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The objectives of this report are to provide information on Tasks 1–6, and to provide guidance about the specific corridor or district on which the remainder of the study (Tasks 7–12) should be focused.

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Authors:
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Work Conducted Under Partnered Pavement Research Program (PPRC) Strategic Plan Element 4.44: Pilot Study Investigating the Interaction and Effects for State Highway Pavements, Trucks, Freight, and Logistics

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PREPARED FOR:

California Department of Transportation
Division of Transportation Planning (DOTP)
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The objectives of this report are to provide information on Tasks 1–6, and to provide guidance about the specific corridor or district on which the remainder of the study (Tasks 7–12) should be focused.

Conclusions

The following conclusions are drawn based on the information provided and discussed in this report:

- Ample information exists to enable the objectives of this pilot study to be met through analyzing the V-PI and logistics situation in a selected corridor in California.
- The San Joaquin Valley corridor is a major production and transportation corridor in California and well-suited to serve as a pilot area for the purposes of this project.

Recommendations

The following recommendations are made based on the information provided and discussed in this report:

- The San Joaquin Valley should be targeted as the pilot study area for the purposes of the remaining tasks in this pilot project.
- Routes I-5, SR 58, and SR 99 are recommended as suitable routes for the pilot field study.
- The work anticipated for Tasks 7–12 should commence once this report has been accepted and approved by the client.

Keywords: Vehicle-pavement interaction, freight transport industry sustainability and competitiveness, pavement roughness, economic evaluation, Cal-B/C, logistics

Proposals for Implementation:

This final Phase 1 report will be studied by the client and decisions regarding the remainder tasks of the project will be based on the outcome of this report.

Related Documents:

- W.J.vdM. Steyn. 2013. Freight-Truck-Pavement Interaction, Logistics, and Economics: Final Phase 1 Report (Tasks 7–8). Research Report prepared for Caltrans Division of Transportation Planning. (UCPRC-RR-2013-08)
- W.J.vdM. Steyn and L. du Plessis. 2013. Freight-Truck-Pavement Interaction, Logistics, & Economics: Final Phase 1 Report (Tasks 9–11). Research Report prepared for Caltrans Division of Transportation Planning. (UCPRC-RR-2014-01)
- W.J.vdM. Steyn, L. du Plessis, N. Viljoen, Q. van Heerden, L. Mashoko, E. van Dyk, and L. Popescu. 2014. Freight-Truck-Pavement Interaction, Logistics, & Economics: Final Executive Summary Report. Summary Report prepared for Caltrans Division of Transportation Planning. (UCPRC-SR-2014-01)
- N. Viljoen, Q. van Heerden, L. Popescu, L. Mashoko, E. van Dyk, and W. Bean. Logistics Augmentation to the Freight-Truck-Pavement Interaction Pilot Study: Final Report 2014. Research Report prepared for Caltrans Division of Transportation Planning.(UCPRC-RR-2014-02)

Signatures

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DISCLAIMER STATEMENT

ACKNOWLEDGMENTS

The input and comments of all organizations contacted for information in this project are acknowledged. Specifically, the input of the following persons are acknowledged:

- Caltrans technical advisors to the project team: Al Arana (DOTP Office of System Planning), Joanne McDermott (DOTP Office of Freight Planning)
- DOTP Economic Analysis Branch staff: Nerie Rose Agacer-Solis, Barry Padilla, and Austin Hicks
- Division of Research, Innovation and System Information (DRISI) Office of Materials and Infrastructure: Joe Holland and Bill Nokes

PROJECT OBJECTIVES

The overall objectives of this project are to enable Caltrans to better manage the risks of decisions regarding freight and the management and preservation of the pavement network, as the potential effects of such decisions (i.e., to resurface and improve ride quality earlier or delay such a decision for a specific pavement) will be quantifiable in economic terms. This objective will be reached through applying the principles of vehicle-pavement interaction (V-PI) and state-of-the-practice tools to simulate and measure peak loads and vertical acceleration of trucks and their freight on a selected range of typical pavement surface profiles on the State Highway System (SHS) for a specific region or Caltrans district.

The objectives of this report are to provide information on Tasks 1–6, and to provide guidance about the specific corridor or district on which the remainder of the study (Tasks 7–12) should be focused.

Note: This document reports information that was developed and provided incrementally by the research team as the pilot study proceeded. For consistency with the incremental nature of the work and the reporting on it, this final report retains the same grammatical tense referring to remaining tasks (as yet to be done), although all tasks and the pilot study have been completed.

EXECUTIVE SUMMARY

Introduction

This pilot study applies the principles of vehicle-pavement interaction (V-PI) and state-of-the-practice tools to simulate and measure peak loads and vertical acceleration of trucks and their freight on a selected range of typical pavement surface profiles on the State Highway System (SHS) for a specific region or Caltrans district. The pilot study is not focusing on the detailed economic analysis of the situation; however, the outputs from the pilot study are expected to be used as input or insights by others toward planning and economic models to enable an improved evaluation of the freight flows and costs in the selected region/district. It is anticipated that use of findings from this study as input by others into planning and economic models will enable calculating the direct effects of ride quality (and therefore road maintenance and management efforts) on the regional and state economy.

The final product of this pilot study will consist of data and information resulting from (1) simulations and measurements, (2) tracking truck/freight logistics (and costs if available), and (3) input for economic evaluation based on V-PI and freight logistics investigation. Potential links of the data and information to available and published environmental emissions models (e.g., greenhouse gas [GHG], particulate matter), pavement construction specifications, and roadway maintenance/preservation will be examined.

The intention of the pilot study is to enable economic evaluation (using tools such as Caltrans' Cal-B/C model) of the potential economic effects of delayed road maintenance and management, leading to deteriorated ride quality and subsequent increased vehicle operating costs, vehicle damage, and freight damage. The study will be conducted as a pilot study in a region or Caltrans district where the probability of collecting the maximum data on road quality, vehicle population, and operational conditions will be the highest and where the outcomes of the study may be incorporated into economic and planning models. The final selection of the region/district will be made based on information collected during Tasks 3–5; the final selection of an appropriate region/district will be made by Caltrans. This focused pilot study enables the approach to be developed and refined in a contained region/district where ample access may be available to required data, information, and models. After the pilot study is completed and the approach has been accepted and shown to provide benefits to Caltrans and stakeholders, it can be expanded to other regions/districts as required.

The overall objectives of this project are to enable Caltrans to better manage the risks of decisions regarding freight and the management and preservation of the pavement network, as the potential effects of such decisions (i.e., to resurface and improve ride quality earlier or delay such a decision for a specific pavement) will be quantifiable in economic terms. This objective will be reached through applying the principles of vehicle-pavement interaction (V-PI) and state-of-the-practice tools to simulate and measure peak loads and vertical acceleration of trucks and their freight on a selected range of typical pavement surface profiles on the State Highway System (SHS) for a specific region or Caltrans district.

The objectives of this report are to provide information on Tasks 1–6, and to provide guidance about the specific corridor or district on which the remainder of the pilot study (Tasks 7–12)should be focused.

The data presented and discussed in Sections 3 to 5 of this document presents information sourced from a range of independent sources. Each of the sets of information is discussed in detail as individual information. Relevant information originating from Sections 3 to 5 is combined to present a case for a specific region/corridor to be focused on. The details of the specific data sets are not necessarily repeated, but reference is made to the relevant sources and locations in the report.

Report Issues

The purpose of this pilot study is to provide data and information that will provide input supporting Caltrans' freight program plans and legislation-mandated requirements with findings potentially contributing to economic evaluations; identification of challenges to stakeholders; and identification of problems, operational concerns, and strategies that "go beyond the pavement"—including costs to the economy and the transportation network (delay, packaging, environment, etc.). Findings could lead to improved pavement policies and practices, such as strategic recommendations that link pavement surface profile, design, construction, and preservation with V-PI. These findings should also provide information for evaluating the relationship between pavement ride quality (stemming from the pavement's condition), vehicle operating costs, freight damage, and logistics.

Road Inventory

The main outcome of Task 3 is to identify routes in each district and county for which ride quality data exists, as well as the actual ride quality for these routes (due to the volume of data, the actual data are kept only in electronic form). Routes in California have been identified and a database containing actual road profiles and ride quality data is available for use in the remainder of the pilot project.

Vehicle Inventory

The deliverable for Task 4 is a table of current vehicle population per standard FHWA vehicle classifications for Caltrans. Based on the various sources used in this task (FHWA truck classifications, commodity flow analysis, and weigh-in-motion [WIM] data), the following was identified:

- The most common truck types in the pilot study area are FHWA Class 9 and 12 (up to 48 percent of the trucks on selected routes), followed by Class 5.

- High truck flows are experienced in District 6, part of the San Joaquin Valley.
- Axle load spectra are heavier at night than in the daytime.
- Axle load spectra and truck type distribution show very little seasonal variation.
- Axle load spectra are much higher in the Central Valley than in the Bay Area and Southern California, particularly for tandem axles.
- More than 90 percent of the truck traffic traveled in the outside or two outside lanes (two- or three-lane [in one direction] highways) or two outside (three-lane [in one direction] highways) lanes.
- Truck speeds typically fall within the range of 50 to 75 mph (80 to 120 km/h).
- Leaf springs are predominantly used in steering axles, with drive axles using air suspension and trail axles using leaf suspension.

Information Review

Task 5 focuses on evaluating the data obtained from the various resources for Tasks 3–4, as well as additional relevant information that may add to the project. The deliverable of Task 5 is a detailed understanding and input to the progress report on the available data sources and required analyses for the project, inclusive of indications of the potential links between the outputs from this project and the inputs for the various economic and planning models.

California Statewide Freight Planning

The purpose of the California Statewide Freight Forecast (CSFF) model is to provide a policy-sensitive model to forecast commodity flows and commercial vehicle flows within California, addressing socioeconomic conditions, land-use policies related to freight, environmental policies, and multimodal infrastructure investments. Appropriate information and data about freight movements and costs are needed to enable accurate modeling.

Commodity Flow Survey

It is evident that truck-based transportation dominates the freight transportation scene in California. Eighty-two percent of the freight tons shipped from California utilizes only trucks. The data indicate that the highest percentage of commodities (in terms of value, tons, and ton-miles) transported by truck consists of manufacturing goods, wholesale trade, and nondurable goods for the whole of California. No specific information for commodity flows into California (destination California) could be identified in this pilot study.

San Joaquin Information

The San Joaquin Valley is composed of eight counties and 62 cities. It has a diverse internal economy and also plays a major role in the distribution of agricultural materials throughout California, the United States, and the world. Trucks are the dominant mode, with more than 450 million tons of goods moved by truck into, out of, or within the San Joaquin Valley in 2007—more than 85 percent of all tonnage associated with these types of moves in the San Joaquin Valley. Truck movement in the San Joaquin Valley relies on a combination of all levels of highways and roads in the area. Key regional highways include the primary north-south corridors (I-5 and SR 99) and east-west corridors (I-580, SR 152, SR 41, SR 46, and SR 58), which in total constitute more than 31,000 lane-miles. There are over 2,700 lane-miles of truck routes in the San Joaquin Valley region, with over 80 percent designated as national STAA Truck Routes.

Farm products are the dominant commodity carried outbound from the San Joaquin Valley, comprising 33 percent of the total outbound movements. These consist of fresh field crops (vegetables, fruit and nuts, cereal grains, and animal feed). Stone and aggregates account for 18 percent of the total, food and tobacco products around 10 percent, and waste and mixed freight 6 percent and 4 percent of the total tonnage, respectively.

The region accounts for over 8 percent of the total gross domestic product (GDP) for California. However, the region accounts for a much higher proportion of output within sectors such as agriculture (nearly 50 percent) and mining and mineral extraction (25 percent). The San Joaquin Valley includes 6 of the top 10 counties in California in total value of agricultural production.

Goods Movement Action Plan

California's Goods Movement Action Plan (GMAP) includes a compiled inventory of existing and proposed goods movement infrastructure projects, including previously identified projects in various regional transportation plans and transportation improvement programs prepared by metropolitan planning organizations, regional transportation planning agencies, and county transportation commissions. One of the four priority regions and corridors identified in the GMAP is the Central Valley region, which coincides with the San Joaquin Valley.

California Life-Cycle Benefit/Cost Analysis Model

Caltrans uses the California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C) to conduct investment analyses of projects proposed for the interregional portion of the State Transportation Improvement Program (STIP), the State Highway Operations and Protection Program (SHOPP), and other ad hoc analyses requiring benefit-cost analysis. The following required inputs are deemed to be potentially affected by the work conducted in this pilot study: roadway type, number of general traffic lanes, number of HOV lanes, HOV restriction, highway free-flow speed, current and forecast average annual daily traffic (AADT), hourly HOV/HOT volumes, percent trucks, truck speed, and pavement condition.

Industry

Potential involvement of industry in Task 8 activities includes:

- GPS tracking and acceleration measurements on selected trucks traveling on designated State Highway segments—need for trucks, trailers and freight
- Truck trailer information as input into computer simulations of vehicles traveling over a range of pavements

Models for Rolling Resistance in Road Infrastructure Asset Management Systems Project

The objective of the Models for rolling resistance In Road Infrastructure Asset Management systems (MIRIAM) project is to conduct research to provide sustainable and environmentally friendly road infrastructure, mainly through reducing vehicle rolling resistance, and subsequently lowering CO_2 emissions and increasing energy efficiency. Potential links between the MIRIAM project and the pilot study mainly lie in the possible use of selected rolling resistance models originating from MIRIAM in the evaluation of the effects of pavement roughness on vehicle energy use, emissions, and rolling resistance. Caltrans and UCPRC have participated in MIRIAM Phase I and plan to continue participating in Phase II. Initial MIRIAM studies indicated that:

- Rolling resistance is a property of tires and the pavement surface.
- A proposed source model for the pavement influence on rolling resistance contains mean profile depth (MPD), pavement roughness (IRI), and pavement stiffness as significant pavement parameters.
- For light vehicles the effect of pavement roughness on rolling resistance is probably around a third of the effect of MPD, and it appears to be higher for heavy vehicles.

California Inter-Regional Intermodal System

The California Inter-Regional Intermodal System (CIRIS) was envisioned as an umbrella concept for rail intermodal service to and from the Port of Oakland and other Northern California locations. The increased use of rail options for these transportation options will affect truck volumes and deterioration of the pavement infrastructure.

I-5/SR 99 Origin and Destination Truck Study

This study indicated that:

- Traffic volumes within the study area were found to be consistent for fall and spring seasons, with the some exceptions, whereas overall truck percentages were higher in spring compared to fall, with a few exceptions.
- Little variance was observed in truck travel patterns between fall and spring.
- The majority of trucks (83.8 percent) were 5-axle double-unit type.

- Seventy percent of the trucks were based within California: 47 percent of these were based in the San Joaquin Valley region, and 34 percent in the Southern California region.
- The top five commodity types by percentage are food and similar products (21 percent), empty trucks (18 percent), farm products (14 percent), miscellaneous freight (12 percent), and transportation equipment (4 percent).

State of Logistics South Africa

The ride quality of a road has, for many years, been used as the primary indication of the quality of a road—mainly due to findings that deterioration in the road structure ultimately translates into a decrease in the ride quality of the road. Various studies about the effect of the ride quality of roads on the vibrations and responses in vehicles have been conducted, with the main conclusions indicating that a decrease in the ride quality of a road is a major cause of increased vibrations and subsequent structural damage to vehicles. These increased vibrations and structural damage to vehicles potentially have many negative effects on the transportation cost of companies (including both truckers/carriers and manufacturers/producers of goods) and the broader economy of a country.

The increase in internal logistics costs due to inadequate road conditions is experienced by most, if not all, transportation companies. This figure eventually adds up to a massive increase in the logistics costs of a country as a whole. As the logistics costs of a country increase, the cost of its products in the global marketplace increases, which can have devastating effects on the global competitiveness of that country. It is therefore of critical importance to manage logistics costs effectively and to minimize unnecessary costs that can translate into higher product costs.

Comparing the estimated annual road maintenance costs per kilometer with the potential savings in vehicle operating costs shows significant benefits that can be realized by keeping the road in a good condition.

The vertical acceleration experienced when traveling over rough road surfaces is what causes damage to vehicles, increased wear and tear and, potentially, damage to and loss of transported cargo. The economic impact of damaged agricultural cargo is absorbed differently by large- and small-scale farming companies.

Freight Logistics

When freight is damaged it results in both direct and indirect losses in potential revenue through effects on logistical operations. These operational repercussions depend on the type of freight and the standard operating procedures of shipper and receiver. They include:

- Product is sent back to the shipper for replacement, repair, or repackaging—placing a burden on the reverse supply chain.
- Product is "written off" and must be disposed of by the receiver.
- Product must be reclassified as damaged before selling.

The most prominent implications for the freight logistics aspect is the link to the Cal-B/C model. To perform a benefit-cost analysis of upgrading/repairing a certain stretch of road, potential freight damage savings accrued by the upgrade must be given as input into the Cal-B/C model. Therefore, the pilot study should develop a methodology whereby field measurements, stakeholder engagements, and existing data sources can be used to estimate freight damage savings along a certain stretch of road.

To achieve the objectives discussed above requires cost calculations at a disaggregate level (consisting of many aspects, including type of goods, type and attributes of truck/trailer, and attributes of roadway). Firstly, the expected freight damage cost incurred by a particular type of shipment must be quantified. Secondly, the individual shipment costs must be aggregated to provide higher-level cost estimates.

Based on the available information, the following commodities should be most relevant for this pilot study:

- Various kinds of manufactured goods, particularly nondurable or electronic goods
- Agricultural and various other food products
- Mining products, such as coal, minerals, gravel

Summary

Based on the information in Section 6.2.2, there exists a good understanding of the SHS pavement conditions in terms of ride quality in California, as well as the major truck types and operational conditions on these pavements. The major commodities being transported have been identified, and the potential links with models such as the Cal-B/C models are apparent. Most of the information on commodity flows and truck operations are available for the San Joaquin Valley, which forms a major corridor for transport of agricultural and related freight.

Motivational Reasons for Recommended Region/Corridor

The information presented in this report provides a good basis of information to describe the freight movement and transport infrastructure conditions in the San Joaquin Valley region in California.

Transportation and logistics in this corridor are being studied in detail in various studies, supporting the notion that the corridor is important for the economy of California. This idea is also supported by data indicating that a large proportion of freight originates, passes through, or is destined for companies and markets in this region.

Based on the information provided in this report, it is thus recommended that the San Joaquin Valley region be used in the remaining tasks of this pilot study. Routes I-5, SR 58, and SR 99 are recommended as suitable routes for the pilot field study. Specific commodities and trucks in the valley need to be identified for the details of Tasks 7–8.

LIST OF ABBREVIATIONS

AADT	Average annual daily traffic
AADTT	Average annual daily truck traffic
CIRIS	California Inter-Regional Intermodal System
CSFF	California Statewide Freight
CSTDM	California Statewide Travel Demand Model
DOTP	Division of Transportation Planning
DPSD	Displacement power spectral densities
DRISI	Division of Research, Innovation, and Systems Information
DTC	Diagnostic trouble codes
FHWA	Federal Highway Administration
GDP	Gross domestic product
GMAP	Goods Movement Action Plan
GPS	Global Positioning System
HOV	High Occupancy Vehicle
HRI	Half-car Roughness Index
IDAS	ITS Deployment Analysis System
IRI	International Roughness Index
LOS	Level of Service
LTL	Less than truckload
MDL	Moving dynamic loading
MIRIAM	Models for rolling resistance In Road Infrastructure Asset Management Systems
MPD	Mean profile depth
MRI	Median Roughness Index
NAICS	North American Industry Classification System
NCHRP	National Cooperative Highway Research Program
NN	National Network
PCS	Pavement condition survey
PIARC	World Road Association
PMS	Pavement Management System
PPRC	Partnered Pavement Research Center
PSD	Power spectral density
RTRRMS	Response-type road roughness measurement systems
SCAG	Southern California Association of Governments
SHOPP	State Highway Operations and Protection Program
SHS	State Highway System
SJVIGMP	San Joaquin Valley Interregional Goods Movement Plan
STAA	Surface Transportation Assistance Act
STIP	State Transportation Improvement Program
TA	Terminal Access
TL	Truckload
TMS	Transportation Management System
TSI	Transportation Systems Information
UCPRC	University of California Pavement Research Center
VOC	Vehicle operating costs
WIM	Weigh-in-motion

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	Kilometers	Km
		AREA		
in^2	square inches	645.2	Square millimeters	mm^2
ft^2	square feet	0.093	Square meters	m^2
yd^2	square yard	0.836	Square meters	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	Square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	Lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2	poundforce per square inch	6.89	Kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	Inches	in
m	meters	3.28	Feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	Miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	Hectares	2.47	Acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	Milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	Gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	Ounces	oz
kg	kilograms	2.202	Pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	Poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380 (Revised March 2003).

1 INTRODUCTION

1.1 Introduction

This pilot study (entitled *Pilot Study Investigating the Interaction and Effects for State Highway Pavements, Trucks, Freight, and Logistics*) will apply the principles of vehicle-pavement interaction (V-PI) and state-of-the-practice tools to simulate and measure peak loads and vertical acceleration of trucks and their freight on a selected range of typical pavement surface profiles on the State Highway System (SHS) for a specific region or Caltrans district. Successfully measuring loads and accelerations requires access to trucks and freight, so this activity is contingent on the extent of private-sector collaboration, as specified in the project proposal. For a given segment of pavement, quantification of loads will enable the prediction of potential damaging effects of these loads on pavement service life. Likewise, quantifying vertical accelerations will enable investigation of the relationship between these accelerations and damage to trucks and their freight. Investigating the damage caused by and imposed on each component in the pavement-truck-freight system enables understanding of small-scale (project-level) effects and also is expected to provide insights about larger-scale (network-level) impacts on freight logistics. The outputs of this pilot study may be used in planning and economic evaluation of the potential effects of deteriorated ride quality and freight in California. Results from this pilot study are intended for evaluation on the SHS statewide. Data and information about the pavement-vehicle-freight system components are expected to be applicable to regional and local evaluations, including metropolitan transportation planning.

V-PI simulations and measurements—Simulations will apply state-of-the-practice computer models to generate expected applied tire loads and accelerations from standard trucks based on indicators of ride quality from California pavement profile survey data. Measurements will include instrumentation of a sample of vehicles with standalone acceleration sensors and Global Positioning System (GPS) to obtain data. Successfully measuring loads and accelerations requires access to trucks that operate on dedicated routes. It is proposed that this access will be through one or more private-sector partners, operating a range of trucks on dedicated routes, through use of a Caltrans vehicle, or through use of a rental truck. It is anticipated that one typical truck will be selected in any of the approaches. A final selection on an appropriate route covering a range of ride qualities and speeds within the selected region/district will be taken during Task 5. Measurements will provide validation of simulations and information for potentially analyzing effects of V-PI on various types of freight, as well as the pavement network, through dynamically generated tire loads.

Different types of freight are affected differently by the vertical accelerations caused by V-PI, therefore it is warranted to observe more than one type of freight for, e.g., mineral resources, agricultural products (fruit, vegetables, and grains), sensitive manufactured goods (electronics), and other manufactured goods. The focus of the pilot project will be roadway segments on selected routes in a selected region/district, to enable the approach to be adopted and applied toward Caltrans-specific requirements (e.g., region/district definitions, traffic volumes, ride quality levels, etc.). In this regard the focus will probably be on segments on one major highway and one minor road in the same region/district, each with a range of ride quality. Typically, major highways on the SHS have different ranges of ride quality levels than lower-volume segments of the SHS, due to differences in traffic volumes, pavement design, and construction practices.

Freight logistics impacts—In this pilot study *freight logistics* refers to the processes involved in moving freight from a supplier to a receiver via a route that includes the segments of road identified for this pilot study. V-PI has ramifications for freight logistics processes beyond the actual road transport, and investigating these effects holistically requires access to selected operational information. Investigating the direct impacts of V-PI on the freight transported requires access to truck fleet operational information (e.g., a combination of routes and vertical accelerations measured on the vehicles). This data will be acquired either from collaboration with private-sector partners who communicate their operations and then allow GPS tracking of their trucks and field measurements of truck/freight accelerations while traveling on California pavements or from published data available through South African State of Logistics studies or the U.S. State of Logistics studies. The private-sector data would be preferable. In addition, access to operational data about packaging practices, loading practices, cost data, and insurance coverage would be valuable in developing a more holistic understanding. Selected data sources and potential data collection methodologies are reported in Tasks 5–6.

Economic implications—The pilot study is not focusing on a detailed economic analysis of the situation; however, the outputs from the pilot study are expected to be used as input or insights by others toward planning and economic models to enable improved evaluation of the freight flows and costs in the selected region/district. Such planning models may include the Caltrans Statewide Freight Model (in development) or the Heavy-Duty Truck Model (used by the Southern California Association of Governments [SCAG]). Input from and interaction with Caltrans will be needed during the pilot study. It is anticipated that use of findings from this pilot study as input by others into planning and economic models will enable the direct effects of ride quality on the regional and state economy to be calculated—and therefore that of road maintenance and management efforts.

