,832,921	$61,063,462
Difference in Cost from Base Case	0%	-5%	-6%	-10%	-13%	-4%	-7%	-10%	-13%

Table 35. Estimated Annual Effects of Alternative Speed Limit Policies on California Urban Highway/Freeway (I-80 East-West Berkeley, Alameda, CA)

Value of Time	Base Case	DSL 70 / 60	DSL 70 / 65	DSL 75/65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
Travel Time for Passenger Car (seconds)	198.22	184.355	184.24	171.735	161.92	198.43	184.875	172.4	163.61
Annual Travel Time for Passenger Car	227	208	198	197	186	195	187	176	167
Travel Time for trucks	604.545	556.825	515.76	475.995	445.1	519.97	486.535	451.185	428.065
Annual Travel Time for Trucks	1471.0595	1354.940833	1255.016	1158.2545	1083.076667	1265.260333	1183.901833	1097.8835	1041.624833
Car VoT (2020)	30.26	30.26	30.26	30.26	30.26	30.26	30.26	30.26	30.26
Truck VoT (2020, ATRI)	55.24	55.24	55.24	55.24	55.24	55.24	55.24	55.24	55.24
Cost of Travel Time for Passenger Cars	$6,880	$6,301	$5,990	$5,961	$5,628	$5,912	$5,661	$5,325	$5,063
Cost of Travel Time for Truck	$81,261	$74,847	$69,327	$63,982	$59,829	$69,893	$65,399	$60,647	$57,539
Car Flow	4387	4398	4385	4395	4402	4392	4386	4394	4397
Truck Flow	161	160	162	165	161	167	171	176	168
Total Cost of Travel Time	$43,264,591	$39,688,813	$37,496,329	$36,756,588	$34,408,535	$37,635,847	$36,013,836	$34,069,958	$31,928,411
Difference in Cost from Base Case	0	-8%	-13%	-15%	-20%	-13%	-17%	-21%	-26%

Value of Time	**Base Case**	**DSL 70 / 60**	**DSL 70 / 65**	**DSL 75/65**	**DSL 80 / 70**	**USL 65**	**USL 70**	**USL 75**	**USL 80**
Vehicle Operating Cost									
Fuel Consumption for Passenger Cars (gallons)	508.1824	515.541	517.43	529.431	541.297	507.533	518.659	542.1821	575.847
Annual Fuel Consumption for Cars	4451677.824	4516139.16	4532686.8	4637815.56	4741761.72	4445989.08	4543452.84	4749515.196	5044419.72
Fuel Consumption for Trucks	120.009	128.008	132.817	139.434	144.815	131.2315	136.7193	142.438	150.524
Annual Fuel Consumption for Trucks	1051278.84	1121350.08	1163476.92	1221441.84	1268579.4	1149587.94	1197661.068	1247756.88	1318590.24
Other Non Fuel Costs cars	$23,442,373	$23,501,153	$23,431,686	$23,485,122	$23,522,527	$23,469,091	$23,437,030	$23,479,778	$23,495,809
Other Non Fuel Costs Trucks	$2,270,680	$2,256,576	$2,284,783	$2,327,094	$2,270,680	$2,355,301	$2,411,716	$2,482,234	$2,369,405
Vehicle Operating Cost for cars ($3.6 per gallon)	$16,026,040	$16,258,101	$16,317,672	$16,696,136	$17,070,342	$16,005,561	$16,356,430	$17,098,255	$18,159,911
Vehicle Operating Cost for trucks ($3.9 per gallon)	$4,099,987	$4,373,265	$4,537,560	$4,763,623	$4,947,460	$4,483,393	$4,670,878	$4,866,252	$5,142,502
Total VOC	$45,839,080	$46,389,095	$46,571,702	$47,271,975	$47,811,009	$46,313,346	$46,876,054	$47,926,519	$49,167,627
Difference in Cost from Base Case	0	1%	2%	3%	4%	1%	2%	5%	7%
Total Operational Cost	$89,103,671	$86,077,908	$84,068,031	$84,028,564	$82,219,543	$83,949,193	$82,889,890	$81,996,476	$81,096,038
Difference in Cost from Base Case	0%	-3%	-6%	-6%	-8%	-6%	-7%	-8%	-9%