The final product of this pilot study will consist of data and information resulting from (1) simulations and measurements, (2) tracking truck/freight logistics (and costs if available), and (3) input for economic evaluation based on V-PI and freight logistics investigation. Potential links of the data and information to available and published environmental emissions models (e.g., greenhouse gas [GHG], particulate matter), pavement construction specifications, and roadway maintenance/preservation will be examined.

Stakeholders (Caltrans if not indicated otherwise) identified to date are (1) Division of Transportation Planning, including the Office of State Planning (Economic Analysis Branch, State Planning Branch, and Team for California Interregional Blueprint/Transportation Plan [CIB/CTP]) and the Office of System and Freight Planning; (2) Division of Transportation System Information, including the Office of Travel Forecasting and Analysis

(Freight Modeling/Data Branch, Statewide Modeling Branch, and Strategic and Operational Project Planning Coordinator); (3) Division of Traffic Operations, Office of Truck Services; (4) Division of Maintenance Office of Pavement and Performance; (5) Project Delivery—Divisions of Construction, Design, and Engineering Services; and (6) private-sector partner(s).

1.2 Background

Freight transport is crucial to California, the home of this country's largest container port complex and the world's fifth-largest port. Freight transported by trucks on California's roadways is crucial. Planning and making informed decisions about freight transported by trucks on the SHS requires reliance on data and information that represent pavement, truck, and freight interactions under conditions as they exist in California. Data, information, and the understanding of V-PI physical effects, logistics, and economic implications within a coherent framework are lacking. This occurs at a time when a national freight policy is expected in the next federal transportation reauthorization bill, and Caltrans already has several freight initiatives in progress, including a scoping study for the California Freight Mobility Plan (which is an updated and enhanced version of the Goods Movement Action Plan [GMAP]) and planning for the Statewide Freight Model (which supports the California Interregional Blueprint [CIB]). These, along with other plans, will support the California Transportation Plan that will be updated by December 2015. Data and information identified in this study also are expected to be needed for evaluations, plans, and decisions to help meet requirements of legislation, including AB 32, SB 375, and SB 391.

1.3 Scope

The overall scope of this project entails the tasks shown in Table 1.1. Task descriptions, deliverables, and time frames are shown for all 12 tasks. Figure 1.1 contains a schematic layout of the tasks and linkages between tasks for this pilot study.

The intention of the pilot study is to demonstrate the potential economic effects of delayed road maintenance and management, leading to deteriorated ride quality and subsequent increased vehicle operating costs, vehicle damage, and freight damage. The study will be conducted as a pilot study in a region/Caltrans district where the probability of collecting the maximum data on road quality, vehicle population, and operational conditions will be the highest, and where the outcomes of the pilot study can be incorporated into economic and planning models. The final selection of the region/district will be made based on information collected during Tasks 3–5 (see Section 6); the final selection of an appropriate region/district will be made by Caltrans. This focused pilot study enables the approach to be developed and refined in a contained region/district where ample access may be available to the required data, information, and models. After the pilot study is completed and the approach is accepted and has been shown to provide benefits to Caltrans and stakeholders, it can be expanded to other regions/districts as required.

Table 1.1: Task Description for Project

Task Description	Deliverable/Outcome	Time Frame
Task 1:		
Finalize and Execute Contract	Executed Contract	Oct 2011/February 2012
Task 2: Kickoff Meeting with Caltrans	Meeting and Project Materials	February 2012
(1 week travel)		
Task 3:		
Inventory of current California ride quality/road profiles Identify existing data available within Caltrans.	Map/table with current riding quality (IRI) for a selected region or district – only on truck outside-lanes for road segments on selected routes	February / April 2012
Task 4:		
Inventory of current California vehicle population - only on truck outside-lanes for road segments on selected routes Identify existing data available within Caltrans.	Table of current vehicle population per standard FHWA vehicle classifications	February / April 2012
Task 5:		
Research/review available information resources (from Tasks 3 and 4 as well as additional material) and related efforts (e.g., Pavement Condition Survey and new Pavement Mgt Sys (PMS) in progress). Data sources include State of Logistics (both USA and South Africa studies), MIRIAM project (Models for rolling resistance in Road Infrastructure Asset Management systems) - (UC Pavement Research Center (UCPRC) is involved in current research), as well as related US/California studies into V-PI and riding quality.	Detailed understanding and input to progress report on the available data sources and required analyses for the project. Inclusive of indications of the potential links between the outputs from this project and the inputs for the various economic and planning models (e.g., Statewide Freight Model, Heavy-Duty Truck Model (SCAG), etc.). Final selection on an appropriate route covering a range of riding qualities and speeds within the selected region/district for potential truck measurements – as agreed on by Caltrans after evaluation of all relevant information.	March / May 2012
Task 6:		
Progress/Planning Meeting and Progress report on Tasks 3 to 5.	Progress report on pilot study containing (i.) updated tasks for identifying additional required information and provisional outcomes of study; (ii.) decision regarding selected region/district for pilot study; and (iii.) recommendations for next tasks.	June 2012

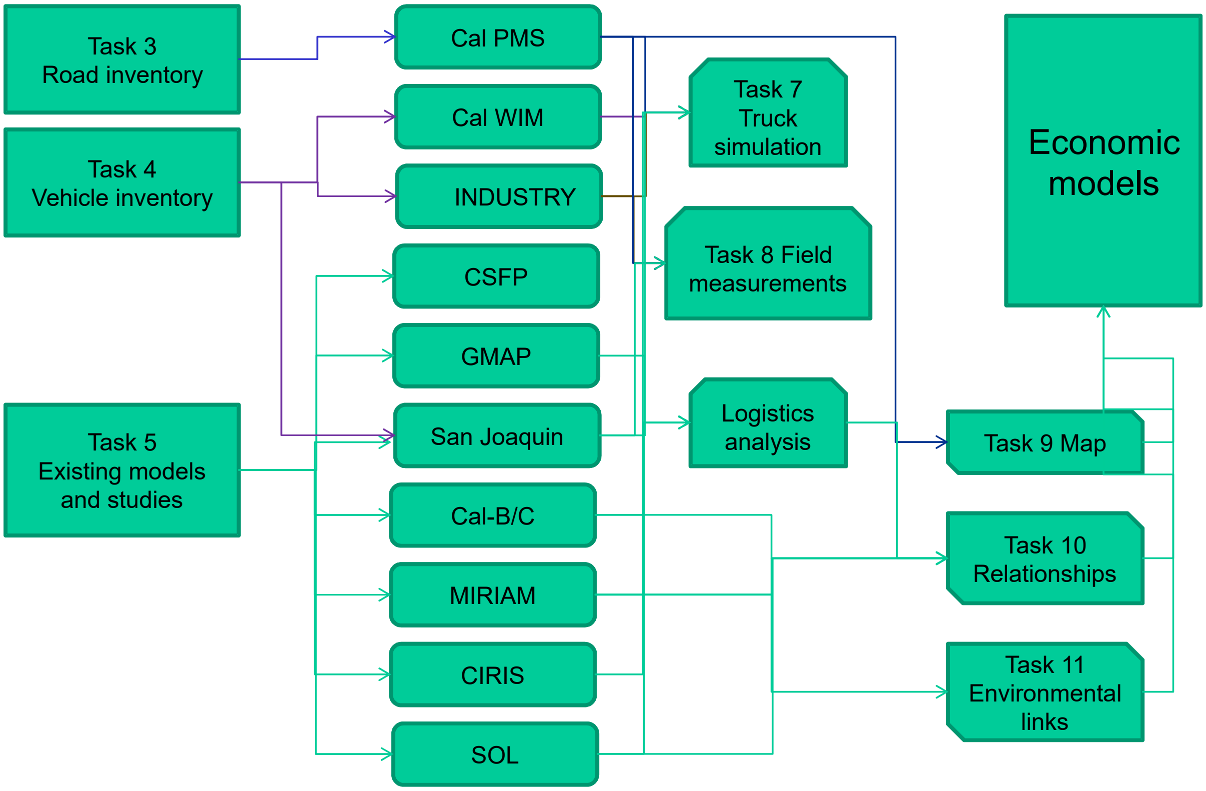

Figure 1.1: Schematic layout and linkages between project tasks.

The detailed scope of this report is as follows:

- Summary of the project background
- Summary of Tasks 1–2
- Progress information on Task 3
- Progress information on Task 4
- Progress information on Tasks 5–6

The purpose of this study is to provide data and information that will provide input that supports Caltrans' freight program plans and the legislation mentioned above. Findings will contribute to economic evaluations; identify challenges to stakeholders; and identify problems, operational concerns, and strategies that "go beyond the pavement," including costs to the economy and the transportation network (delay, packaging, environment, etc.). Findings could lead to improved pavement policies and practices such as strategic recommendations that link pavement surface profile, design, construction, and preservation with V-PI. These findings should also provide information for evaluating the relationship between pavement ride quality (stemming from the pavement's condition), vehicle operating costs, freight damage, and logistics. Better understanding this relationship could provide input for development of construction ride quality specifications and pavement management strategies that maintain or reduce the costs of freight transport and pavements.

Better understanding the pavement-vehicle-freight system can help improve California's economy only if it helps those manufacturers/producers and shippers/handlers (those focusing on shipping, cargo handling, and logistics management, and associated private firms), which work in a highly competitive landscape. The freight shipping industry, consisting of about 17,000 companies nationally and faced with fierce international competition, is highly fragmented, with the top 50 companies accounting for 45 percent of total industry revenue. Profitability of an individual firm depends on its experience and relationships but also on efficient operations, which includes transporting freight over public highways that the firm does not own, operate, or maintain—unlike its truck fleet—but on which its business survival depends. Not performing this pilot study would prevent development of data and information needed for statewide planning, policy, legislative, and associated activities intended to improve the efficiency of freight transport and California's overall economy.

Considering the broader economic impact on shipping firms in California, "through traffic" in the pilot district may also be important, as the origin or destination of the freight may not be in the same district or even within the state, although the shipper earning revenue from the transport is based in California, and thus operational efficiency affects its success and revenue (which in turn affects tax income for the state).

1.4 Objectives

The overall objectives of this project are to enable Caltrans to better manage the risks of decisions regarding freight and the management and preservation of the pavement network, as the potential effects of such decisions (i.e., to resurface and improve ride quality earlier or delay such a decision for a specific pavement) will be quantifiable in economic terms. This objective will be reached through applying the principles of vehicle-pavement interaction (V-PI) and state-of-the-practice tools to simulate and measure peak loads and vertical acceleration of trucks and their freight on a selected range of typical pavement surface profiles on the State Highway System (SHS) for a specific region or Caltrans district.

The objectives of this report are to provide information on Tasks 1–6, and to provide guidance about the specific corridor or district on which the remainder of the pilot study (Tasks 7–12) should be focused.

2 TASKS 1 AND 2 SUMMARY

2.1 Introduction

This section provides information on the work conducted on Tasks 1–2 between December 2011 and February 2012. These two tasks have been completed. Both tasks covered administrative issues.

2.2 Summary

Tasks 1 and 2 were used for the finalization of the contract (Task 1) and the kickoff meeting with Caltrans to ensure that the scope, objectives, and communication for the projects are agreed on.

Task 1 activities were primarily conducted up to January 2012, mainly through electronic communications.

Task 2 activities were primarily handled during a series of meetings held toward the last week of January 2012 and in the first week of February 2012, in Sacramento, California. A copy of the minutes of the kickoff meeting is provided in Appendix A of this report.

3 TASK 3 PROGRESS—ROAD INVENTORY

3.1 Introduction

This section contains information on Task 3—Inventory of current California ride quality/road profiles. Work on the task started in February 2012 and has been completed.

3.2 Task 3 Progress

The objective of Task 3 is to identify existing ride quality data available within Caltrans. The deliverable for Task 3 is a map and/or table with current ride quality data in terms of International Roughness Index (IRI) for a selected region or district, only on-truck/outside lanes for road segments on selected routes.

3.2.1 Required Data

This task covers the identification and collection of ride quality data for the project. The project will require ride quality data on two levels:

1. Ride quality in terms of IRI data is required to enable the selection of an appropriate corridor to be evaluated for the project.
2. Pavement profile data are required for the specific corridor in order to conduct the V-PI simulations envisaged for Task 7 and for analysis of the acceleration data measured during Task 8.

3.2.2 Ride Quality Background

Two pavement components are important in V-PI analyses:

- Pavement roughness/profile
- Pavement materials and structure

Only the pavement profile is covered in this report, as materials fall outside the current project scope. However, it should be appreciated that material properties (and construction quality) will affect the way in which the materials react to the applied tire loads and environmental conditions, and thus the progressive changes in the pavement profile.

The main cause of vehicle induced dynamic loading is the irregularities of the pavement surface (pavement roughness, pavement profile or ride quality); Figure 3.1 shows the vertical profile for the left and right wheelpaths for two typical routes designated nbl (northbound lane) and sbl (southbound lane). These irregularities cause an irregular input to the vehicle through the tire-suspension combination. The response of the vehicle to these inputs constitutes the dynamic nature of vehicle loading (1).

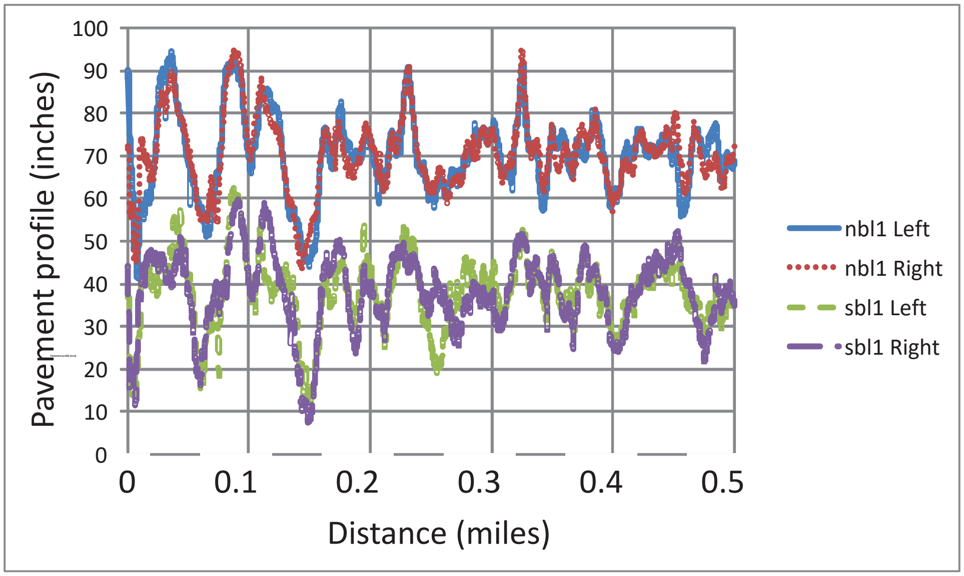

Figure 3.1: Example of four typical road profiles.

Pavement roughness is defined as the variation in surface elevation that induces vibrations in traversing vehicles *(2)*, or as "the deviations of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic pavement loads, and drainage, for example, longitudinal profile, transverse profile and cross slope" *(3)*.

Pavement roughness is typically divided into roughness, macrotexture, and microtexture. The dividing lines between them are based on functional considerations such as traffic safety and ride quality. Roughness is the largest scale, with characteristic wavelengths of 0.32–328 ft (0.1–100 m) and amplitudes of 0.04–3.94 in. (1.0–100 mm), mainly affecting vehicle dynamics. The macrotexture has wavelengths and amplitudes of 0.01–0.39 in. (0.25–10 mm) and microtexture of 0.00039–0.39 in. (0.01–10 mm), and they mainly affect pavement-tire traction characteristics (Figure 3.2) *(4)*. These relate to the frequency ranges (frequency = inverse of wavelength) for various surface characteristics, as specified by the PIARC Technical Committee on Surface Characteristics. The roughness frequency range is the range that induces relative motion in road vehicle suspension systems over a reasonable range of operating speeds *(5)*. The frequency range with wavelengths of 1.64–164 ft (0.5–50 m) is considered best to indicate pavement roughness.

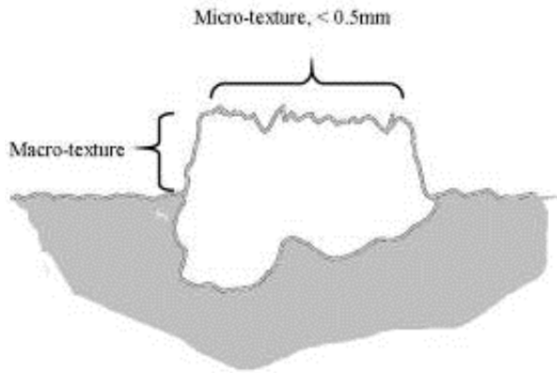

Figure 3.2: Definition of macrotexture and microtexture of pavement surfacing aggregate *(6)*.

Roughness Indices

Pavement roughness is one of the prime indicators of the deterioration of a pavement *(7,8)*. Roughness indices are used to provide a simple value indicating the roughness level and trends in roughness level over time of a specific pavement. These indices are calculated either from the response of a roadmeter to the pavement roughness inputs or using mathematical equations and measured pavement profiles.

Although several roughness indices exist, they do not all measure roughness in the same way, and are not necessarily sensitive to the same types of roughness or applicable to the same conditions. The World Bank sponsored a major study of pavement roughness (the International Road Roughness Experiment [IRRE]) during which various methods for obtaining pavement roughness data, analysis of these data, and presentation into standard formats were investigated. The concept of the International Roughness Index (IRI) was consequently developed. The IRI roughness scale best satisfied the criteria of being time stable, transportable, relevant, and readily measurable. It is a standardized roughness measurement related to the various response-type road roughness measurement systems (RTRRMS) and uses the units meter per kilometer (m/km) or millimeter per meter (mm/m). It is widely accepted as the index of choice for reporting pavement roughness *(9)*.

The true value of the IRI is derived by obtaining a suitable accurate measurement of the profile of a wheelpath, processing it through an algorithm that simulates the way a specific reference vehicle would respond to the roughness inputs, and accumulating the suspension travel. It is calculated at a standard speed of 50 mph (80 km/h), as pavement roughness (and thus applied tire load frequencies) is dependent on vehicle speed *(1,10)*. IRI indicates the extent to which the surface of the pavement has deformed with respect to the specific wavelengths that affect the response of a specific vehicle traveling over the road *(11)*.

The Half-car Roughness Index (HRI) is based on the same equations and assumptions as the IRI, but the average of the two wheelpaths is used in the calculation of the statistic. HRI is always less than or equal to the IRI calculation. IRI indicates vehicle response at the tires, while HRI indicates vehicle response at the center of the vehicle. The Median Roughness Index (MRI) is defined as the average of the IRI for the left and right wheelpaths.

The IRI of two pavements may be similar even though their roughness differs. This is possible if one pavement has more pronounced longer wavelengths and the other more pronounced shorter wavelengths, and both these bands fall into the IRI wavelength band *(11)*.

IRI is particularly sensitive to wavelength bands related to shorter wavelengths (associated with axle resonance), and longer wavelengths linked with body bounce. These wavelengths cause dynamic load variations that reduce the road-holding ability of tires and contribute to road damage caused by commercial vehicles. The IRI is most sensitive to slope sinusoids with wavelengths of 50 and 7.5 ft (15.4 and 2.3 m), with a gain of 1.5 and 1.65, respectively. The gain (ratio of output amplitude to input amplitude) decreases to 0.5 for wavelengths of 100 and 4.3 ft (30.3 and 1.3 m) *(11)*. The IRI scale ignores wavelengths outside the 4.3–100 ft (1.3–30 m) wavelength band since these do not contribute to the roughness experienced by road-using vehicles at speeds near 50 mph (80 km/h) (approximately 17–1.35 Hz) *(2)*. The vehicle speed affects the perception of roughness frequency, with higher speeds causing perceived higher frequencies as unevenness on the pavement is experienced at shorter intervals in the vehicle.

The IRI is not related to all vehicle response variables. It is most appropriate when a roughness measure is desired that relates to overall vehicle operating cost, overall ride quality, and overall surface condition *(12)*. It is intended to reflect the pavement roughness attributes that affect the ride quality of passenger vehicles and was not intended to describe the pavement roughness characteristics affecting heavy trucks, as is needed in this report.

The IRI does not show sensitivity to excitation frequencies as observed under heavy vehicle traffic (IRI sensitivity is at 1.5 and 11 Hz, while heavy vehicle sensitivity is at 3.5 and 12 Hz) *(13)*. Because of these different wavelengths affecting different vehicles, IRI is a poorer measure of ride quality for truck drivers than for car occupants, and this is partly why this study's analyses measured surface profile. Trucks may be more sensitive to longer wavelengths, inducing pitch and roll response modes *(5,11)*.

Response Modes

A vehicle traveling on a pavement has two response modes: the body bounce at frequencies typically around 1–4 Hz, and the axle hop at frequencies around 10–18 Hz *(14)*. Vehicle response to the pavement profile can be modeled in the frequency domain as a response function. The vehicle response characteristics amplify profile frequencies around the natural frequencies of the response modes and attenuate profile frequencies well removed from those of the response modes. Mathematically, the vehicle frequency response function acts as a multiplier to the input road profile power spectral density (PSD) to give the PSD of the vehicle response (PSD measures the frequency content of a stochastic process to assist in identifying periodicity). For frequency characterization of road profiles and frequency domain analysis of vehicle responses to the profile, the road profile can be characterized as a PSD. The PSD shows the variance in road profile elevation (or slope) as related to spatial frequency (measure of how often sinusoidal components of the pavement repeat per unit of distance) *(5)*.

Dynamic load profiles for all heavy vehicles are characterized by two distinct frequencies. Body bounce (1.5–4 Hz) generally dominates the dynamic loading; it is mainly caused by the response of the vehicle's sprung mass (mass of body carried by suspension system of the vehicle) to the pavement roughness. Axle hop (8–15 Hz) becomes more significant at higher vehicle speeds and greater pavement roughness; it is mainly caused by the reaction of the unsprung mass (mass of tires axles and suspension system) to pavement roughness. The main cause for the dominating effect of the body bounce may lie in the load ratio of approximately 10:1 between the sprung mass and the unsprung mass *(1)*.

Power Spectral Density

The PSD of pavement profiles is categorized into eight classes (A to H) according to the ISO 8608 procedure *(15)*. An example of three pavement profiles—with relatively smooth, average, and rough ride qualities—are shown in Table 3.1 and Figure 3.3 to illustrate the different types of ride quality indices and related PSD classes. The displacement power spectral density (DPSD; PSD of vertical profile) plot shows the DPSD versus spatial frequency. Dominant peaks on this graph would indicate dominant spatial frequencies in the pavement profile data. As relatively few such peaks occur in the data shown, no specific cause (i.e., construction faults) is expected to be the cause of the specific roughness on the pavements indicated.

The spatial frequencies occurring at body bounce (approximately 3 Hz) and axle hop (approximately 15 Hz) at the three speeds selected for the analyses in this report are also shown in Figure 3.3. All the lower frequencies (body bounce) occur at positions where the DPSD indicates a marked difference between the three pavement sections. However, the higher frequencies (axle hop) occur at DPSD values where less difference exists between the DPSD values. This is partly caused by the dominance of higher frequencies in the DPSD analysis. As the body bounce mode of moving dynamic loading (MDL) is the more dominant factor in MDL, due to its higher magnitude, this is less of a concern in the various analyses.

Ride Quality Analyses

The standard software used for analysis of ride quality properties of pavement profiles is ProVal™ *(16)*. ProVal was developed by the Federal Highway Administration, and is freely available from an FHWA website (*www.roadprofile.com*). All ride quality analyses in this report have been conducted using ProVal.

Table 3.1: ISO *(15)* Classification and IRI and HRI Values for Three Typical Pavement Sections

Parameter	Pavement Identification and Data		
	Smooth (S)	Average (A)	Rough (R)
ISO classification	A	B/C	C/D
IRI (mm/m) L;R* (in./mi)	1.5; 1.5 [96; 96]	3.9; 4.4 [250; 282]	7.8; 5.5 [500; 352]96; 96
HRI (mm/m) (in./mi)	1.2 [77]	3.5 [198]	5.3 [340]

*Left and right wheelpaths

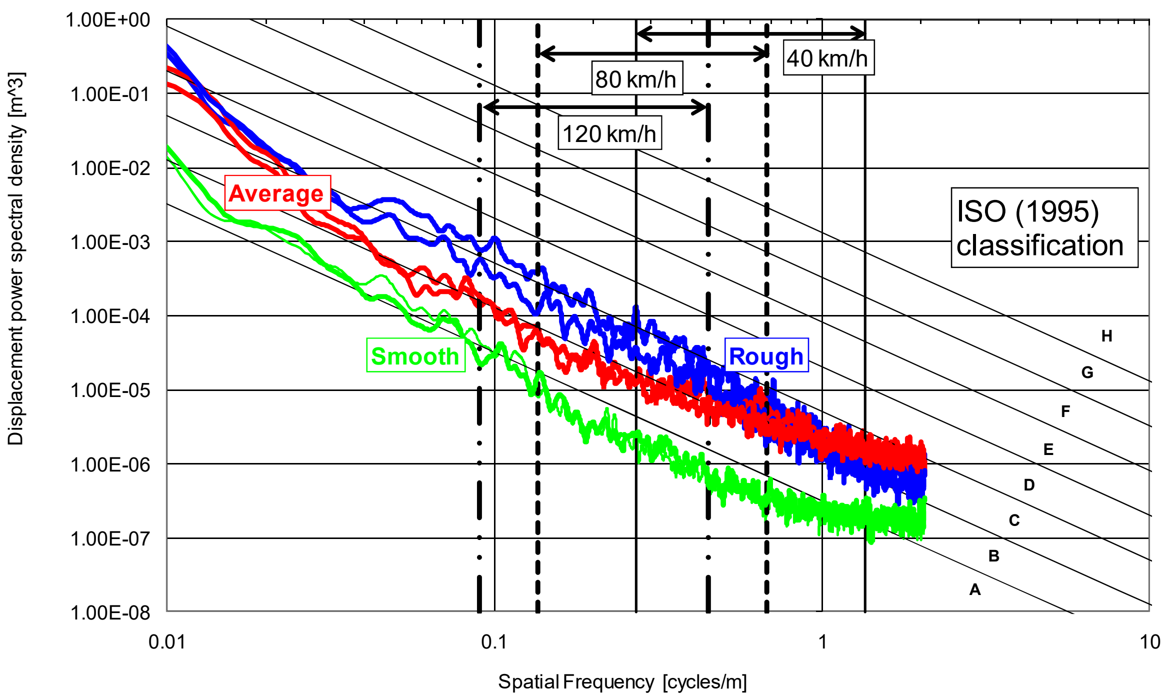

Figure 3.3: Displacement power spectral densities (DPSDs) on ISO classification for three different pavements.

3.3 Task 3 Information Resources

The following information sources have been identified for Task 3.

3.3.1 Caltrans PMS IRI Data

Data originating from the Caltrans Pavement Management System (PMS) database were obtained through UCPRC on April 3, 2012. An example of two records in the PMS database is shown in Table 3.2. These data include the location of the section of road, information on the road type, the ride quality for left and right wheelpaths (IRI-LWP and IRI-RWP), rut depth, and any damage that occurs on the road section. In this project the focus of the data analysis is on the road location and the ride quality data.

3.3.2 Caltrans PMS Pavement Profile Data

There are detailed road profiles available for each of the road sections available in the PMS database. These profiles are in .erd file format and can be analyzed using ProVal. The profiles can also be used as input profiles in TruckSIM^{TM} for the planned Task 7 analyses.

3.3.3 Caltrans Routes

Route maps for each district were obtained from the Caltrans website *(17)*, and are shown in Figure 3.4 to Figure 3.15.

Table 3.2: Typical Road Profile Information from PMS Database

Session	**Section number**	
	1A80A800	**1A80A800**
Start postmile	0	9
End postmile	9	19
Pavement type	JPC	JPC
Lane type	JPC	JPC
IRI-LWP	113 in./mi	102 in./mi
IRI-RWP	104 in./mi	98 in./mi
MPD	0 in.	0 in.
Mean rut depth, LWP	8 in.	8 in.
Standard deviation rut depth, LWP	0 in.	1 in.
Maximum rut depth, LWP	8 in.	9 in.
Mean rut depth, RWP	6 in.	4 in.
Standard deviation rut depth, RWP	4 in.	0 in.
Maximum rut depth, RWP	9 in.	4 in.
Number of faults	1	1
Mean fault height	5.1 in.	5.2 in.

Abbreviations: LWP = left wheelpath, RWP = right wheelpath, MPD = maximum profile depth

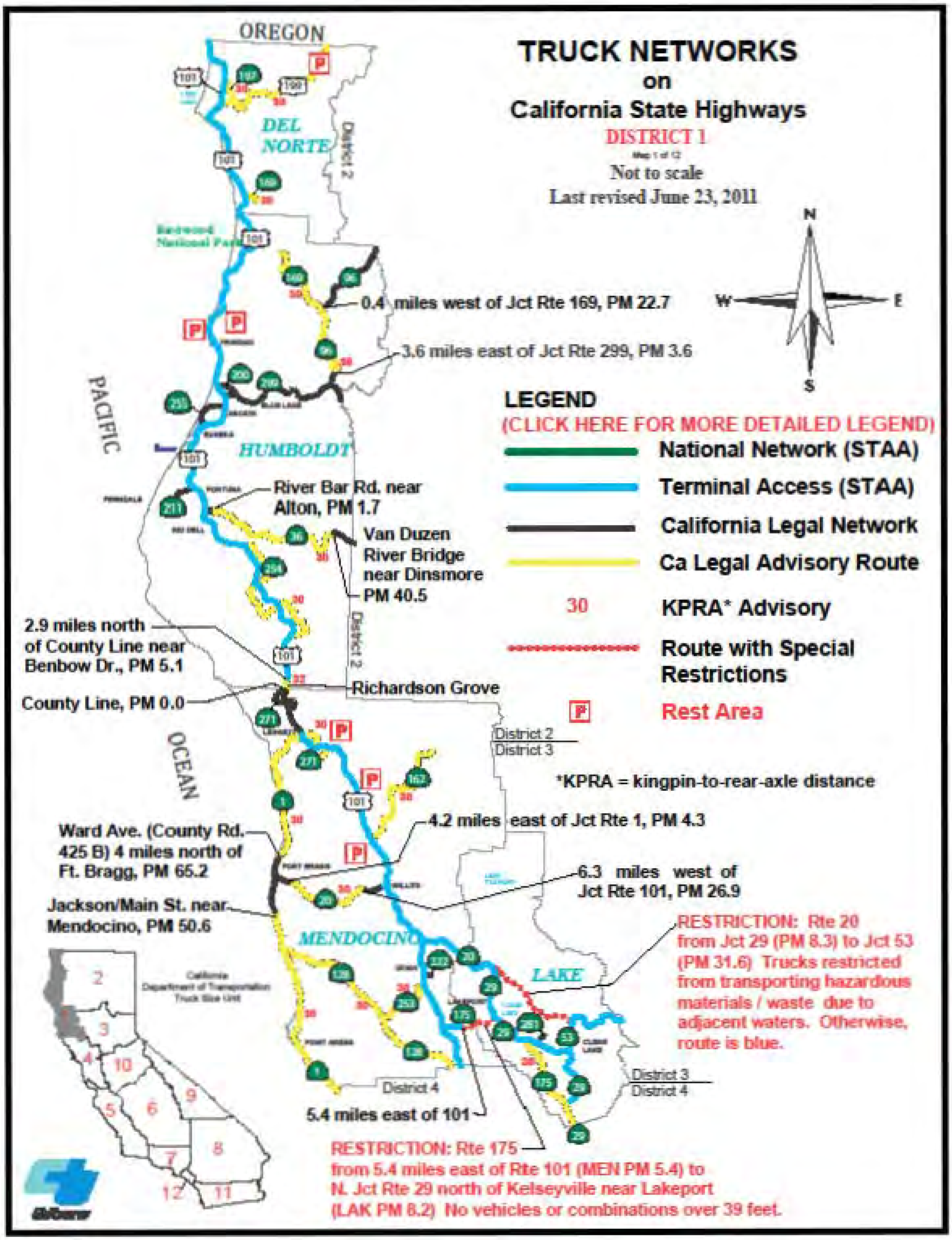

Figure 3.4: Caltrans District 1 routes.

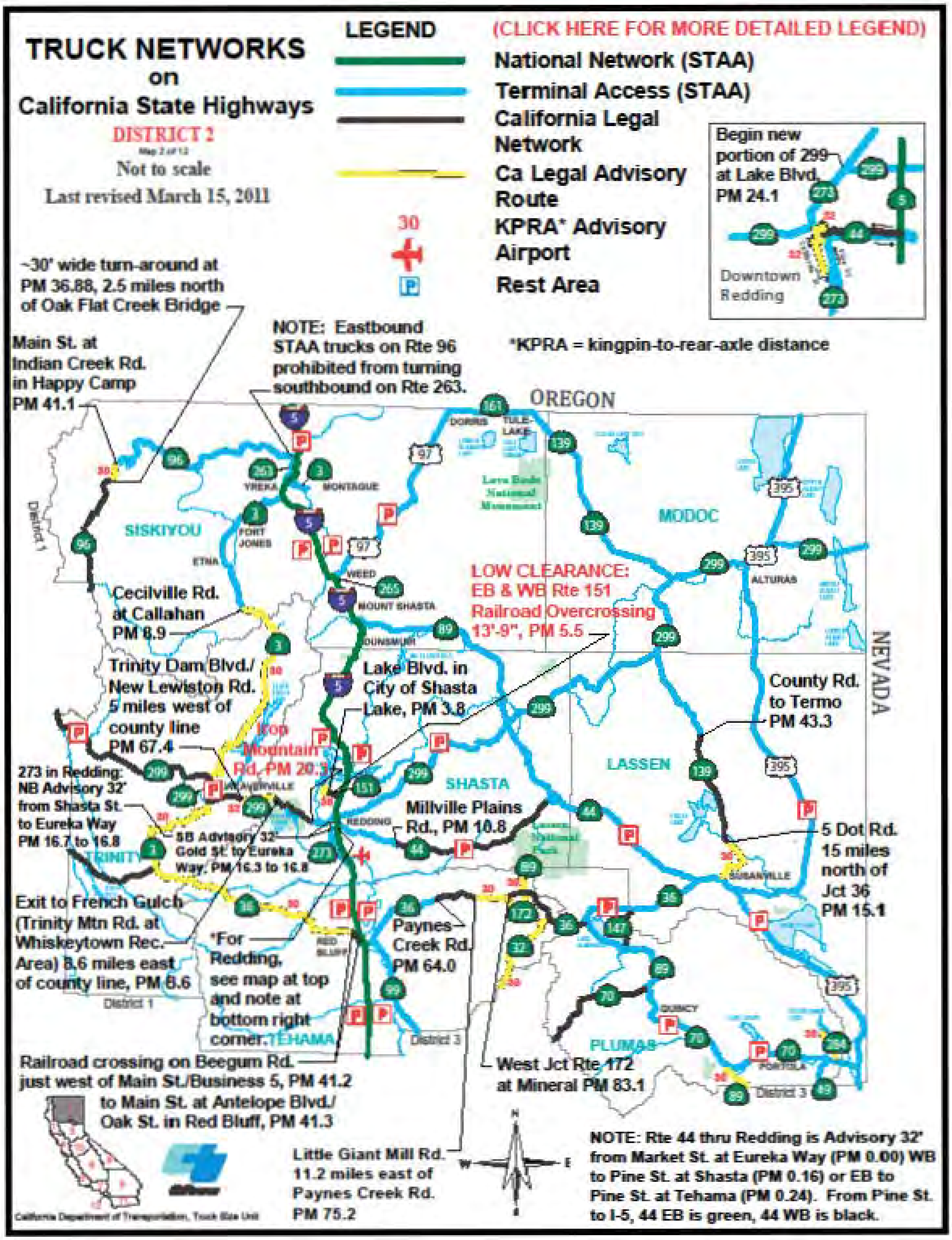

Figure 3.5: Caltrans District 2 routes.

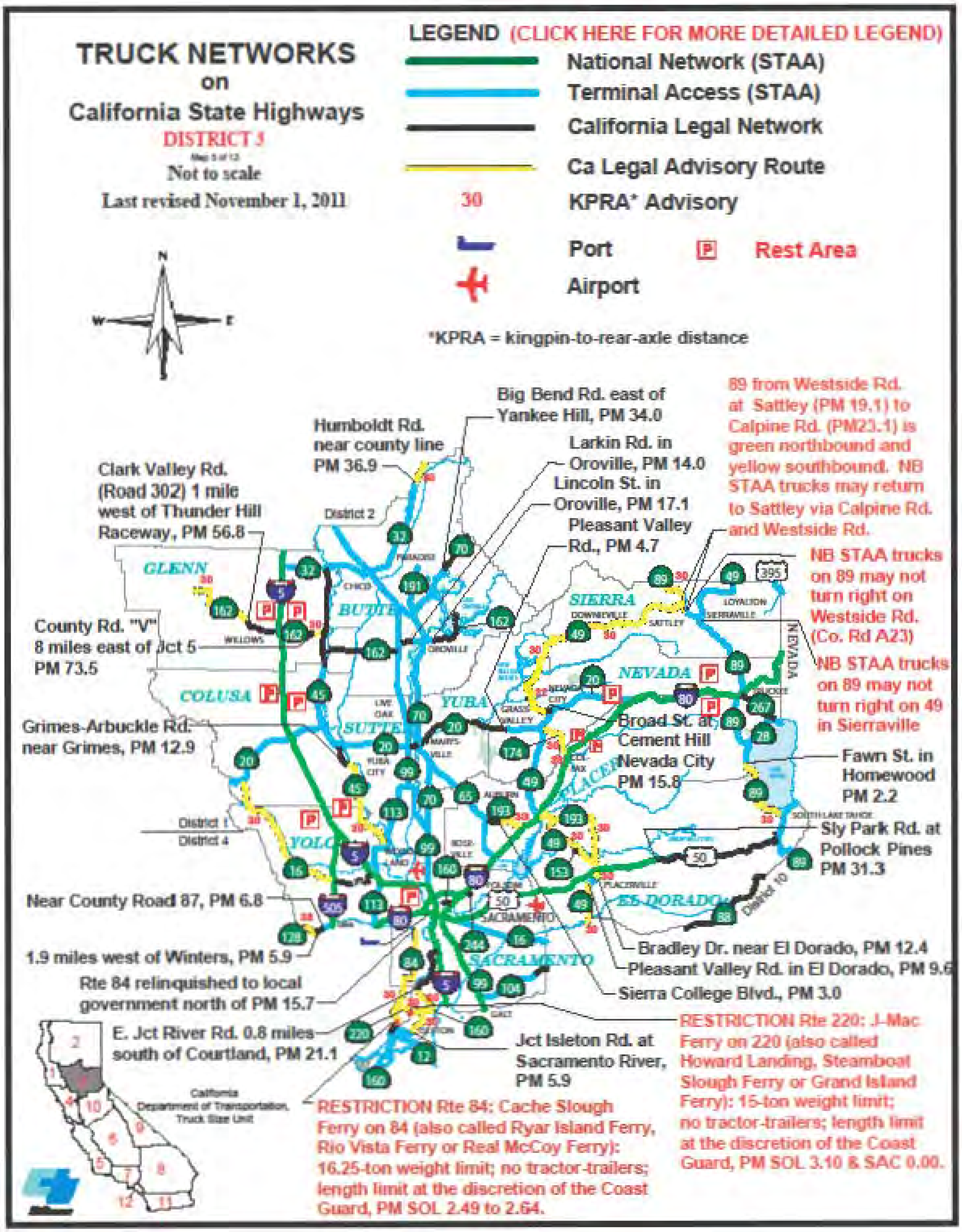

Figure 3.6: Caltrans District 3 routes.

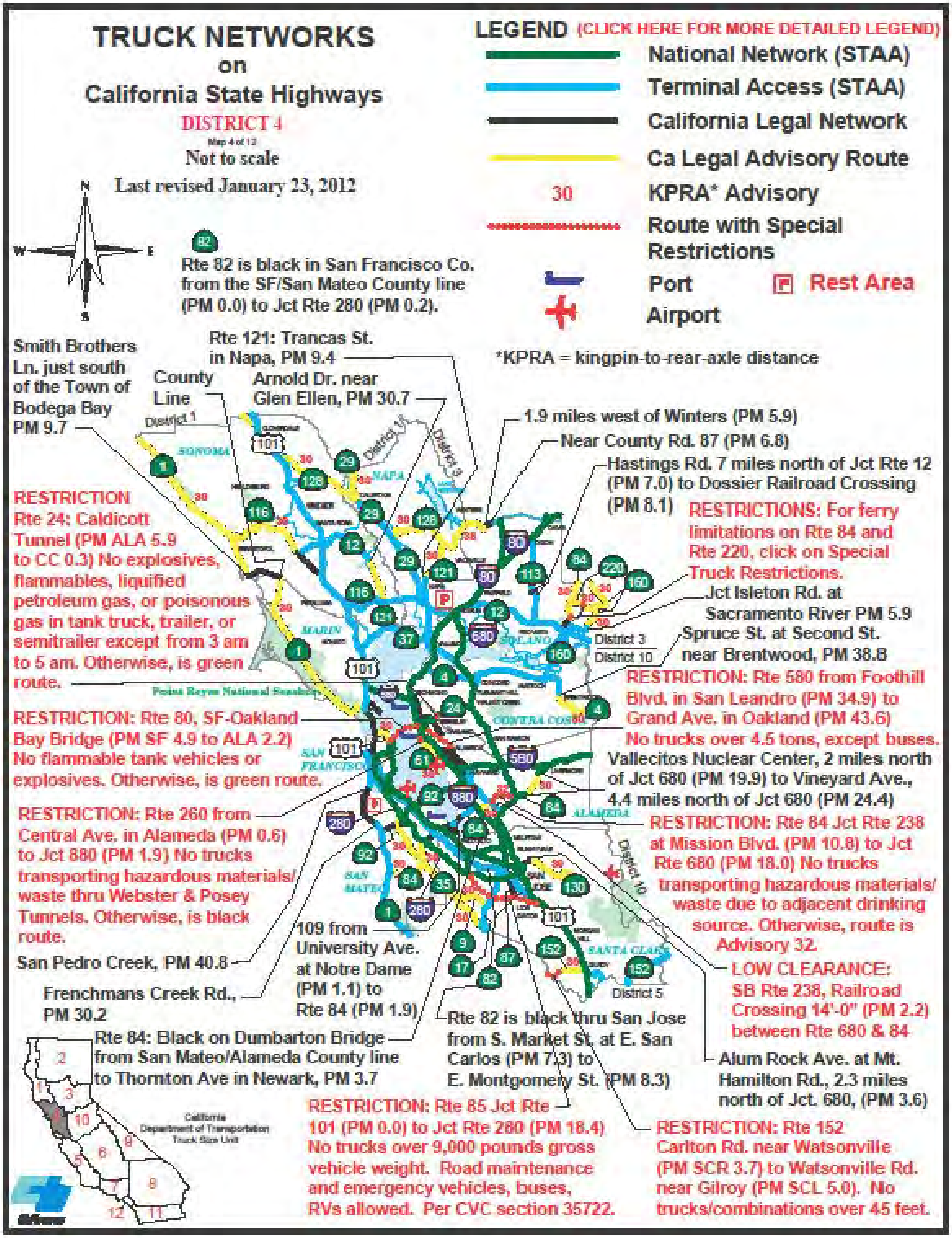

Figure 3.7: Caltrans District 4 routes.

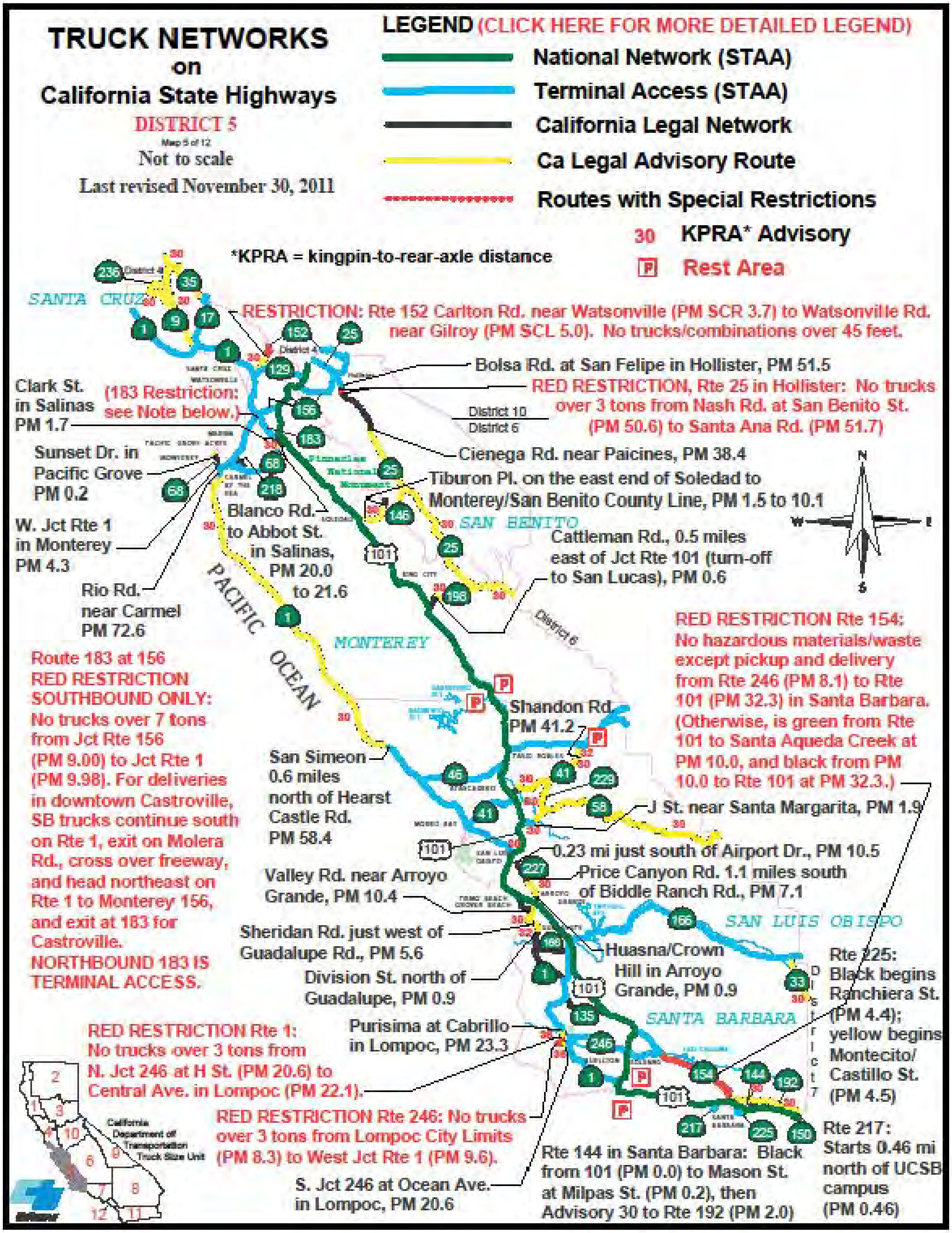

Figure 3.8: Caltrans District 5 routes.

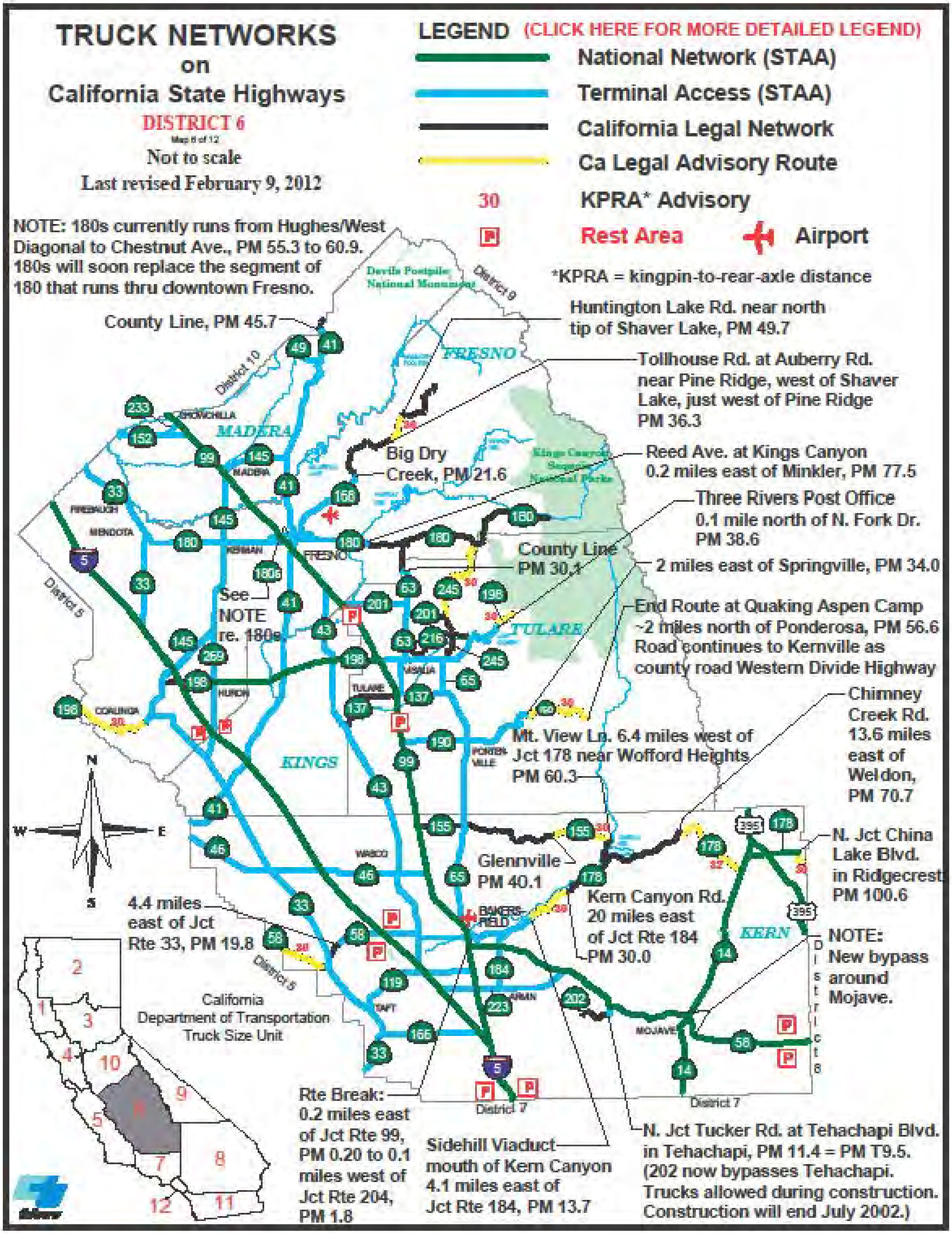

Figure 3.9: Caltrans District 6 routes.