Table 36. Estimated Operational Cost of Alternative Speed Limit Policies on California Urban Highways

Operational Cost for Urban Areas	Base Case (70/55)	DSL 70 / 60	DSL 70 / 65	DSL 75/65	DSL 80 / 70	USL 65	USL 70	USL 75	USL 80
I-5 North Orange	$72,630,438	$69,857,082	$70,381,838	$68,981,474	$67,678,057	$72,502,678	$70,255,282	$68,802,068	$67,572,632
Segment Length (mile) urban	3	3	3	3	3	3	3	3	3
SR 99 North South Merced	$70,085,292	$66,681,286	$65,641,179	$63,339,041	$61,174,397	$67,573,207	$65,003,619	$62,832,921	$61,063,462
Segment Length (mile) urban	9	9	9	9	9	9	9	9	9
I 80 East West Alameda	$89,103,671	$86,077,908	$84,068,031	$84,028,564	$82,219,543	$83,949,193	$82,889,890	$81,996,476	$81,096,038
Segment Length (mile) urban	5	5	5	5	5	5	5	5	5
Weighted Operational Cost	$13,636,435	$13,095,075	$12,946,532	$12,726,416	$12,416,000	$13,177,946	$12,832,282	$12,566,557	$12,337,184
Urban Miles (Design Speed 55, 60, 65, 70)	2703	2703	2703	2703	2703	2703	2703	2703	2703
Total Operational Cost	$36,859,284,688	$35,395,987,892	$34,994,476,735	$34,399,503,613	$33,560,447,507	$35,619,987,430	$34,685,657,708	$33,967,402,903	$33,347,409,030
Percentage Change from Base Case	0%	-4%	-5%	-7%	-9%	-3%	-6%	-8%	-10%

Table 37. Estimated Operational Cost of Alternative Speed Limit Policies on California Rural Highways

Operational Cost for Rural Areas	Base Case (70/55)	DSL 70 / 60	DSL 70 / 65	DSL 75/70	DSL 80 / 75	USL 65	USL 70	USL 75	USL 80
I-5 North South Fresno/Coalingo	$151,179,276	$150,997,629	$149,128,673	$144,863,540	$137,742,945	$151,448,493	$147,830,138	$143,920,968	$139,676,757
Segment Length (mile) urban	9	9	9	9	9	9	9	9	9
I-5 North South Kern	$183,546,373	$177,037,372	$177,250,393	$169,453,495	$164,800,771	$182,468,873	$175,071,156	$168,731,341	$163,988,310
Segment Length (mile) rural	17	17	17	17	17	17	17	17	17
I-15 North South San Bernardino	$199,235,394	$199,301,055	$198,469,755	$193,117,593	$187,065,488	$210,812,963	$199,694,982	$192,296,253	$185,615,935
Segment Length (mile) rural	10	10	10	10	10	10	10	10	10
I-5 North South San Diego	$129,763,147	$125,017,952	$126,434,051	$121,510,439	$117,390,626	$130,449,928	$125,246,171	$121,080,412	$117,521,187
Segment Length (mile) rural	11	11	11	11	11	11	11	11	11
Weighted Operational Cost	$14,121,791	$13,879,873	$13,857,082	$13,381,810	$12,914,890	$14,365,537	$13,783,882	$13,319,765	$12,910,685
Rural Miles (Design Speed 55, 60, 65, 70)	7770	7770	7770	7770	7770	7770	7770	7770	7770
Total Operational Cost	$109,726,318,306	$107,846,609,425	$107,669,530,223	$103,976,663,261	$100,348,695,246	$111,620,225,464	$107,100,762,160	$103,494,577,132	$100,316,021,519
Percentage Change from Base Case	0%	-2%	-2%	-5%	-9%	2%	-2%	-6%	-9%