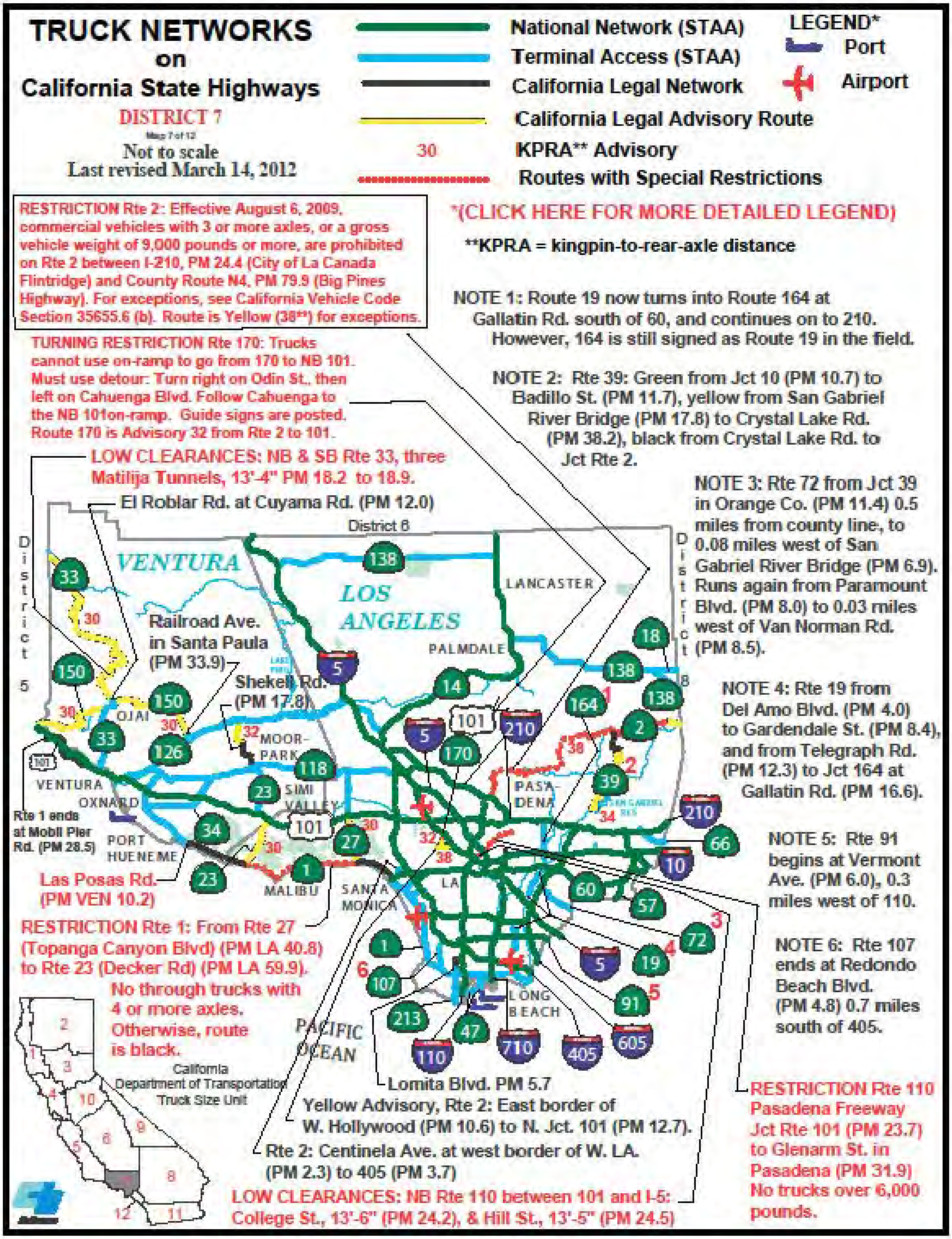

Figure 3.10: Caltrans District 7 routes.

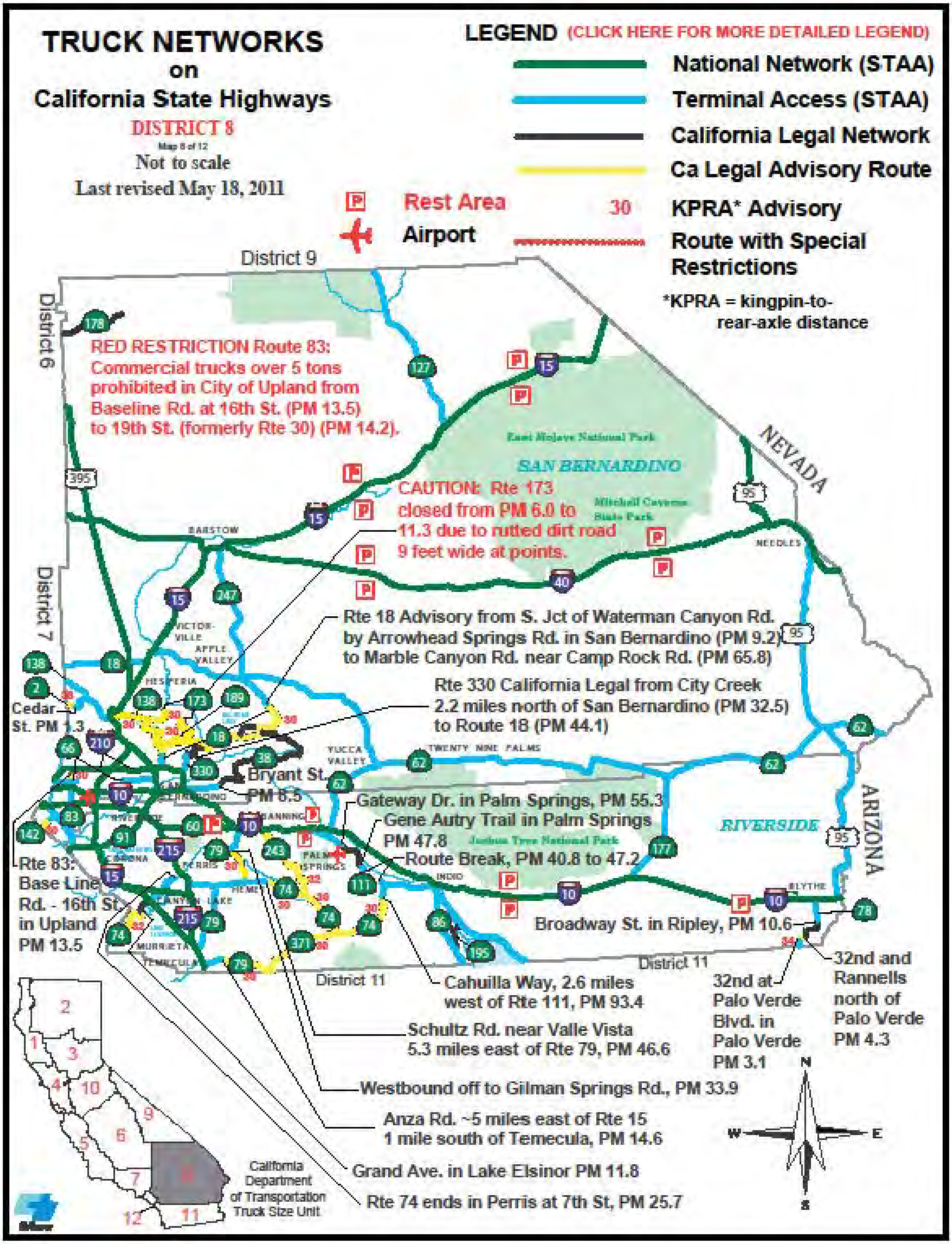

Figure 3.11: Caltrans District 8 routes.

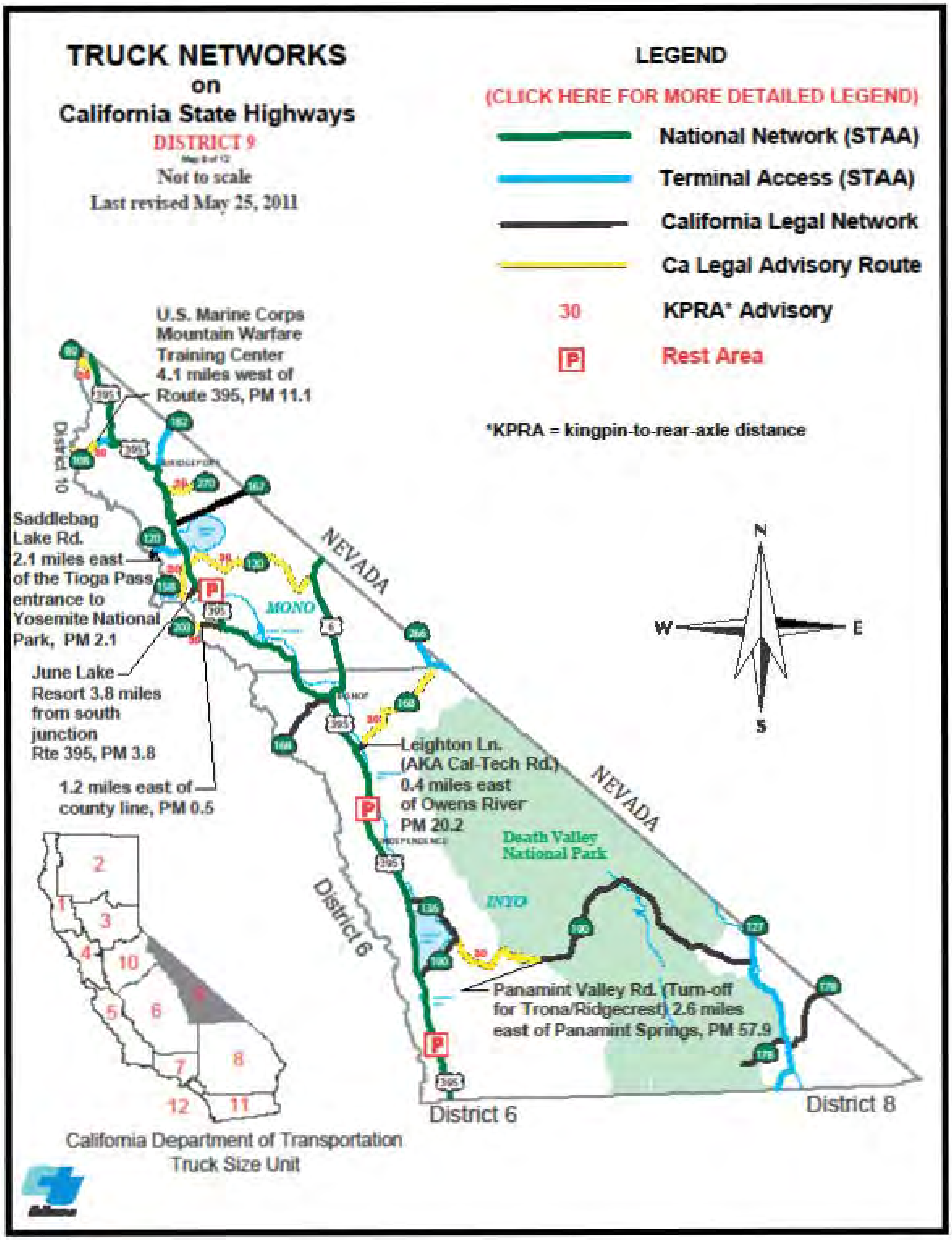

Figure 3.12: Caltrans District 9 routes.

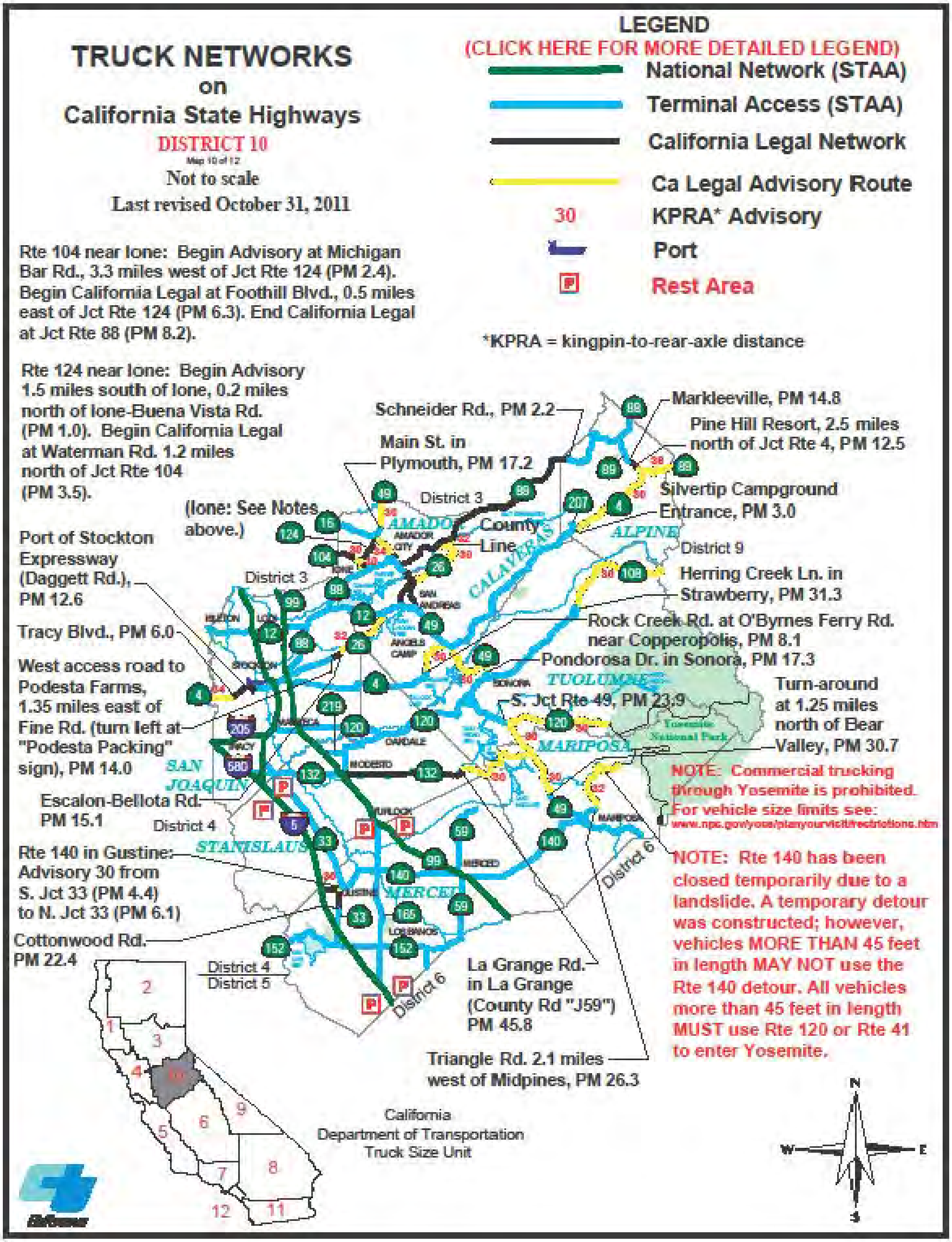

Figure 3.13: Caltrans District 10 routes.

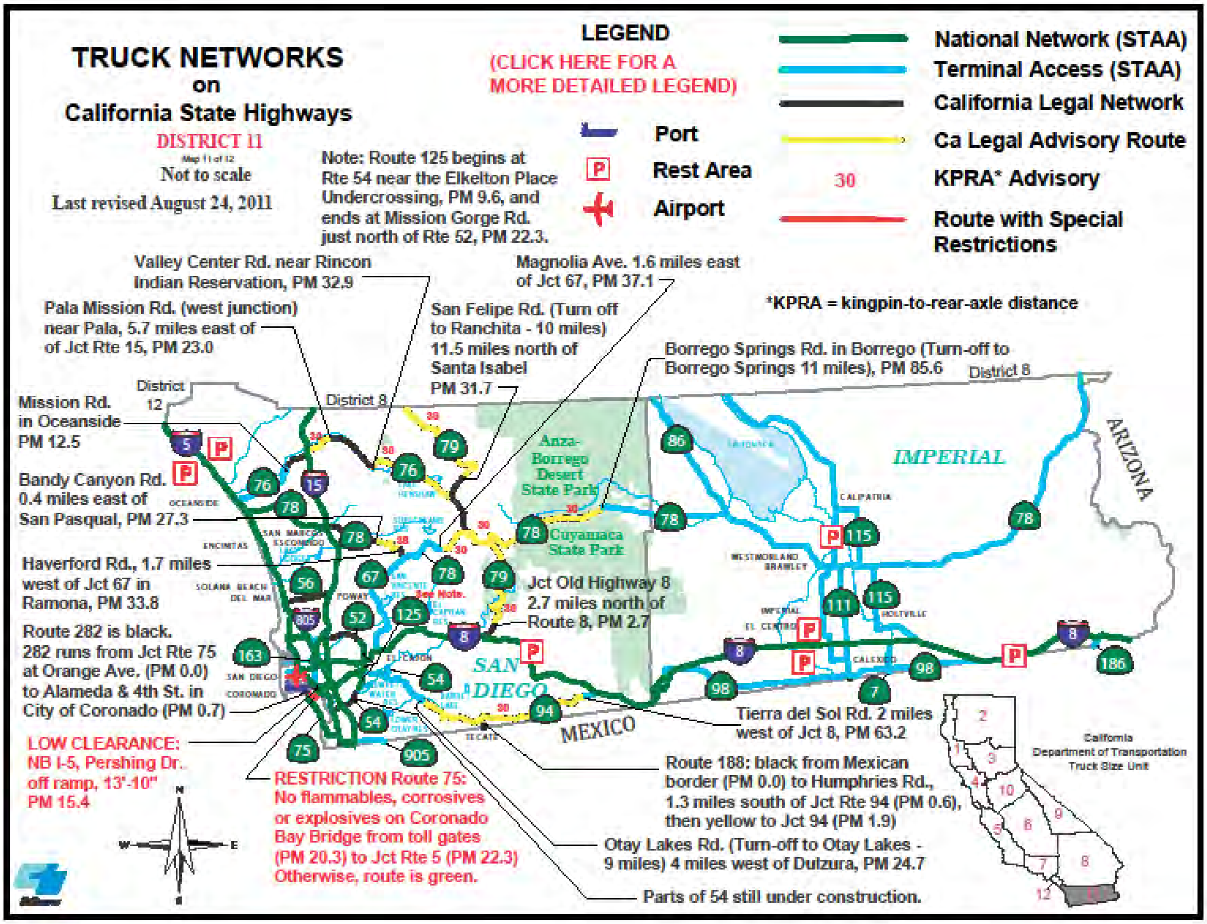

Figure 3.14: Caltrans District 11 routes.

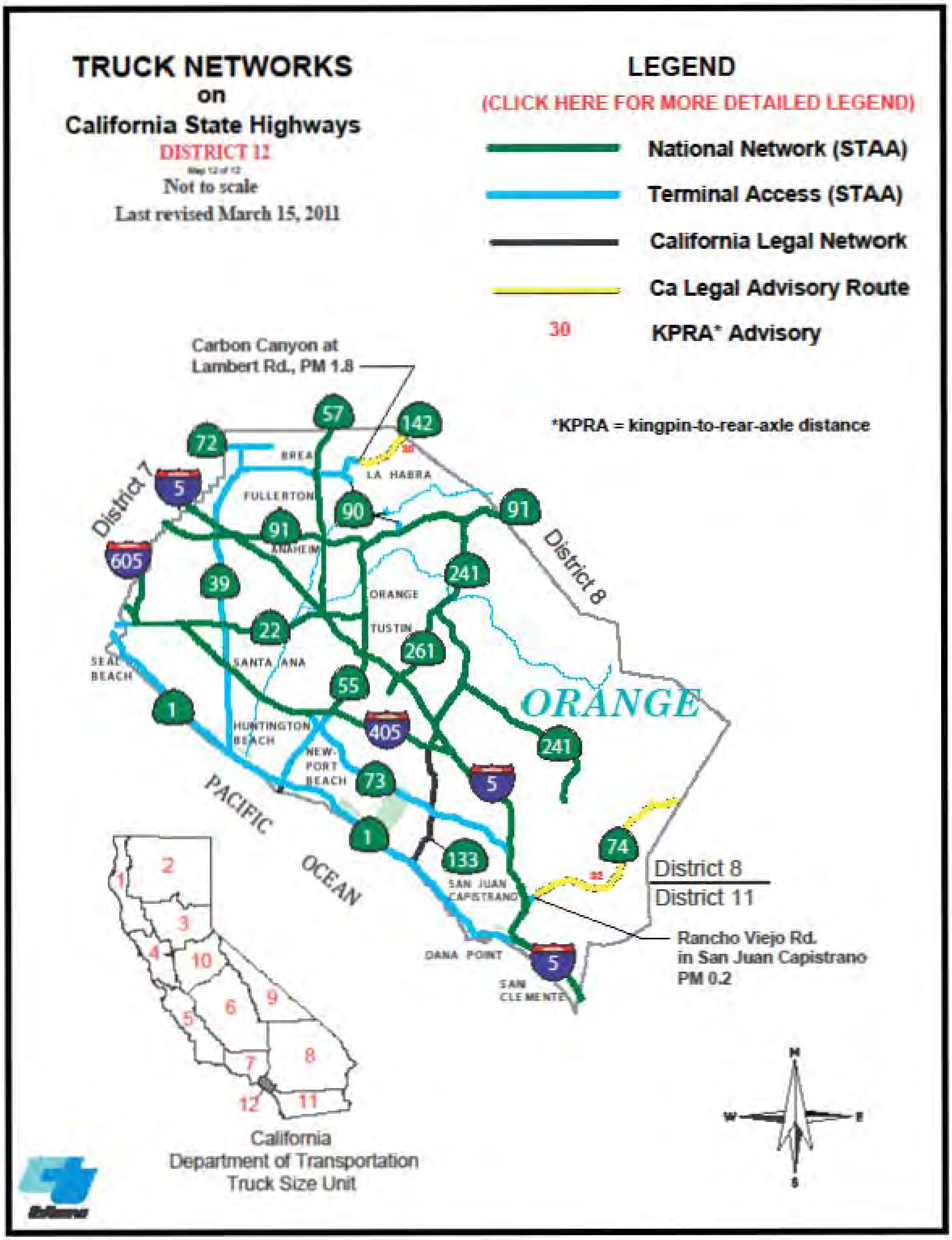

Figure 3.15: Caltrans District 12 routes.

3.4 Task 3 Analysis

The summary of the number of sections as well as miles of sections for which ride quality data exist in the current PMS database is provided in Table 3.3 and Table 3.4. It provides an information breakdown for the various districts (Table 3.3) and counties (Table 3.4). This represents approximately 67 percent of all the sections in Caltrans. It is anticipated that all the sections will be available on the PMS database by July 2012.

Table 3.3: Number of Sections and Lane-Miles of Sections for Which Data Ride Quality Exist in the Current PMS Database, by District

District	Number of sections	Lane-miles of sections
1	358	4,102.8
2	342	4,399.9
3	429	4,309.2
4	903	6,674.2
5	358	3,281.5
6	473	5,900.1
7	703	6,055.9
8	517	6,317.9
9	132	1,894.2
10	299	3,381.3
11	357	3,543.0
12	200	1,074.0
Total		50,934.0

Analysis of the data in Table 3.3 and Table 3.4 show the following:

- Districts 4, 7, and 8 have the highest number of lane-miles of road with ride quality data in the current PMS database.
- Districts 9 and 12 have the lowest number of lane-miles of road with ride quality data in the current PMS database.
- LA (Los Angeles) county has the highest number of lane-miles of road with ride quality data in the current MS database.
- ALP (Alpine) county has the lowest number of lane-miles of road with ride quality data in the current PMS database.
- There are a total of 8,100 lane-miles of road in the San Joaquin Valley counties for which ride quality data exists.

Table 3.4: Number of Sections and Lane-Miles of Sections for Which Ride Quality Data Exist in the Current PMS Database, by County

County	Number of sections	Lane-miles of sections		County	Number of sections	Lane-miles of sections
ALA	204	1,380.2		ORA	267	1,597.7
ALP	13	110.2		PLA	54	511.4
AMA	36	320.9		PLU	33	385.4
BUT	48	429.9		RIV	206	2,433.1
CAL	17	290.4		SAC	107	897.3
CC	87	641.6		SB	97	929.4
COL	21	300.5		SBD	311	3,884.8
DN	23	475.1		SBT	29	207.7
ED	31	469.2		SCL	176	1,345.2
FRE	122	1,495.1		SCR	37	480.0
GLE	19	255.9		SD	317	2,734.2
HUM	75	1,278.4		SF	70	326.0
IMP	70	988.7		SHA	73	907.4
INY	67	1,186.3		SIE	19	213.8
KER	200	2,411.2		SIS	75	927.7
KIN	34	672.9		SJ	94	893.5
LA	657	5,461.7		SLO	100	745.9
LAK	29	290.7		SM	137	944.8
LAS	51	790.2		SOL	96	729.8
MAD	39	378.2		SON	56	628.7
MEN	73	930.8		STA	55	586.7
MER	58	855.1		SUT	23	229.2
MNO	65	707.9		TEH	48	552.9
MOD	27	417.2		TRI	33	406.1
MON	82	910.1		TUL	71	888.4
MPA	24	322.3		TUO	33	390.9
MRN	42	368.9		VEN	82	682.7
NAP	49	318.3		YOL	48	505.5
NEV	41	355.5		YUB	20	153.9
				Total		51,864.3

3.5 Task 3 Outcome

The outcomes of Task 3 are:

- Identified routes in each district and county for which ride quality data exists, as well as the actual ride quality for these routes (due to the volume of data the actual data are kept only in electronic form).
- Maps indicating the location of routes in each district and county, and the location of each county in the various districts.

The specific routes on which Tasks 7–12 of this project will focus on will be identified as part of the discussions based on this report. Once the decision has been taken on these specific routes, the ride quality data for them will be extracted.

The data identified and collected for Task 3 will be used in combination with the data obtained in Tasks 4 and 5 in the analyses discussed in Task 5.

4 TASK 4 PROGRESS—VEHICLE INVENTORY

4.1 Introduction

This section contains information on Task 4 – Inventory of current California vehicle population. Work on the task started in February 2012 and has been completed.

4.2 Task 4 Progress

The objective of Task 4 is to identify existing vehicle population data available within Caltrans. The deliverable for Task 4 is a table of current vehicle population per standard FHWA vehicle classifications for Caltrans.

4.3 Task 4 Information Sources

4.3.1 FHWA Vehicle Classifications

The FHWA developed the 13-vehicle class system for most federal vehicle classification count reporting (Table 4.1) *(18)*. Although all states currently use this classification scheme, most states separate one or more of the FHWA categories into additional classifications to track vehicles of specific interest to them. These categories are then aggregated when reporting to the FHWA. Fine-tuning the classification algorithm is needed because the visual basis of the FHWA 13 categories does not translate to an exact set of axle spacings. When the FHWA 13 categories cannot be used it is recommended that the classes be either a subset of the FHWA classes or a clean disaggregation of the FHWA classes.

4.3.2 California Truck Definitions and Information

Truck definitions for California Department of Transportation STAA routes are shown in Figure 4.1 and Figure 4.2. The definitions used in the figures Figure 4.1are defined as follows *(17)*:

- STAA: The federal Surface Transportation Assistance Act of 1982
- KPRA: kingpin-to-rear-axle distance
- Double: A truck tractor that tows a semitrailer and trailer
- STAA Truck: A truck tractor-semitrailer (or double) that conforms to the STAA requirements
- California Legal Truck: A truck tractor-semitrailer (or double) that can travel on virtually any route in California
- National Network (NN): Primarily the interstates, also called the National System of Interstate and Defense Highways
- Terminal Access (TA) routes: State or local routes that have been granted access to STAA trucks
- Service Access routes: Roads that allow STAA truck access for fuel, food, lodging, and repair within one road mile of a signed exit from the National Network

- STAA Network: The routes that allow STAA trucks, which include the National Network, Terminal Access routes and Service Access routes
- CVC: California Vehicle Code

Table 4.1: FHWA Vehicle Classes with Definitions *(18)*

Class	Description	Definitions
1	Motorcycles (Optional)	All two or three wheeled motorized vehicles. Typical vehicles in this category have saddle type seats and are steered by handlebars rather than steering wheels. This category includes motorcycles, motor scooters, mopeds, motor powered bicycles, and three wheel motorcycles. This vehicle type may be reported at the option of the State.
2	Passenger Cars	All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers and including those passenger cars pulling recreational or other light trailers.
3	Other Two Axle, Four Tire, Single Unit Vehicles	All two axle, four tire vehicles, other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two axle, four tire, single unit vehicles pulling recreational or other light trailers are included in this classification. Because automatic vehicle classifiers have difficulty distinguishing class 3 from class 2, these two classes may be combined into class 2.
4	Buses	All vehicles manufactured as traditional passenger carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger carrying vehicles. Modified buses should be considered to be a truck and should be appropriately classified.
5	Two Axle, Six Tire, Single Unit Trucks	All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with two axles and dual rear wheels.
6	Three Axle Single Unit Trucks	All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with three axles.
7	Four or More Axle Single Unit Trucks	All trucks on a single frame with four or more axles.
8	Four or Fewer Axle Single Trailer Trucks	All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.
9	Five Axle Single Trailer Trucks	All five axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.
10	Six or More Axle Single Trailer Trucks	All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.
11	Five or fewer Axle Multi Trailer Trucks	All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.
12	Six Axle Multi Trailer Trucks	All six axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.
13	Seven or More Axle Multi Trailer Trucks	All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

Note: In reporting information on trucks the following criteria should be used:

- Truck tractor units traveling without a trailer will be considered single-unit trucks.
- A truck tractor unit pulling other such units in a "saddle mount" configuration will be considered one single-unit truck and will be defined only by the axles on the pulling unit.
- Vehicles are defined by the number of axles in contact with the road. Therefore, "floating" axles are counted only when in the down position.
- The term "trailer" includes both semi- and full trailers.

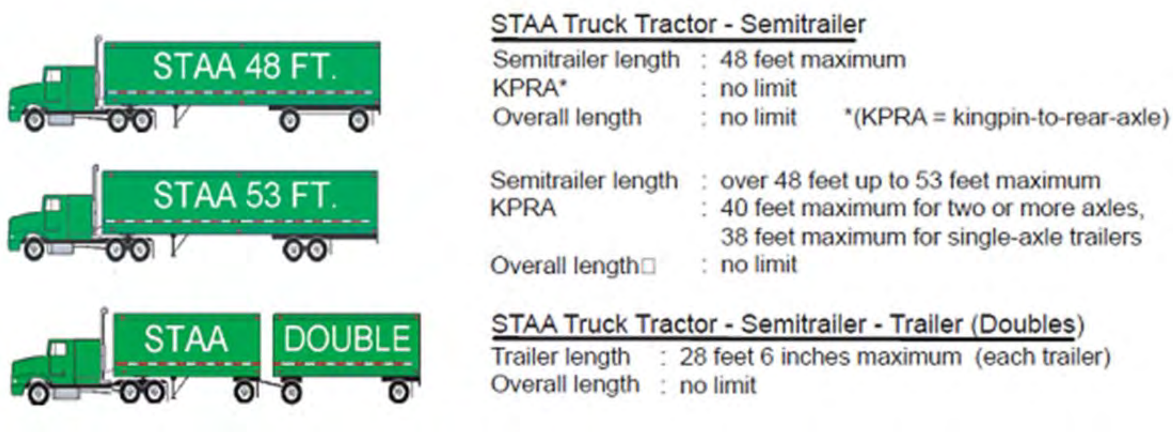

Figure 4.1: California Truck Map legend for STAA routes *(17).*

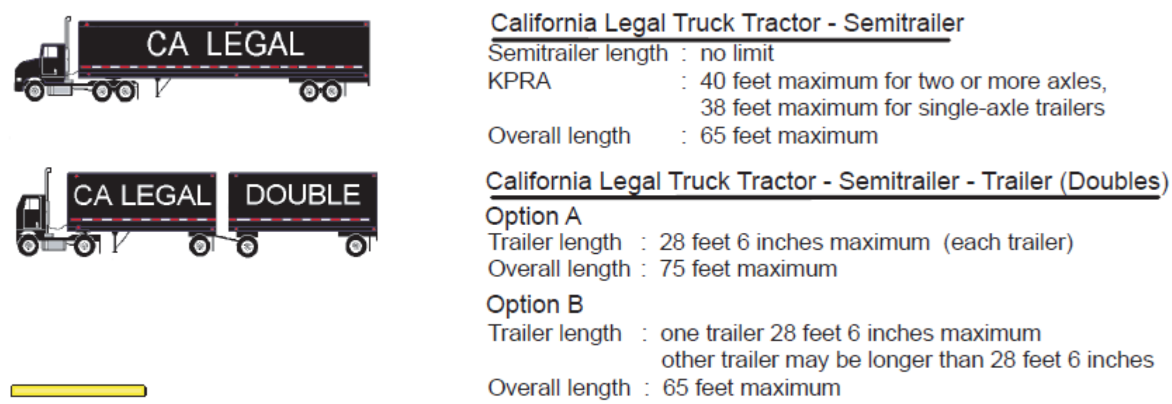

Figure 4.2: California Truck Map legend for California Legal routes *(17).*

The FHWA classes that the California truck types aggregate to are as follows:

- STAA 48 FT—Type 9 (3S2 Split)
- STAA 53 FT—Type 9 (3S2)
- STAA Double—Type 12 (3S1-2)
- CA Legal—Type 9 (3S2)
- CA Legal Double—Type 11 (2S1-2)

Typical axle distances for trucks operated in California are provided in Table 4.2 *(17)*. These truck types have been identified as being the most common for transporting goods in California.

Table 4.2: Most Common Truck Types in California Used for Transporting Goods

	Distance Between Axles (ft.)/[m]				
CA truck type nomenclature	Axle 1 to 2	Axle 2 to 3	Axle 3 to 4	Axle 4 to 5	Axle 5 to 6
STAA 48 feet (STAA Truck Tractor-Semitrailer)—FHWA Class 9	6–26 [1.8–7.9]	3–5.99 [0.9–1.8]	6–46 [0.8–14.0]	3–10.99 [0.9–3.4]	
STAA 53 feet (STAA Truck Tractor-Semitrailer)— FHWA Class 9	6–26 [1.8–7.9]	3–5.99 [0.9–1.8]	6–46 [1.8–14.0]	3–10.99 [0.9–3.4]	
STAA Double (STAA Truck Tractor-Semitrailer-Trailer [Doubles])—FHWA Class 12	6–26 [1.8–7.9]	3–5.99 [0.9–1.8]	11–26 [3.4–7.9]	6–24 [1.8–7.3]	11–26 [3.4–7.9]
CA Legal Double (California Legal Truck Tractor-Semitrailer-Trailer [Doubles])— FHWA Class 9	6–26 [1.8–7.9]	11–26 [3.4–7.9]	6–20 [1.8–6.1]	11–26 [3.4–7.9]	

4.3.3 Commodity Flow Survey

The Commodity Flow Survey report provides statistics of national and state-level data on domestic freight shipments by American establishments in mining, manufacturing, wholesale, auxiliaries, and selected retail industries. Data are provided on the types, origins, values, weights, modes of transport, distance shipped, and ton-miles of commodities shipped. It is a shipper-based survey that is conducted every five years as part of the Economic Census *(19)*. Various types of data relevant to this study were obtained from this report. No specific information for commodity flows originating outside California and transported into California (destination California) could be identified in this pilot study.

Truck Count Data

An example of the 2010 truck count data is shown in Table 4.3, with analyzed data relevant to California shown in Table 4.4 and Figure 4.3 to Figure 4.5.

Analysis of the data in Figure 4.3 to Figure 4.5 indicates that the four most highly populated districts carry the highest traffic loads (in terms of average annual daily traffic [AADT]) (Figure 4.3), while the highest percentage trucks (Figure 4.4) are located in the districts where major linkages with adjacent states or countries exist (i.e., Districts 2, 8, and 11) or where major interstate truck movements occur (Districts 6 and 7). District 6 forms part of the San Joaquin Valley (refer to discussions in Sections 5 and 6).

A similar picture emerges from Figure 4.5, with the most highly populated metropolitan counties showing the highest traffic volumes (i.e., Los Angeles, Orange, and Ventura) while counties with major interstate truck routes or cross-border truck traffic showed higher percentage trucks on the routes (i.e., Kern, Madera, Modesto, and Trinity).

Table 4.3: 2010 Truck Count Data Example *(19)*

Route	District	County	Postmile	AADT Total	Total Trucks	Total Truck Percent	2 Axle Volume	2 Axle Percent	3 Axle Volume	3 Axle Percent	4 Axle Volume	4 Axle Percent	5 Axle Volume	5 Axle Percent	Year Verified/ Estimate
1	12	ORA	0.129	37,000	2,301	6.22	781	33.93	1,089	47.32	308	13.39	123	5.36	03E
1	12	ORA	0.78	39,000	1,899	4.87	644	33.93	899	47.32	254	13.39	102	5.36	03E
1	12	ORA	9.418	40,000	696	1.74	272	39.08	320	45.98	64	9.2	40	5.75	03E

Table 4.4: Summarized Analysis of Truck Count Data per District *(19)*

District	AADT Total	Total Trucks	Total Truck Percent	2 Axle/Class 5		3 Axle/Class 6		4 Axle/Classes 7 and 8		5 Axle/Classes 9 and 11	
				Volume	Percent	Volume	Percent	Volume	Percent	Volume	Percent
1	1,135,860	101,876	9	46,237	45	14,475	14	5,603	5	35,207	35
2	3,662,370	540,168	15	52,913	10	33,515	6	13,907	3	416,907	77
3	12,481,183	980,516	8	334,299	34	93,000	9	45,644	5	504,006	51
4	43,707,890	1,925,535	4	850,496	44	222,646	12	72,584	4	850,374	44
5	6,270,340	478,600	8	201,503	42	46,750	10	21,406	4	195,688	41
6	8,250,955	1,417,304	17	423,796	30	94,751	7	52,977	4	816,238	58
7	56,002,040	3,283,835	6	1,301,599	40	360,991	11	125,496	4	1,428,555	44
8	21,450,950	2,351,222	11	819,266	35	182,365	8	78,184	3	1,271,394	54
9	201,825	18,334	9	5,886	32	1,778	10	917	5	9,752	53
10	6,412,135	944,602	15	194,754	21	87,701	9	30,713	3	619,819	66
11	17,715,618	940,633	5	498,081	53	95,452	10	36,021	4	304,845	32
12	19,297,800	1,057,294	5	526,137	50	102,220	10	49,109	5	342,897	32
Total	196,588,966	14,039,919	7	5,254,967	37	1,335,644	10	532,561	4	6,795,682	48

The breakdown of data in Table 4.4 indicates that 48 percent of the trucks on these routes are 5 axle (FHWA Class 9 and 11) trucks, with 2 axle (FHWA Class 5) trucks making up the second highest percentage of all trucks. Three and 4 axle trucks (FHWA classes 6, 7, and 8) comprise only around 14 percent of the trucks on all routes. Once a selection is made about the specific routes to be used for the remaining analyses in this project, this data will be analyzed in more detail for the specific districts and counties involved, as there are minor differences in the distribution of the four main types of vehicles for the different districts.

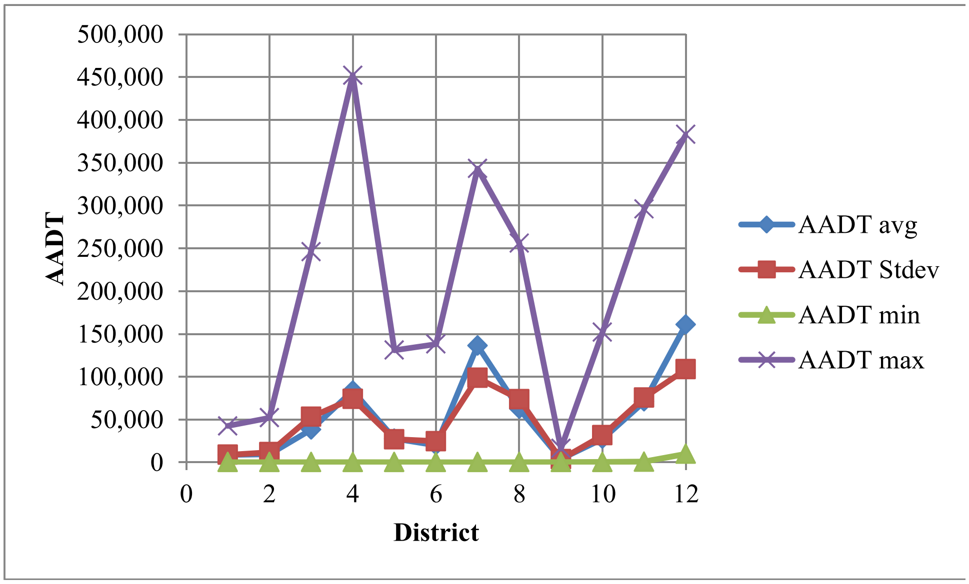

Figure 4.3: Average annual daily traffic (AADT) data for 12 Caltrans districts.

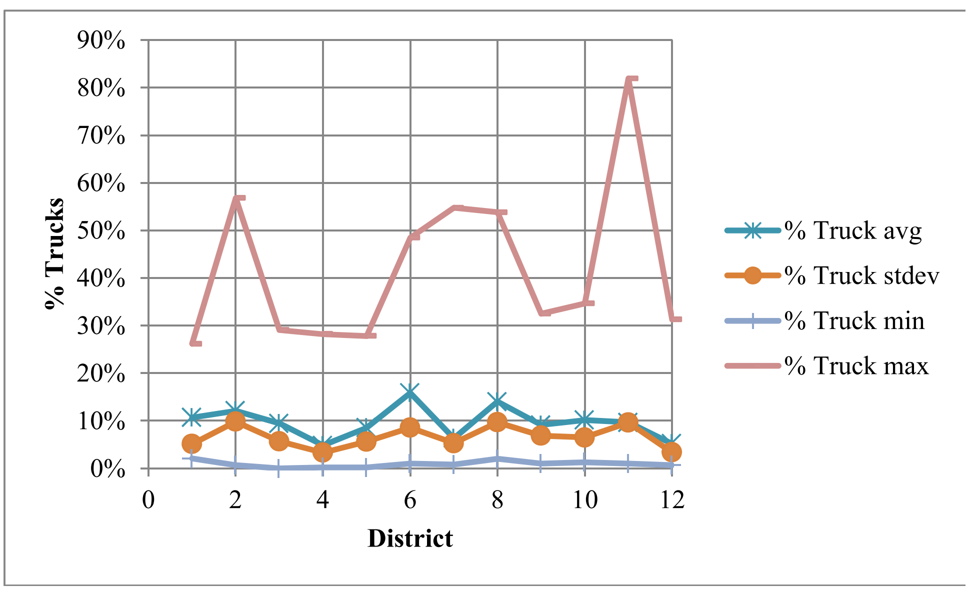

Figure 4.4: Percentage trucks data for 12 Caltrans districts.

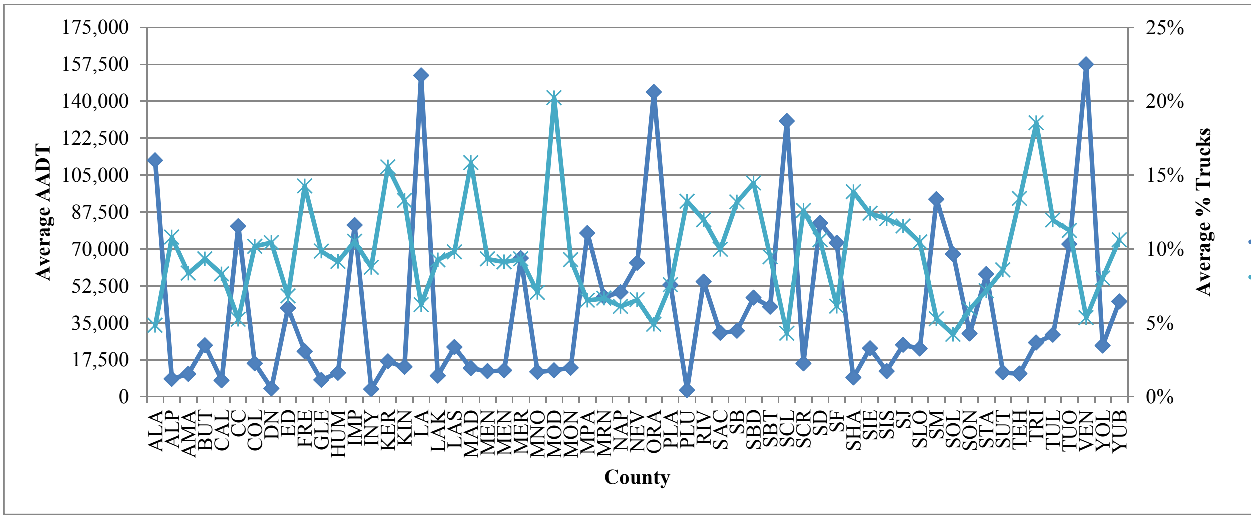

Figure 4.5: AADT and percentage trucks data for Caltrans counties (◆=AADT; × = % Trucks).

4.3.4 Truck Traffic Analysis Using WIM Data in California

Lu et al. *(20)* analyzed weigh-in-motion (WIM) data for the decade 1991–2001. In lieu of a more recent updated version of this report, the information originating from this report was used to obtain an indication of the truck traffic trends in California. A preliminary comparison between these data and the latest data on the WIM database (not analyzed in the same manner) indicates that similar trends exist in the latest data. Data from the latest WIM measurements will be verified when a specific corridor has been selected for this pilot study. Figure 4.6 shows the location of WIM stations in California. Table 4.5 shows the basic information for each WIM station in California.

Table 4.5: Summary of Basic Information for Each WIM Station in California (*20*)

Station Number	Location Information					WIM System	Lane Configuration	
	Name	District	County	Route	Postmile		Number of Lanes	Direction
1	Lodi	10	San Joaquin	5	43.7	DAW 200	4	N2N1S1S2
2	Redding	2	Shasta	5	R24.9	DAW 200 (7/99)	4	S2S1N1N2
						IRD (7/99–present)	4	N2N1S1S2
3	Antelope	3	Sacramento	80	15	DAW 200 (8/95)	4	W4W3W2W1
	Antelope (EB) After 95					IRD (8/95–present)	4	E4E3E2E1
4	Antelope (WB) After 98	3	Sacramento	80	17.2	IRD	4	W4W3W2W1

Conclusions from the WIM analysis *(20)* that are of importance to this report are as follows:

- Across all truck types operating in California (legal load limit for single axle loads is 20 kip [89 kN], legal limit for tandem axle loads is 34 kip [151 kN]):
    - A small portion of the axle loads are over the legal limit.
    - Nearly all steering axle loads are less than 20 kip (90 kN).
    - Nearly all single axle loads are less than 24.7 kip (110 kN).
    - Nearly all tandem axle loads are less than 47.2 kip (210 kN).
    - Nearly all tridem axle loads are less than 58.4 kip (260 kN).
- All four axle types had a bimodal pattern of load spectra (distribution of loads). For tandem axles, the bimodal pattern is due to the empty and full load status of Truck Type 9 (the predominant truck type, consisting of a tractor with a tandem axle and a single semitrailer with a tandem axle [3S2]). For the other three axle types, the bimodal pattern is caused by the different load levels associated with the various truck types.
- Axle load spectra are heavier (heavier axle loads) at night than in the daytime. Two possible reasons for this are (1) it is more efficient to carry heavier loads when car traffic is lighter and (2) heavier, potentially overloaded trucks operate more at night when more Highway Patrol load enforcement stations are closed.
- Axle load spectra and truck type distribution show very little seasonal variation. This contradicts the assumption that truck loads are significantly influenced by agricultural hauling during the harvest season.
- Axle load spectra are much higher (heavier axle loads) in the Central Valley than in the Bay Area and Southern California, particularly for tandem axles. Axle load spectra are similar between the Bay Area and Southern California.
- The predominant truck types across the state are Truck Type 9, accounting for 49 percent of all trucks, and Truck Type 5 (2-axle truck with dual tires at the back [2D]), accounting for 23 percent of all trucks. Truck Type 11 (tractor with single axle, one semitrailer with a single axle and another trailer with single axles [2S12]) accounted for 8 percent of all trucks, and the rest of the truck types together accounted for the remaining 20 percent of all trucks.

Data from a set of six WIM sites selected to represent different combinations of direction, region (Bay Area, Central Valley, and Southern California), and urban versus rural indicated that:

- Steering axle load spectra were similar across all six stations.
- Axle load spectra for other axle types varied considerably across the six stations.
- Axle load spectra were similar for both directions.
- Axle load spectra were much heavier in the outside lanes.

- Axle load spectra for steering and single axles remained fairly constant across the years. Axle load spectra for tandem and tridem axles exhibited yearly variation.
- The right-side (outside) ends of each axle were heavier on average than the left-side ends, which can probably be attributed to the transverse slope of most facilities. The difference was typically less than 3 percent on average.
- For facilities with two lanes in each direction, more than 90 percent of the truck traffic traveled in the outside lane. For facilities with three or more lanes in each direction, more than 90 percent of the truck traffic traveled in the two outside lanes.
- All six sites showed growth of average annual daily truck traffic (AADTT), with growth rates ranging between 2 and 5 percent.
- The growth rates for different truck types varied considerably.
- Truck speeds typically fall within the range of 50–75 mph (80–120 km/h).

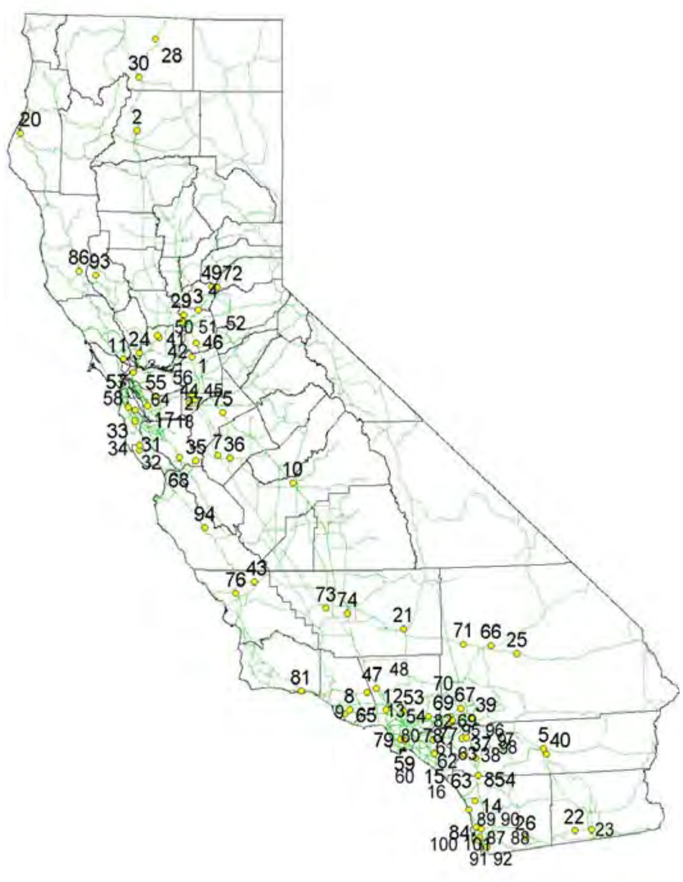

Figure 4.6: Distribution of WIM stations on California state highway network in March 2001.

4.3.5 Truck Route List

A truck route list was obtained from the Caltrans website (Office of Truck Services) *(17)*. It provides information on typical truck routes followed in California; the type of details are shown in Table 4.6. The data provide the standard origin and destination information for each of the routes, as well as information on restrictions for the specific routes. A summary of these restrictions is provided in Table 4.7.

4.3.6 Truck Tire and Suspension Use

In order for the analyses in Task 7 to be conducted it is important to know the type of tires and suspension used by trucks on the various routes. Although a detailed evaluation will be conducted once a final corridor and trucks are selected for the Task 8 measurements, a preliminary evaluation of the dominant tire and suspension types was conducted.

No recent California-specific data could be identified on this topic, however, a 2004 report originating from Texas focused on current truck configurations on Texas highways. As the truck population in the United States is relatively homogeneous, the data collected and summarized in this report are used as a preliminary indication of these dominant factors *(21)*.

It was found, based on a sample of 623 trucks with 9,600 tires, that:

- The overall average tire inflation pressure was 96.75 psi (667 kPa) with a standard deviation of 15.03 psi (103.6 kPa).
- 295-75R22.5 (25.7 percent), 11R24.5 (21.8 percent), 11R22.5 (17.3 percent), and 285-75R24.5 (15.4 percent) were the four most popular tire sizes found in the sampled trucks.
- 11R24.5 (24.1 percent) was the most popular tire size on front (steering) axles.
- 295-75R22.5 (26.2 percent) was the most popular nonfront tire.
- Very few wide-base tires were noted.
- Leaf springs were predominantly used in steering axles (98 percent).
- Drive axles mostly used air suspension (72 percent).
- Trailer axles used mostly leaf suspension (66 percent).

Incidentally, the most common truck class was 3-S2 (80.3 percent), which is classified as STAA (or FWHA Class 9) trucks. These trucks were also dominant in the California surveys (Table 4.4).

Table 4.6: Example Data from Truck Route List.xlsx

Route	District	County	Begin Postmile	End Postmile	Segment Miles	Special Restriction/ Type	Begin Location	End Location	Comment
1	12	ORA	0.129	33.719	33.740		Junction 5	Orange–Los Angeles County Line	
1	7	LA	0.000	34.576	34.516		Pacific Coast Highway	Lincoln Blvd. at I10 overcrossing in Santa Monica	
1	7	LA	34.576	40.769	6.157		Lincoln Blvd. at I-10 overcrossing in Santa Monica	Topanga Canyon Blvd.	
1	7	LA	40.769	62.867	22.098	R/1	Topanga Canyon Blvd.	Los Angeles–Ventura County Line	No through trucks with 4 or more axles. (Otherwise, CL-40.)
1	7	VEN	0.000	10.229	10.229	R/1	Los Angeles–Ventura County Line	Las Posas Rd.	No through trucks with 4 or more axles. (Otherwise, CL-40.)
1	7	VEN	10.229	21.075	10.846		Las Posas Rd.	Begin Route Break—S. Junction 101 in Oxnard	Route break for 9.633 miles along 101; PM Equation: 21.075 = 21.250

Table 4.7: Summary of Typical Advisories and Restrictions on Caltrans Network

Kingpin-to–Rear Axle (KPRA) Advisories	
38	KPRA over 38 ft not advised
36	KPRA over 36 ft not advised
34	KPRA over 34 ft not advised
32	KPRA over 32 ft not advised
30	KPRA over 30 ft not advised
<30	KPRA advised for the route is less than 30 ft, but is posted as 30 ft
Special Restrictions	
1	Number of axles
2	Weight
3	Length
4	Turns, widths, other
5	Hazardous materials

4.4 Task 4 Outcome

The objective of Task 4 is to develop an inventory of current California vehicle population. For this purpose information was sourced from various statewide sources. The outcome of Task 4 is:

A table of current vehicle population by standard FHWA vehicle classification. These data are summarized in Table 4.4.

The data identified and collected for Task 3 will be used in combination with the data obtained in Tasks 4–5 in the analyses discussed in Task 5.

5 TASK 5 PROGRESS—INFORMATION REVIEW

5.1 Introduction

This section contains information on the progress with Task 5—Research/review available information resources. Work on the task started in February 2012 and the first draft is completed. Once the inputs of the client have been obtained on the current (first draft) version, the information will be updated and a final output prepared.

5.2 Task 5 Progress

Task 5 focuses on evaluating the data obtained from the various resources for Tasks 3–4, as well as additional relevant information that may add to the project. Potential sources include pavement condition survey (PCS) and new Pavement Management System (PMS) data, State of Logistics studies, rolling resistance studies (MIRIAM project), and various California-specific studies and models (e.g., Statewide Freight Model, Heavy-Duty Truck Model [SCAG]), as well as related U.S./California studies into V-PI and ride quality.

The deliverable of Task 5 is a detailed understanding and input to the progress report on the available data sources and required analyses for the project, inclusive of indications of the potential links between the outputs from this project and the inputs for the various economic and planning models. Final selection of an appropriate route covering a range of ride qualities and speeds within the selected region/district for potential truck measurements will be made by Caltrans after evaluation of all relevant information.

5.3 Task 5 Information Resources

The following information sources have been identified for Task 5, in addition to the sources discussed in Sections 3 and 4.

A schematic indication of the way the various transportation models relate to each other is shown in Figure 5.1. Each of the separate models is discussed in this section as an information source, before an analysis is conducted using all the available information.

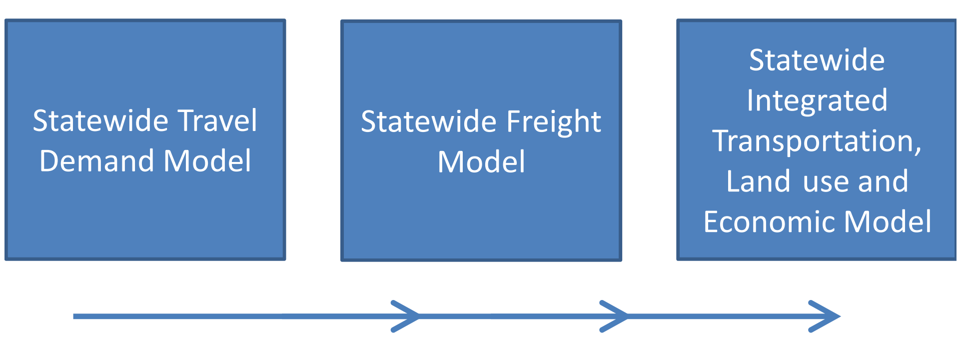

Figure 5.1: Schematic of how the various transportation models are being developed

5.3.1 California Statewide Freight Planning

The Caltrans Division of Transportation Systems Information (TSI) houses the Statewide Freight Planning group. The California Statewide Freight Forecast (CSFF) model supports the need for a statewide, commodity-based, policy-sensitive and freight infrastructure–based transportation model. The California Statewide Travel Demand Model (CSTDM) and various freight models (e.g., the SCAG) existed before development of the CSFF model. The purpose of the CSFF model is to provide a policy-sensitive model to forecast commodity flows and commercial vehicle flows within California, addressing socioeconomic conditions, land-use policies related to freight, environmental policies, and multimodal infrastructure investments. The model development project has a two-year timeline and it is due for completion by June 2013. Due to the anticipated completion date for the CSFF model, it will not affect the pilot study, but may affect the potential implementation of the findings of the pilot study.

The CSFF has been developed in three phases. The first phase focused on development of a Freight Data Repository that included compilation of 16 different publicly available freight data sources http://moon.its.uci.edu/calfred/). The second phase focused on developing a conceptual framework for the Statewide Freight Model and consisted of developing the scope, time, and cost for full construction of the freight model. The third phase started in October 2011 and focuses on the construction of the Statewide Freight Model. It is developed (as the other phases of the project) by UC Irvine and planned to be completed by June 2013.

5.3.2 Commodity Flow Survey

Section 4.3.3 stated that the Commodity Flow Survey report provides statistics of national and state-level data on domestic freight shipments by American establishments in mining, manufacturing, wholesale, auxiliaries, and selected retail industries originating in California. (Data on flow originating from others states are also available, but this report focuses on California.) Data are provided on the types, origins, values, weights, modes of transport, distance shipped, and ton-miles of commodities shipped. It is a shipper-based survey conducted every five years as part of the Economic Census *(19)*. Various types of data relevant to this study were obtained from this report. In this section the focus is on shipment data. No specific information for commodity flows into California (destination California) could be identified in this pilot study.

Shipment Characteristics by Mode of Transportation

Shipment characteristics by mode of transportation for freight trips originating in California is shown in Table 5.1. It is evident that truck-based transportation dominates the freight transportation scene in the state. The data in each of the columns are combinations of the different modes of transportation and do not necessarily add up to 100 percent in each case.

It is also noted that 82 percent of the tons shipped from California utilize only trucks and do not make use of truck-rail or other modal combinations. This is significant, as it implies that freight is not transferred between modes. However, freight may still be transferred between different trucks. In the notes to Table 5.1 it is clear that this 82 percent includes for-hire and private truck combinations. Truck as a single mode also accounts for 66.7 percent of the monetary value of outgoing shipments and 72.6 percent of the total ton-miles, making this mode by far the most impactful mode of transport in terms of physical traffic, freight flow, and economic impact. A ton-mile is one ton of freight transported over one mile. The more ton-miles incurred by a shipment, the more that shipment is subjected to V-PI and the higher the probability of freight damage.

It is interesting to note that the road-rail split for freight shipped from California is similar to the road-rail split for land freight in South Africa. In 2010, 70.2 percent of the ton-miles incurred by land freight movement (i.e., excluding air and coastal shipping) in South Africa were by road, while 29.8 percent was by rail *(22)*. Table 5.1 shows that 72.6 percent of the ton-miles traveled by freight shipped from California is by road, while 9.2 percent is rail-only, and 6.7 percent uses a road-rail (intermodal) combination. These figures are not exactly comparable, but a mention of the underlying logistics trends is worthwhile.

In South Africa, service unreliability and cost and time inefficiencies in the rail environment are commonly cited as reasons why truck transport is preferred over rail transport, even for “rail-friendly ” freight. The current road-rail split in South Africa is a cause of great concern from a transport vulnerability and sustainability point of view—especially in light of recent oil-price volatility. The reasons for the road-rail split of outgoing freight in California may very well be different from the South African situation. One reason could be a lack of capacity in the rail western rail system. However, given that shipments leaving California are either being exported by sea (as bulk or loaded in intermodal containers) or traveling across the vast interior of the United States, it does seem intuitive that more freight should travel by rail. Another restriction to intermodal transportation (truck-rail combinations) could be industry reluctance to using intermodal containers for domestic freight.

Comparing the statistics of for-hire trucks and private trucks it is observed that although more tons are carried on private trucks, the ton-miles accrued to for-hire trucks far outweigh that of private trucks. Similarly, the average miles per shipment are 962 for for-hire trucks and only 47 for private trucks. This suggests that for-hire trucks are used for long-haul transportation while private fleets are mainly used for local distribution, which is intuitive.

It is important to note that Table 5.1 only lists statistics for shipments that originate in California. These shipments could be destined for in-state locations or exported to other states or countries. The table does not account for shipments that originate outside of California but are destined for locations inside California. Thus the statistics do not give an overall view of all freight shipments in California.

Commodity Characteristics of Shipments

Table 5.2 classifies California shipments according to North American Industry Classification System (NAICS) codes for all types of trucks. Table 5.2 again only focuses on shipments originating from California and thus is not an accurate reflection of all shipments traveling in the state. The data indicate that the highest percentage of commodities (in terms of value, tons, and ton-miles) transported by truck are manufacturing goods, wholesale trade. and nondurable goods for the whole of California. These percentages will differ for specific counties and districts, but this detail is not available from the source.

Table 5.1: Summarized Shipment Characteristics by Mode of Transportation for State of Origin−California *(23)*

Mode of Transportation	2007 Value		2007 Tons		2007 Ton-Miles[a]		Average Miles per Shipment
	Million $	Percent of Total	Thousands	Percent of Total	Millions	Percent of Total	
All modes	1,341,220	100	900,817	100	180,976	100	975
Single modes	1,017,796	75.9	848,278	94.2	152,625	84.3	408
Truck[b]	893,972	66.7	738,550	82	131,440	72.6	361
For-hire truck	501,681	37.4	308,940	34.3	106,747	59	962
Private truck	392,291	29.2	429,610	47.7	24,693	13.6	47
Rail	15,202	1.1	22,101	2.5	16,641	9.2	832
Water	2,787	0.2	S	S	673	0.4	1,882
Shallow draft	2,574	0.2	S	S	475	0.3	S
Deep draft	214	–	S	S	198	0.1	2,331
Air (including truck and air)	48,014	3.6	906	0.1	1,543	0.9	1,801
Pipeline[c]	57,820	4.3	80,403	8.9	S	S	S
Multiple modes	294,387	21.9	27,161	3	23,132	12.8	1,447
Parcel, USPS, or courier	268,455	20	5,213	0.6	6,030	3.3	1,447
Truck and rail	13,039	1	8,854	1	12,179	6.7	1,284
Truck and water	S	S	S	S	4,605	2.5	1,726
Rail and water	S	S	S	S	133	0.1	1,458
Other multiple modes	S	S	S	S	185	0.1	S
Other and unknown modes	29,037	2.2	25,378	2.8	5,219	2.9	106

KEY: S = Estimate does not meet publication standards because of high sampling variability or poor response quality. – = Zero or less than half the unit shown; thus, it has been rounded to zero.

[a] Ton-miles estimates are based on estimated distances traveled along a modeled transportation network.

[b] "Truck" as a single mode includes shipments that were made by only private truck, only for-hire truck, or a combination of private truck and for-hire truck.

[c] Estimates for pipeline exclude shipments of crude petroleum.

Notes: Rows are not shown if all cells for that particular row have no values. For example, specific state by mode rows are not shown in this table because there are no data for those rows. Value-of-shipment estimates are reported in current prices. More information on sampling error, confidentiality protection, nonsampling error, sample design, and definitions may be found at *http://www.bts.gov/cfs*.

Table 5.2:Summary of Freight Descriptions (for NAICS Industries) Transported in 2007−All Trucks

NAICS Description	2007 Value		2007 Tons		2007 Ton-Miles	
(All Truck Types)	Million $	Percent	Thousands	Percent	Millions	Percent
Apparel manufacturing	5,480	0.1	42	0.0	2	0.0
Apparel, piece goods, and notions merchant wholesalers	22,170	0.5	2,829	0.1	2,264	0.3
Beer, wine, and distilled alcoholic beverage merchant wholesalers	28,586	0.7	13,228	0.4	549	0.1
Beverage and tobacco product manufacturing	27,585	0.7	31,145	1.0	6,712	0.9
Chemical and allied products merchant wholesalers	18,984	0.5	13,518	0.4	5,794	0.8
Chemical manufacturing	55,940	1.4	40,106	1.3	27,406	3.8
Commercial equipment merchant wholesalers	47,521	1.2	4,010	0.1	1,262	0.2
Computer and electronic product manufacturing	51,951	1.3	860	0.0	641	0.1
Corporate, subsidiary, and regional managing offices	45,194	1.1	26,127	0.8	12,458	1.7
Drugs and druggists' sundries merchant wholesalers	50,484	1.2	3,784	0.1	2,102	0.3
Electrical and electronic goods merchant wholesalers	48,376	1.2	4,347	0.1	1,676	0.2
Electrical equipment, appliance, and component manufacturing	18,342	0.4	3,086	0.1	4,622	0.6
Electronic shopping and mail-order houses	5,994	0.1	796	0.0	350	0.0
Fabricated metal product manufacturing	41,104	1.0	9,368	0.3	5,844	0.8
Farm product raw material merchant wholesalers	7,038	0.2	11,234	0.4	3,869	0.5
Food manufacturing	126,075	3.1	98,744	3.1	50,840	7.1
Fuel dealers	388	0.0	450	0.0	14	0.0
Furniture and home furnishing merchant wholesalers	13,618	0.3	4,892	0.2	2,251	0.3
Furniture and related product manufacturing	18,332	0.4	5,293	0.2	3,897	0.5
Grocery and related product merchant wholesalers	139,840	3.4	81,965	2.6	18,519	2.6
Hardware and plumbing merchant wholesalers	20,582	0.5	3,568	0.1	936	0.1
Leather and allied product manufacturing	595	0.0	147	0.0	272	0.0
Lumber and other construction materials merchant wholesalers	27,982	0.7	37,057	1.2	5,808	0.8
Machinery manufacturing	36,263	0.9	3,469	0.1	4,844	0.7
Machinery, equipment, and supplies merchant wholesalers	40,420	1.0	10,639	0.3	4,510	0.6
Manufacturing	621,991	15.2	599,374	18.9	186,600	26.2
Merchant wholesalers, durable goods	394,593	9.6	275,942	8.7	47,569	6.7
Merchant wholesalers, nondurable goods	472,374	11.5	344,614	10.9	59,567	8.4
Metal and mineral (except petroleum) merchant wholesalers	23,154	0.6	11,111	0.3	2,337	0.3
Mining (except oil and gas)	5,889	0.1	214,304	6.7	12,413	1.7
Miscellaneous durable goods merchant wholesalers	44,024	1.1	14,195	0.4	19,613	2.8
Miscellaneous manufacturing	14,472	0.4	1,276	0.0	2,044	0.3
Miscellaneous nondurable goods merchant wholesalers	36,103	0.9	37,093	1.2	6,808	1.0
Motor vehicle and parts merchant wholesalers	126,943	3.1	4,720	0.1	3,225	0.5
Newspaper, periodical, book, and directory publishers	3,805	0.1	2,406	0.1	662	0.1
Nonmetallic mineral product manufacturing	24,838	0.6	193,329	6.1	15,498	2.2

NAICS Description (All Truck Types)	2007 Value		2007 Tons		2007 Ton-Miles	
	Million $	**Percent**	**Thousands**	**Percent**	**Millions**	**Percent**
Paper and paper product merchant wholesalers	20,566	0.5	10,055	0.3	1,686	0.2
Paper manufacturing	28,832	0.7	23,673	0.7	17,247	2.4
Petroleum and coal products manufacturing	25,735	0.6	128,243	4.0	6,569	0.9
Petroleum and petroleum products merchant wholesalers	143,813	3.5	169,460	5.3	7,532	1.1
Plastics and rubber products manufacturing	31,850	0.8	12,527	0.4	9,099	1.3
Primary metal manufacturing	20,823	0.5	10,908	0.3	8,327	1.2
Printing and related support activities	11,993	0.3	5,004	0.2	3,418	0.5
Textile mills	3,986	0.1	828	0.0	924	0.1
Textile product mills	4,737	0.1	704	0.0	851	0.1
Transportation equipment manufacturing	48,927	1.2	4,648	0.1	7,056	1.0
Warehousing and storage	201,827	4.9	52,599	1.7	9,873	1.4
Wholesale trade	866,966	21.2	623,157	19.6	106,672	15.0
Wood product manufacturing	14,945	0.4	24,425	0.8	10,107	1.4
Total	4,092,030		3,175,299		713,139	

5.3.3 San Joaquin Valley Information

The San Joaquin Valley is composed of eight counties, (Kern, Kings, Tulare, Fresno, Madera, Merced, Stanislaus, and San Joaquin) and 62 cities, of which Fresno, Bakersfield, Modesto, and Stockton have populations in excess of 200,000. It has a diverse internal economy and also plays a major role in the distribution of agricultural materials throughout California, the United States, and the world.

Goods movement in the San Joaquin Valley depends on truck, rail, water, and air cargo transportation modes. Of these, trucks are the dominant mode choice, with more than 450 million tons of goods moved by truck into, out of, or within the San Joaquin Valley in 2007—more than 85 percent of all tonnage associated with these types of moves in the San Joaquin Valley. Understanding the character of truck goods movement activities is essential to goods movement studies, as the impact of freight moving over the transportation system, and potential improvements to efficiency and safety, should be considered when making system infrastructure investment decisions *(24)*.

Caltrans and the eight San Joaquin Valley Regional Planning Agencies are developing the San Joaquin Valley Interregional Goods Movement Plan (SJVIGMP) which aims to create a prioritized goods movement investment plan for the multimodal infrastructure of the entire San Joaquin Valley. The project creates a blueprint for future investment into the region's goods movement system and also aims to:

- Co-operate with regional freight stakeholders to understand issues, challenges, limitations, and opportunities of the San Joaquin Valley's multimodal goods movement system.
- Assess supply chain and logistics trends and their impacts on future goods movement.
- Create a prioritized investment plan of project improvements and strategies to increase the efficiency and reliability of the region's goods movement system.
- Contribute to the valley's economic development, industries, and environmental health *(25)*.

Truck movement (the primary freight infrastructure for the region) in the San Joaquin Valley relies on a combination of all levels of highways and roads in the area. Key regional highways (Figure 5.2) include the primary north-south corridors (I--5 and SR 99) and east-west corridors (I-580, SR 152, SR 41, SR 46, and SR 58) and in total constitute more than 31,000 lane-miles. There are more than 2,700 miles of truck routes in the San Joaquin Valley region, with over 80 percent designated STAA National Truck Routes. In recent years, however, new clusters of industries have been developing along regional roads not intended for heavy truck traffic—accelerating pavement deterioration and raising safety concerns. SR 99, I-5, and SR 58 each carry around 50,000 vehicles per day, of which more than 20 percent consists of truck traffic.

According to the FHWA's Freight Analysis Framework (FAF3) routing tool, the main highway corridors used for truck movements are I-5, SR 99, and I-580 to 205, with all these corridors carrying volumes in excess of 10 million annual tons. Truck volumes moving on key truck route corridors in the San Joaquin Valley are shown in Table 5.3; I-5 and SR 99 carry the highest overall truck volumes *(24)*.

Fifty-three percent of the freight moved by truck into, out of, and within the San Joaquin Valley in 2007 was classified as internal moves, with around 23 percent shipped outbound and 24 percent shipped inbound to the San Joaquin Valley (Figure 5.3). The internal commodity flows demonstrate the interconnectedness of the valley's supply chain, with products being shipped by truck within the region for further processing, consolidation, and then distribution to other regions *(24)*.

Farm products are the dominant commodity carried outbound from the San Joaquin Valley, comprising 33 percent of the total outbound movements (Figure 5.4). They consist of fresh field crops (vegetables, fruit and nuts, cereal grains, and animal feed). Stone and aggregates account for 18 percent of the total; food and tobacco products around 10 percent; and waste and mixed freight, 6 percent and 4 percent of the total tonnage, respectively.

Figure 5.2: Key regional truck routes in the San Joaquin Valley *(24).*

Table 5.3: Major Highway Corridors and Proportion of Truck Traffic, San Joaquin Valley *(24)*

Facility Type	Route Number	County	Maximum AADT	Truck AADT	Truck Percent	Facility Type	Route Number
Interstate	5	San Joaquin, Merced, Fresno, Kern	152,000	39,500	26	Interstate	5
State route	58	Kern	70,000	17,500	25	State route	58
State route	99	All San Joaquin Valley	132,000	27,700	21	State route	99
State route	119	Kern	12,500	2,600	21	State route	119
State route	46	Kern	10,500	2,000	19	State route	46
State route	190	Tulare	23,100	4,200	18	State route	190
Interstate	580	San Joaquin	32,000	5,800	18	Interstate	580
State route	33	Merced, Fresno, Kern	11,800	1,700	14	State route	33
State route	43	Fresno, Kings, Kern	18,500	2,600	14	State route	43
State route	201	Fresno	17,600	2,500	14	State route	201
State route	4	San Joaquin	89,000	11,600	13	State route	4
State route	137	Tulare	25,000	3,000	12	State route	137
Interstate	205	San Joaquin	105,000	12,600	12	Interstate	205
State route	132	San Joaquin, Stanislaus	19,200	1,900	10	State route	132
State route	145	Madera, Fresno	19,100	1,900	10	State route	145
State route	12	San Joaquin	35,000	3,200	9	State route	12
State route	65	Tulare, Kern	24,700	2,200	9	State route	65
State route	152	Merced, Madera	33,500	3,000	9	State route	152
State route	196	Kings, Tulare	61,000	5,500	9	State route	196
State route	219	Stanislaus	14,200	1,300	9	State route	219

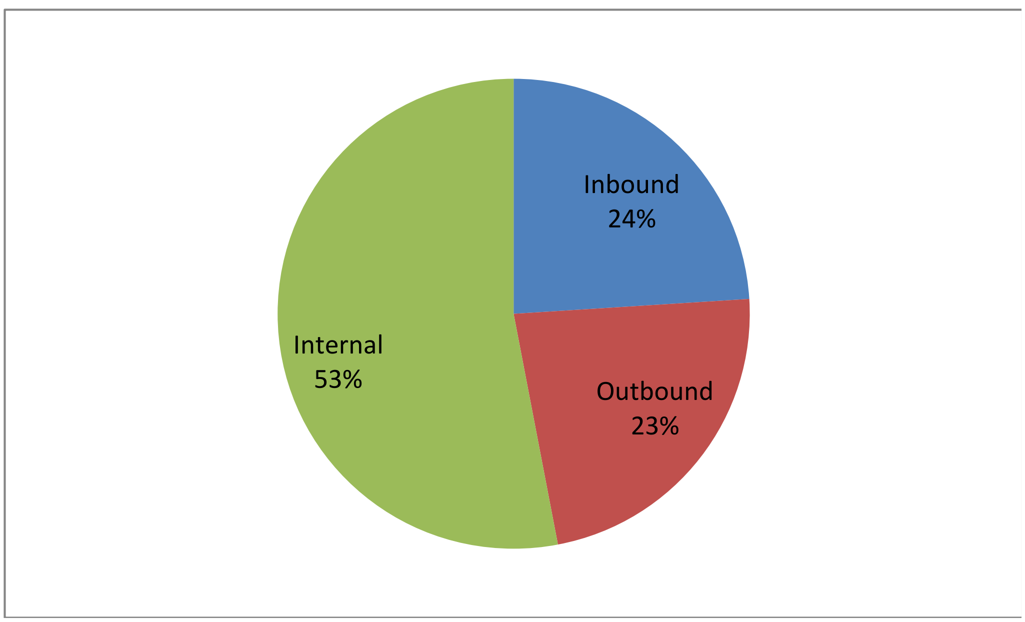

Figure 5.3: Inbound, outbound, and internal commodity distribution, 2007 *(24)*.

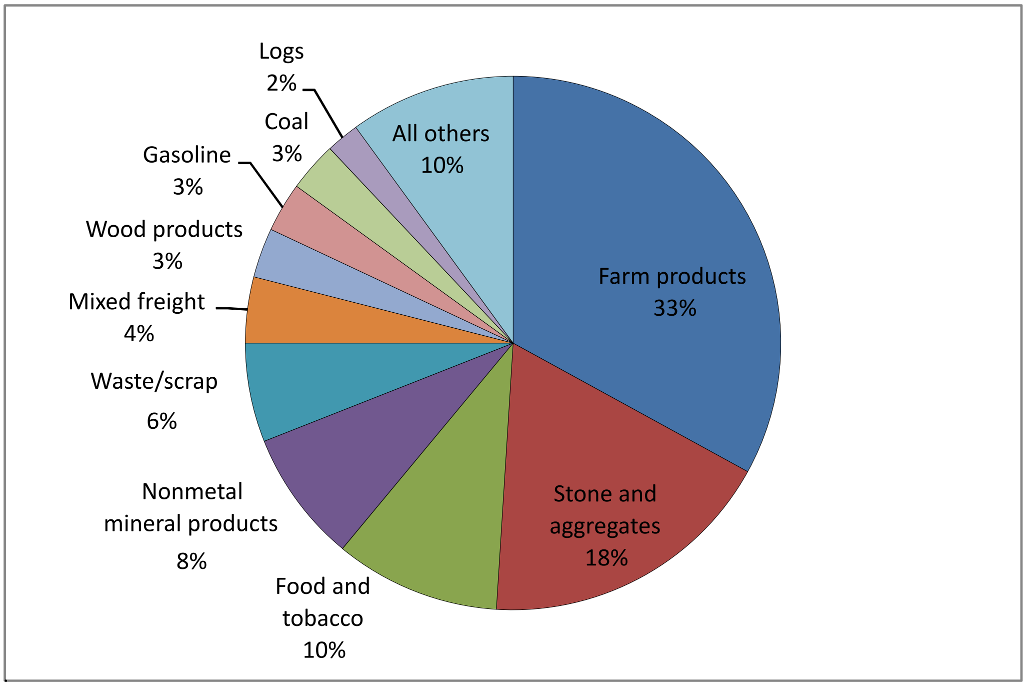

Figure 5.4: Outbound commodities from the San Joaquin Valley *(24)*

Agricultural commodities accounts for more than 30 percent of the inbound freight flow (Figure 5.5), with a more equal distribution among the remaining inbound commodities than for outbound commodities.

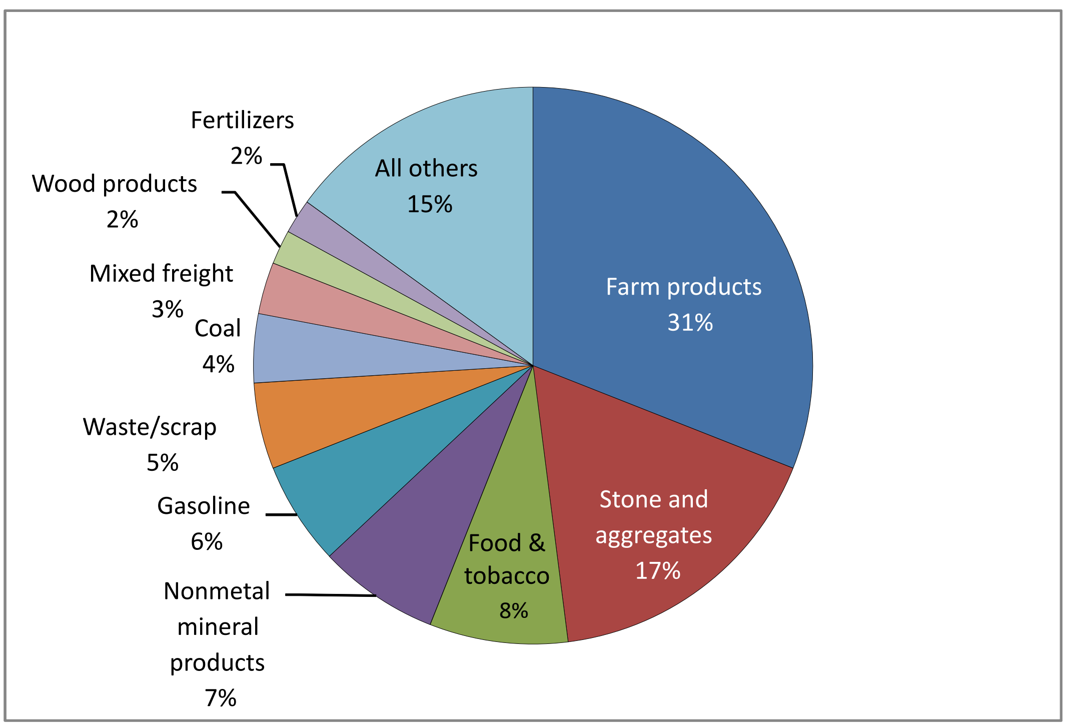

Figure 5.5: Inbound commodities from the San Joaquin Valley *(24).*

Outbound and inbound commodity movements from each of the eight San Joaquin Valley counties are summarized in Table 5.4 and Table 5.5, respectively. Farm products constitute the majority of both inbound and outbound freight flows in all but Kern County, where a large proportion of inbound and outbound truck flows constitute movement of construction stone and aggregates. Mixed freight (including packaged food products) is also a dominant commodity, testifying to the growing importance of warehousing and distribution operations throughout the San Joaquin Valley.

For many origins and destinations in the San Joaquin Valley region, the highway system as presently constituted provides only one or two options for truck drivers. Therefore, any congestion on the network creates severe challenges to the movement of trucks on the system. Heavy congestion is typically experienced on SR 99, affecting a major goods movement corridor in the state. Several segments operate at Level of Service (LOS) E or F, with the majority of the remainder of the corridor operating at LOS C or D. Continued deterioration is expected with continued growth on SR 99. The wide ranges of LOS may also cause wider speed profiles to be experienced on some of these routes *(24)*.

The population of the San Joaquin Valley has grown over 20 percent since 2000, gaining nearly 700,000 residents. It is expected that the region will more than double in population by 2040, accompanied by increased activity in certain goods movement-dependent industries, such as construction, retail, and wholesale trade. These trends will create pressure on the transportation system, as well as contribute to increasing congestion, emissions, and air quality concerns. Forty-four percent of the roughly 1.2 million people employed across all sectors in the San Joaquin Valley are associated with goods movement-dependent industries, including agriculture (187,000), wholesale and retail trade (170,000), manufacturing (102,000), and transportation and utilities (48,000). The region accounts for over 8 percent of the total gross domestic product (GDP) for California and provides nearly 50 percent of California's agricultural output ($13 billion) and 25 percent (over $5 billion) of California's total output for mining and mineral extraction *(24)*.

Table 5.4: Outbound Commodity Movements, by County (tons) *(24)*

Description	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	Total San Joaquin Valley
Farm products	16,239,285	10,493,976	3,536,695	2,979,494	5,618,971	15,720,402	12,041,855	8,830,275	75,460,953
Stone and aggregate	834,609	38,361,268	0	19,079	201,957	699,531	802,772	152,908	41,072,124
Food and tobacco	3,897,081	2,453,346	1,191,628	848,067	2,061,135	3,569,071	4,093,055	3,349,295	21,462,678
Nonmetal minerals	3,808,221	2,073,313	618,245	627,917	1,234,277	3,494,399	3,784,061	1,822,395	17,462,828
Waste/scrap	2,925,958	1,592,982	475,014	482,446	948,328	2,684,840	2,907,395	1,400,195	13,417,157
Mixed freight	1,848,447	1,577,796	97,945	119,336	385,849	3,093,817	1,040,549	1,194,550	9,358,288
Wood products	1,627,928	886,294	264,286	268,420	527,625	1,493,777	1,617,600	779,033	7,464,964
Gasoline	131,141	6,027,638	0	2,998	31,733	109,916	126,138	24,026	6,453,590
Coal	1,232,477	670,998	200,086	203,216	399,456	1,130,913	1,224,657	589,792	5,651,596
Logs	894,341	541,099	154,473	164,630	296,191	798,846	834,316	433,532	4,117,428
All others	4,289,493	7,743,664	571,560	589,970	1,140,595	3,726,903	3,613,521	1,836,301	23,512,007
Total	37,728,980	72,422,374	7,109,930	6,305,572	12,846,117	36,522,415	32,085,920	20,412,303	225,433,612

Table 5.5: Inbound Commodity Movements, by County (tons) *(24)*

Description	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare	Total San Joaquin Valley
Farm products	14,149,353	8,755,573	3,305,016	2,462,123	5,371,847	15,872,154	11,852,322	7,865,654	69,634,043
Stone and aggregate	797,379	36,650,061	0	18,228	192,948	668,327	766,962	146,087	39,239,991
Food and tobacco	3,498,791	2,169,435	1,013,931	740,837	1,770,656	3,204,992	3,652,661	2,858,513	18,909,816
Nonmetal minerals	3,547,218	1,931,215	575,872	584,882	1,149,683	3,254,904	3,524,714	1,697,494	16,265,982
Waste/scrap	256,551	11,791,906	0	5,865	62,080	215,030	246,765	47,002	12,625,198
Mixed freight	2,595,991	1,413,338	421,445	428,039	841,383	2,382,065	2,579,522	1,242,292	11,904,075
Wood products	1,908,707	1,039,170	309,888	314,736	618,644	1,751,419	1,896,598	913,410	8,752,572
Gasoline	1,100,306	939,199	58,303	71,036	229,680	1,841,626	619,397	711,068	5,570,615
Coal	1,396,143	986,675	127,501	140,417	250,381	1,104,475	875,119	512,640	5,393,350
Logs	1,074,272	651,011	146,570	123,826	290,368	902,180	813,219	456,346	4,457,791
All others	6,821,416	11,073,774	689,645	775,840	1,469,246	4,925,741	4,452,827	2,545,224	32,753,712
Total	37,146,128	77,401,356	6,648,170	5,665,828	12,246,917	36,122,912	31,280,105	18,995,731	225,507,146

A region's goods movement system reflects the industries and businesses that make up its economy. Industries that depend on the movement of goods rely on transportation as a key part of their business model. Such businesses may receive daily shipments of raw supplies to support their manufacturing process or daily delivery of refined or finished products to market. They include industries such as agriculture, manufacturing, wholesale trade, construction, transportation, warehousing, and mining sectors. These activities remain the foundation for many local area economies within the San Joaquin Valley region. Due largely to available land, historic development patterns, and access to infrastructure, certain goods movement–oriented businesses in the San Joaquin Valley, such as retail, manufacturing, and wholesale, tend to agglomerate in clusters along the major freight transportation corridors within the valley, such as SR 99. There also are large proportions of freight-oriented businesses concentrated near the urban centers of Fresno, Bakersfield, Visalia, and Stockton. For the agricultural industry, most crop production areas are more dispersed and located in rural areas, adding strain to smaller connector roads, such as county roadways *(26)*.

The GDP for goods movement–dependent industries in the San Joaquin Valley was about $56 billion in 2010. The industries that contribute the most to regional GDP include wholesale and retail trade ($14 billion, 26 percent of total), agriculture ($13 billion, 24 percent of total), and manufacturing ($12 billion, 21 percent of total). The region accounts for over 8 percent of the total GDP for California. However, the region accounts for a much higher proportion of output within sectors such as agriculture (nearly 50 percent) and mining and mineral extraction (25 percent). The San Joaquin Valley includes 6 of the top 10 counties in California for total value of agricultural production (Table 5.6).

Table 5.6: Top Agricultural Producing Counties in San Joaquin Valley *(26)*

State Rank	County	Crop Value (thousands)	Major Commodities
1	Fresno	$5,372,009	Grapes, tomatoes, poultry, almonds, cattle and calves
2	Tulare	$4,046,355	Milk, oranges, grapes, cattle and calves, corn
4	Kern	$3,606,356	Grapes, milk, vegetables, almonds, pistachios
5	Merced	$2,460,474	Milk, chickens, almonds, cattle and calves, sweet potatoes
6	Stanislaus	$2,310,071	Milk, almonds, chickens, cattle and calves, tomatoes
7	San Joaquin	$2,000,474	Grapes, milk, cherries, tomatoes, walnuts
11	Kings	$1,304,783	Milk, cotton, cattle and calves, processing tomatoes, pistachios
14	Madera	$963,128	Grapes, almonds, milk, pistachios, cattle and calves
	All counties	$22,063,650	

I-5 and SR 99 (Figure 5.2) account for a large volume of truck traffic, with as much as 30 percent of the traffic on some San Joaquin Valley segments of I-5 consisting of trucks. I-5 is the favored route for truck movements through the study area and is preferred for longer trips due to faster speeds, less congestion, and greater safety and has the benefit of being entirely closed-access. I-5 has had some issues with pavement deterioration due to the heavy truck use. Due to connections with major population centers along SR 99, many goods movement–oriented industries (such as food processing and warehousing and distribution) are located close to the highway. SR 99 is therefore the preferred route, and the only practical route, for truck service within the San Joaquin Valley. SR 99 is an older, more congested route, with portions of legacy construction. Large portions of SR 9 are limited access, and Caltrans has planning initiatives to further convert the highway into a full limited-access freeway.

SR 99 consists primarily of two lanes in each direction, which can cause congestion in the busier urban areas and those where the three-lane sections narrow. There also are a number of older interchanges and on- and off-ramp locations that are difficult for large modern trucks to negotiate. Trucks outbound from San Joaquin Valley origins to other regions typically either follow SR 99 north or south or use one of several state highways to access I-5. Inbound trucks either use SR 99 from the north or south or use one of the east-west routes to access the population centers from I-5.

Other major highway routes include State Highways 33, 41, 43, 58, 65, 132, 152, 198 and Interstate 580, many of which travel east-west for at least a portion of the route.

The major east-west route to and from the Bay Area is I-580/I-205/SR 120. This region has major industrial and business park development, and the highways have become a major commuter route linking population growth centers in San Joaquin County with the San Francisco Bay Area. It is a highly congested route with much competition between trucks and autos for the use of available capacity during peak-periods.

SR 132 between I-5 and Modesto is a narrow, two-lane rural road and is considered dangerous by many truckers; some trucking companies prohibit their drivers from using SR 132. SR 140 connects I-5 and SR 99 through Gustine and Merced. It is a less-direct east-west route and not heavily used by truckers.

SR 152 is one of only two continuous east-west routes connecting SR 99 and US 101 and provides an alternative to the congested I-580/I-238/I-880 east-west corridor. It is a vital artery for California's agricultural heartland (San Joaquin Valley and Monterey Peninsula) and a major international trade highway corridor. Nearly 50 percent of California's $34 billion in agricultural production takes place in counties along and adjacent to the SR 152 corridor. The highway through Los Banos is a major east-west connector between SR 99, I-5, and the coastal areas around Gilroy and Watsonville. Between I-5 and Los Banos, and between Los Banos and SR 99, SR 152 is a four-lane, divided highway. Through Los Banos, SR 152 becomes a boulevard through the center of town, significantly slowing through-truck traffic. It is also a major east-west corridor for interregional traffic connecting the San Francisco Bay Area, North Central Coast, and Central Valley regions. The closest east-west routes for trucks are I-580, SR 198 and SR 46.

SR 198 serves Kings and Tulare counties in the south-central portion of the San Joaquin Valley. It is a two-lane rural highway for much of its western length, traversing the foothills east of US 101 and intersecting I-5 in Coalinga. West of I-5, SR 198 is not an STAA-designated route, accessible to California Legal Trucks only. It is a designated truck route between I-5 and SR 99. Between Lemoore in Kings County to just east of Visalia in Tulare County, the roadway alternates between two-lane highway, expressway, and freeway. The two-lane, 10-mile section of SR 198 between SR 43 and SR 99 in Kings and Tulare counties is being widened into a four-lane expressway.

On SR 65, unlike the other four highways, the truck traffic tends to be local, serving local customers between Bakersfield and Porterville. Any through traffic to/from points north of Porterville tends to use parallel route SR 99. The other four routes have a number of points in common:

- They carry through-truck traffic, with relatively few on-route customers.
- They can be used as discretionary alternatives to SR 58, which is the primary east-west route through Bakersfield.
- The local customers are primarily agricultural in nature.

SR 46 and SR 166 are also used to access the coastal region west of Kern County. A larger proportion of the trucks on these routes is refrigerated trucks, due to the nature of the commodities that originate in these counties. Many of the refrigerated trucks operate either empty or with dry freight westbound. Many of these trucks operate at night and on the weekends due to the distances involved.

SR 58 is located at the southern end of the San Joaquin Valley and carries truck trips between I-5 and SR 99, through Bakersfield and Tehachapi in Kern County and I-15 in San Bernardino County. It is used as a primary route for shipment to the eastern areas of California as well as outside the state via I-15 and I-10, and as an alternative to both I-5 and I-10/I-210 to avoid storms on the Grapevine and traffic congestion in Los Angeles County, respectively.

Highway freight movements originate at shipper locations and terminate at receiver locations. Shippers are the only true freight movement generators, although a number of other loaded or empty truck movements may be required to accomplish the complete freight movement, including:

- Empty trips to position the truck for loading
- Trips to and from intermediate handling points
- Trips for truck fueling, cleaning, and servicing
- Trips to and from the driver’s home or company location
- Trips to return merchandise or shipping equipment

Locations where truck movements begin or end can thus include:

- Shipping and receiving points
- Carrier terminals or other freight handling points
- Truck fueling, cleaning, and servicing locations
- Rest areas, restaurants, driver homes, etc.

Trucks also have a home base that may differ from the location of the freight movement generator which can include a for-hire carrier terminal or parking lot, shipping location for a private fleet, or a driver's home *(26)*.

Agricultural Case Studies

Tioga evaluated the tomato industry and its effects on transportation in the San Joaquin Valley *(27)*. A summary of this report serves as an indication of the type of information relevant to a specific type of freight—in this case agricultural produce.

According to the United States Department of Agriculture, California produces about 96 percent of all processing tomatoes and about a third of all fresh market tomatoes in the United States.

Fresh market tomato production in California has stayed relatively steady, but processing tomato production has risen significantly over many years. This reflects a change in production locations in the United States toward California. Processing tomatoes are largely delivered by growers to independent processors. It dominates both the overall production and the transportation needs of the San Joaquin Valley. Significant inflows of tomatoes occur during the harvest season (lasting from July through September or October) with growers, packaging, and processing material suppliers delivering their produce and products by truck. The processors produce their canned products and store the paste, canned tomatoes, sauces, etc. in warehouses either at or very near the plant. The finished product is shipped from these warehouses year-round in response to customer orders. Most shipments of finished product to other California locations go by truck, although those to the east or north (which account for the bulk of the finished product) go by rail. An analysis of the typical damage that may be caused to produce such as tomatoes is provided in Section 5.4.

Another type of agricultural produce is that of the dairy industry *(28)*. California ranks first in U.S. milk production. In 2010, California produced 21 percent of the nation's milk supply. The eight San Joaquin Valley counties constitute the eight largest producers of milk statewide, and account for roughly 86 percent of all California milk production. Although the bulk of California milk production occurs in the San Joaquin Valley, the valley's eight counties account for only about one-third of the licensed milk processors in the state. There are several very large milk processing plants located in the valley, and their locations tend to mirror those of milk production. These dairies provide raw milk to many of these processors in other regions, placing a premium on efficient and reliable highway transportation.

Dairy operations also affect local beef production, feed production, etc. Virtually all inputs to the production of milk and outputs from dairy farms are transported to and from the dairy farms by truck. Unlike most agricultural commodities, milk production tends to be relatively constant throughout the year, requiring constant input of feed. Feed dealers deliver their product by truck, but often obtain feed components, particularly grain, by rail. While most farms use their herds' offspring for replacement, there is also considerable purchase and sale of heifers and more mature animals. Trucks transport the dairy livestock. They are also involved in manure disposal. Transport from farm to processor is exclusively by truck. Milk in its raw state is highly perishable and has stringent sanitation and handling requirements. Milk is collected from the farm every 24–48 hours. The tank trucks used for milk have heavily insulated stainless steel bodies to keep the milk cold in transit.

With constant milk production there is a constant inbound flow of fluid milk to processors. Most dairy products are only mildly seasonal. Since the raw milk inputs are largely interchangeable, the inbound flows to processors can fluctuate in volume and pattern from week to week. Many of the specialty handlers ship all their output and receive their containers exclusively by truck, but the larger operations also utilize rail for shipping finished products to regions beyond the Rockies. Products that are exported would move primarily to Oakland or Los Angeles/Long Beach by refrigerated truck.

The most important transportation need for the dairy industry in the San Joaquin Valley is reliable, efficient trucking. Besides being highly perishable and requiring specialized equipment, milk and milk products are heavy. Tank trucks of fluid milk can place a significant burden on rural road and arterial pavements, and they move all year long, seven days per week. Truck movements of animal feed and manure are also heavy, and can stress rural roads. Dairy farms and dairy processors often start operations early in the morning, every morning. In some parts of the state, the traffic, noise, and odor of dairies has brought them into conflict when adjacent land uses are not well planned. Outbound rail service is critical for the processor serving national markets. Processing plants are served by a mix of Class 1 railroads (large freight railroad companies based on operating revenue) and shortlines.

As stated, tank trucks of fluid milk can place a significant burden on rural road and arterial pavements, and move every day, year-round. The incoming and outgoing loads associated with dairy farming are heavy and many of the trucks are highly specialized, with expensive equipment. Therefore these industries could cause a lot of pavement damage, and high vehicle operating costs (VOC) are implicated (expensive trucks). From a freight perspective, the potential damage from specialized cooling trucks and the robustness requirements of some packaging may pose specific V-PI issues for this industry.

5.3.4 Goods Movement Action Plan

The California Goods Movement Action Plan (GMAP) has been developed through a two-phase process *(29)*. Phase I characterized the why and what of California's involvement in goods movement in the following four segments:

- Goods movement industry and its growth potential
- Four port-to-border transportation corridors that constitute California's goods movement backbone and the associated inventory of infrastructure projects
- Environmental and community impacts
- Key aspects of public safety and security issues

It includes a compiled inventory of existing and proposed goods movement infrastructure projects, including previously identified projects in various regional transportation plans and regional transportation improvement programs prepared by metropolitan planning organizations, regional transportation planning agencies, and county transportation commissions.

Phase II consists of a statewide action plan for goods movement capacity expansion, goods movement–related public health and environmental impact mitigation and community impact mitigation, and goods movement–related security and public safety enhancements. It presents a framework for decision making on candidate actions and potential solution sets to achieve simultaneous and continuous improvement for each of the subject areas. The priority regions and corridors identified in the GMAP are shown in Figure 5.6. The San Joaquin Valley comprises most of the Central Valley region.

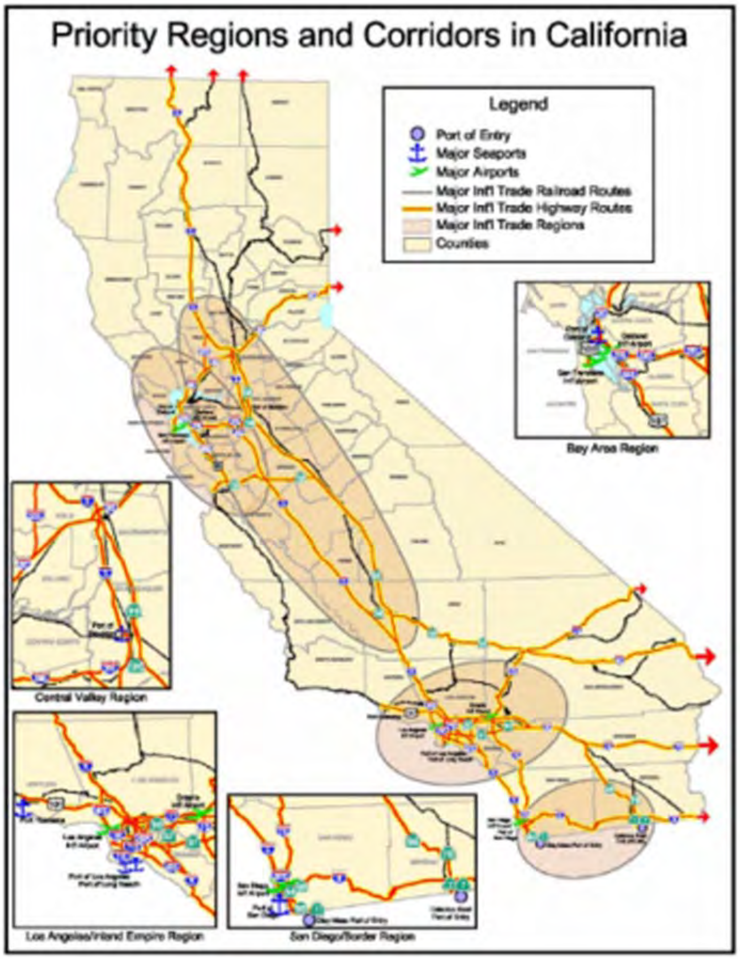

Figure 5.6: Priority regions and corridors in California *(29).*

5.3.5 California Life-Cycle Benefit/Cost Analysis Model

Caltrans uses the California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C) to conduct investment analyses of projects proposed for the interregional portion of the State Transportation Improvement Program (STIP), the State Highway Operations and Protection Program (SHOPP), and other ad hoc analyses requiring benefit-cost analysis. Cal-B/C offers a simple, practical method for preparing economic evaluations on prospective highway and transit improvement projects within California. The latest update expands the base model and is part of Caltrans' efforts to mainstream ITS and implement the Transportation Management System (TMS) Master Plan produced by the Caltrans Division of Traffic Operations. It also builds on research into the benefits of ITS sponsored by the Caltrans Division of Research and Innovation and the Federal Highway Administration's ITS Deployment Analysis System (IDAS).

Cal-B/C is a spreadsheet-based tool that can prepare analyses of highway, transit, and passenger rail projects. The model calculates life-cycle costs, net present values, benefit-cost ratios, internal rates of return, payback periods, annual benefits, and life-cycle benefits. The current version of Cal-B/C focuses on capacity-expansion projects, as well as TMS and operational improvements, and companion tools that support link and network analysis (Cal-B/C Corridor and Cal-NET_BC). The three tools are illustrated in Figure 5.7.

Cal-B/C provides economic benefit-cost analysis for a range of capacity-expansion transportation projects. The model measures four categories of benefits that result from highway or transit projects:

- Travel time savings
- Vehicle operating cost savings
- Accident cost savings
- Emission reductions

Each of these benefits is estimated for a peak (or congested) period and a nonpeak (or uncongested) period). The distinction is intended to capture the difference in congested and free-flow conditions on the highway as well as different operating characteristics for transit at peak times. The graphical user interface of the Cal-B/C model is shown in Figure 5.8.

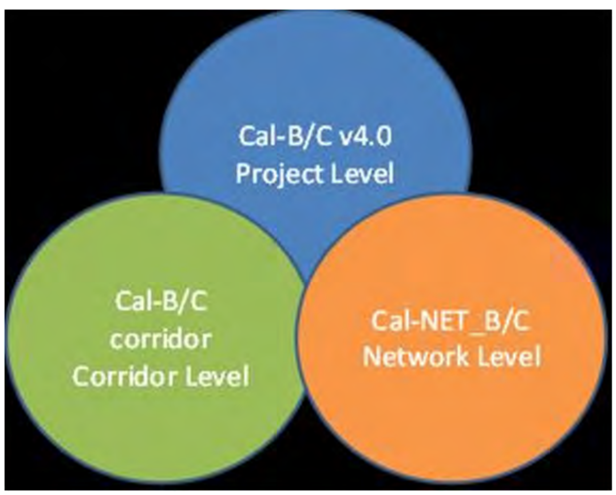

Figure 5.7: Cal-B/C framework.

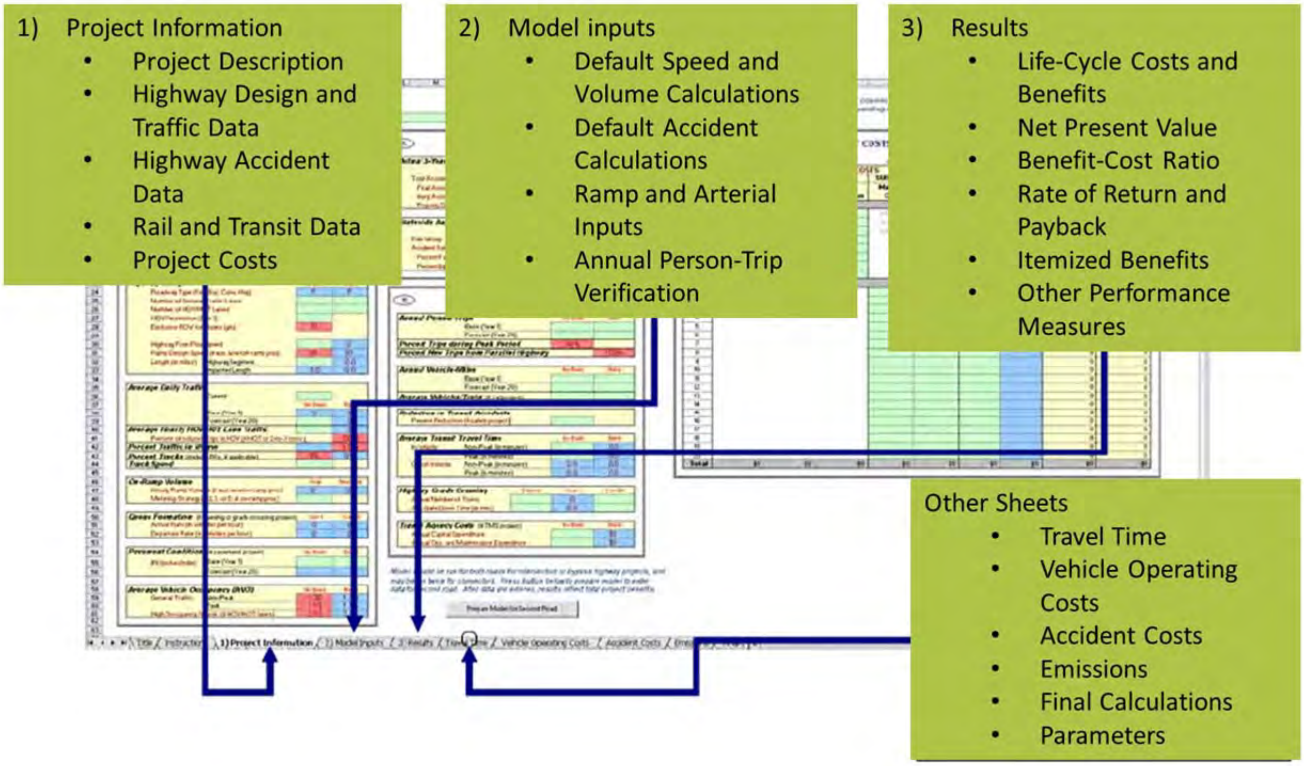

Figure 5.8: Cal-B/C graphical user interface.

The output presents the final investment measures as well as annualized and life-cycle benefits and allows users to include the effects of induced travel and vehicle emissions. Cal-B/C calculates induced travel benefits using consumer surplus theory. Cal-B/C summarizes analysis results on a per-project basis using several measures:

- Life-cycle costs
- Life-cycle benefits
- Net present value
- Benefit/cost ratio
- Rate of return on investment
- Project payback period

Benefits are calculated for:

- Travel time savings
- Vehicle operating cost savings
- Accident cost savings
- Emission cost savings

Highway design and traffic data must be entered for highway projects. Statewide default values are provided for some inputs. The following required inputs are deemed to be potentially affected by the work conducted in this pilot study:

- Roadway type—Indicate if the road is a freeway, expressway, or conventional highway in build and no build cases.
- Number of general traffic lanes—Indicate number of general-purpose lanes in both directions for build and no build cases.
- Number of HOV lanes—Indicate number of HOV lanes in both directions for the build and no build cases.
- HOV restriction—If a highway facility has/will have HOV lanes, the HOV restriction needs to be provided.
- Highway free-flow speed—Indicate free-flow speed for build and no build cases.
- Current average annual daily traffic (AADT)—Indicate current two-way AADT on facility.
- Forecast AADT—Indicate projected AADT for 20 years after construction completion.
- Hourly HOV/HOT volumes.
- Percent trucks—Indicate estimated percentage of AADT made up of trucks.
- Truck speed—Enter estimated speed for slow vehicles.
- Pavement condition—Indicate base International Roughness Index (IRI).

5.3.6 Private Industry

Discussions were held with the California Trucking Association about potential interest and support from private industry in the pilot study. Concerns were raised about the potential effects on the trucking industry, specifically regarding potential increased fees and the long-term outcome of this pilot study. A standard boilerplate with background to the pilot study and the objectives of the pilot study was shared with the focus on future prioritization of maintenance work, potential economic impacts of rough roads on freight damage, and more efficient utilization of existing maintenance funds.

The potential involvement of industry in Task 8 activities (measurement of truck and freight response on a range of pavement types) was discussed. Potential involvement includes:

- GPS tracking and acceleration measurements on selected trucks traveling on designated state highway segments—need for trucks, trailers and freight
- Truck trailer information as input into computer simulations of vehicles traveling over a range of pavements

Decisions regarding privacy and confidentiality around collected data and operations were briefly discussed. These issues may be dealt with through UC and other universities' standard procedures. The proposed field work procedure indicated in Section 6.3 was shared with the CTA to identify potential industry partners.

5.3.7 MIRIAM Project

The Models for rolling resistance In Road Infrastructure Asset Management systems (MIRIAM) project was initiated by 12 partners from Europe and the United States with the objective of conducting research to provide sustainable and environmentally friendly road infrastructure, mainly through reducing vehicle rolling resistance and subsequently lowering CO_2 emissions and increasing energy efficiency. In the first phase the focus is on investigation of:

- Pavement characteristics
- Energy efficiency
- Modeling
- Raising awareness of the project to secure economic and political support for a second phase, during which incorporation of CO_2-controlling models into road infrastructure asset-management systems could be developed and implemented

Potential links between the MIRIAM project and this pilot study mainly lie in the potential use of selected rolling resistance models originating from MIRIAM in the evaluation of the effects of pavement roughness on vehicle energy use, emissions, and rolling resistance.

The influencing parameters and potential energy losses that should be included in the concept of rolling resistance form one of the important potential links between MIRIAM and this pilot study. Correlations are required between rolling resistance coefficients or fuel consumption and road surface parameters to enable modeling of the concept in PMS. Initial MIRIAM studies indicated that *(29)*

- Rolling resistance is a property of tires and the pavement surface. In preliminary studies it was shown that the rolling resistance coefficient for test tires increased by 21–55 percent due to changes in surface roughness—corresponding to fuel consumption differences between 7 and 18 percent.
- Macrotexture is a major factor influencing rolling resistance.
- A substantial bias exists between various series of measurements made by presently available rolling resistance trailers; temperature appears to be partly responsible for such differences.
- It is proposed that a tentative source model for the pavement influence on rolling resistance contain mean profile depth (MPD), pavement roughness (IRI), and pavement stiffness as significant pavement parameters.

- For light vehicles the pavement roughness effect on rolling resistance is probably around a third of that of the effect of MPD, and it appears to be higher for heavy vehicles.

5.3.8 California Inter-Regional Intermodal System

Foreign trade is one of the cornerstones of California's prosperity, and is supported through the transportation of international containers between the Central Valley and the Port of Oakland. Increasingly congested freeways are affecting the economical movement of goods on these routes, jeopardizing the ability to compete and grow. The California Inter-Regional Intermodal System (CIRIS) was envisioned as an umbrella concept for rail intermodal service between the Port of Oakland and other locations in Northern California. Inland intermodal facilities served by rail shuttle operations offer potential solutions to Northern California's looming need for better trade lifelines to Bay Area ports. Previous feasibility studies have established the potential viability and value of the CIRIS concept and concluded that the concept is worth pursuing from multiple perspectives.

The increased use of rail options for these transportation options will have an effect on truck volumes and deterioration of the pavement infrastructure. In order to conduct a pilot study on the CIRIS it is necessary to:

- Verify the ability of the railroads, terminal operators, and trucking companies to maintain competitive service and reliability standards.
- Determine actual operating costs and explore system efficiencies.
- Verify market acceptance and long-term volume potential.
- Enable customers, ocean carriers, drayage firms, and other participants to adjust to new operating methods.

Although the effort may be regarded as a demonstration project for funding purposes, it should be planned as the initial stage of a system that will eventually attain long-term operation and significant volume *(32)*.

5.3.9 I-5/SR 99 Origin and Destination Truck Study

An origin and destination truck study was conducted to gain statistical information on the origin and destination of heavy-duty trucks traveling on SR 99 and I-5 within Kern, Kings, Tulare, and Fresno counties *(31)*.
The study comprised three main data collection tasks.

Vehicle Classification Counts

Traffic volumes within the study area were found to be consistent for both fall and spring seasons, with some exceptions, while overall truck percentages were higher in spring compared to fall, with a few exceptions.

Truck Intercept Surveys

- Little variance was observed in truck travel patterns between the fall and spring.
- The majority of trucks (83.8 percent) were 5-axle double-unit type.
- 70 percent of the trucks were based within California. Of these, 47 percent were based in the San Joaquin Valley region and 34 percent in the Southern California region.
- The definitions of places where the trips originated from included:
    - Shipper—Location where goods originate
    - Consignee/receiver—Location where goods are delivered
    - Yard—Place where trucks are stored and dispatched from
    - Home—Residence of truck driver
    - Port—Trips originating from and destined to ports of Los Angeles, Long Beach, and Hueneme
    - Other
- 40.9 percent of the trips originated from a shipper and 36.9 percent from a yard. The percentage of other locations dropped off significantly.
- 34.8 percent of the trips ended at a consignee/receiver, 27.4 percent at a yard, and 20 percent at a shipper.
- The top five commodity types by percentage are:
    - Food and similar products (21 percent)
    - Empty trucks (18 percent)
    - Farm products (14 percent)
    - Miscellaneous freight (12 percent)
    - Transportation equipment (4 percent)

Commercial Fleet Operator Survey

A commercial fleet operator survey of truck fleet operators provided information to obtain a better understanding of commodities being transported in the corridors:

- Truck operations are mostly local and regional, with trucks using SR 99 more often than I-5 due to origins and destinations that cluster along SR 99.
- Trucks tend to use I-5 to connect Kern County points with regions to the north and south (e.g., the Bay Area or the Los Angeles Basin).
- Regional trips place a burden on east-west connectors such as SR 166, SR 58, and SR 46.

Based on the origin-destination data, it is important to measure varying loads, as empty trucks respond differently to pavement roughness than partially and fully loaded trucks, and thus incur a different level of wear and maintenance.

5.3.10 State of Logistics South Africa

Selected extracts are provided (below) from the series of four South Africa State of Logistics articles that focused on vehicle-pavement interaction issues. The original metric units are kept in this section, although imperial units are provided where possible)

The Potential Cost of Bad Roads in South Africa (33)

The ride quality of a road has, for many years, been used as the primary indication of the quality of a road—mainly due to findings that the most of the deterioration in the road structure ultimately translates into a decrease in the riding quality of the road. Various studies about the effect of the ride quality of roads on the vibrations and responses in vehicles have been conducted, with the main conclusions indicating that a decrease in the ride quality of a road is a major cause of increased vibrations and subsequent structural damage to vehicles. These increased vibrations and structural damage to vehicles can have many negative effects on the transportation cost of companies and the broader economy of a country. The potential effects that worsening road conditions can have on the broader economy are depicted in Figure 5.9.

Potential vehicle damage for vehicles traveling on uneven roads can only be addressed by mechanical engineers through the improvement of the design of each vehicle traveling on the specific road. This immediately multiplies the costs to a huge number of individual solutions. The poor quality of the road in this case, therefore, has an increased cost effect on the vehicle and vehicle component design costs, manufacturing costs, and maintenance costs. All these costs are typically incorporated into the cost that the vehicle owner charges to the customer for transporting cargo, and therefore ride quality affects the logistical cost and ultimately the cost of goods to the customer.

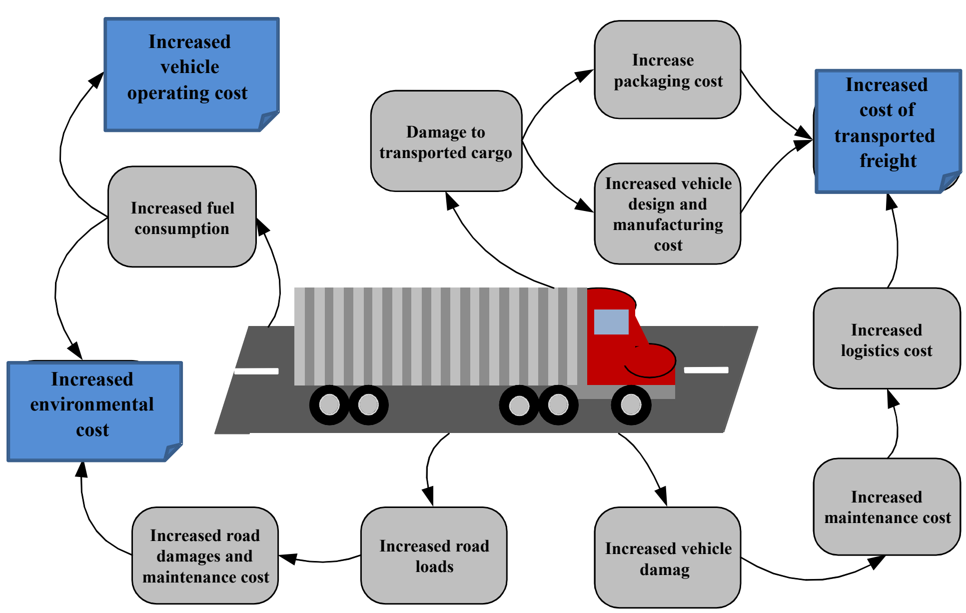

Figure 5.9: Potential effects of deteriorating road quality on the broader economy.

Driving on an uneven road surface affects the speeds at which the vehicle can travel safely, which immediately affects the logistics of delivering goods at optimum times to a customer. A decrease in the ride quality of a road causes a direct increase in the road maintenance cost. It also shortens the life of the road due to the increased vibration of the vehicles, which in turn increases the dynamic component of the vehicle loads on the road. The vibrations from the road are translated to the transported cargo, which results in damages to the cargo. Potential solutions to this problem include improvements to the packaging of the cargo or improvements in the design of the cargo itself. Decreases in ride quality also affect the environment and environmental costs through increased vehicle operating costs and increased emissions due to slower speeds and longer durations of transport. Congestion levels are very high in some areas, and the effect of this is that travel times, fuel consumption, and emissions released into the environment increase.

A limited case study was conducted at a transportation company in South Africa to investigate the potential effect of bad road surfaces on vehicle damages and costs. Anecdotal evidence was analyzed to obtain an indication of the potential effect road condition could have on vehicle damage and costs. The analysis indicated that the trucks traveling on the roads with worse ride conditions experience an increase in cost of between 685 percent and 1,560 percent, when moving from a road in good condition to an average- or poor-condition road (Table 5.7).

Table 5.7: Potential Increase in Vehicle Damage Cost under Deteriorating Road Conditions

Road Condition	Percent of Total Vehicle Damages	Percent of Total Cost of Vehicle Damages	Percent Increase in Cost
2 (good)	5.2	3.9	
3 (average)	17.4	30.8	684
4 (poor)	77.4	65.2	1,560

Cost of Bad Roads to the Economy (34)

Increased vehicle maintenance and repair cost leads to increased vehicle operating costs of transport operators. In addition, worsening road conditions can result in increased vehicle vibrations, which may eventually translate into increased damages to transported cargo. The transport operator may be held liable for any damages during the transportation of goods. It therefore follows that on roads with deteriorating ride quality the transport operator either has to take a loss or increase transport tariffs due to the higher operating costs. Consequently, the selling price of products may increase, as the increased transportation cost must either be absorbed by the seller or transferred to the consumer through increased prices.

To understand the potential effects of bad roads on the total logistics cost of companies, a case study was conducted at two operating companies within a large logistics service provider in South Africa. The average repair and maintenance cost of vehicles of the two companies traveling on specific routes, the associated IRI, and condition rating of that route is shown in Table 5.8. Company A identified 10 trucks from its fleet traveling mostly on the same route, and provided a database of actual maintenance and repair costs for the selected vehicles for

January–June 2008. Company B provided a database of its actual maintenance and repair costs for a fleet of 577 trucks operating on a range of roads in South Africa for January–September 2008,. For each company, similar truck types were used to ensure that the route—and therefore the IRI—was the only factor of difference in the analysis of the two companies. A graphical depiction of the potential increase in vehicle maintenance and repair cost as a result of worsening road conditions is provided in Figure 5.10.

To investigate the impact that the increase in vehicle maintenance and repair cost may have on the total logistics cost of a company, a further analysis is done in this section. A summary of the potential increase in vehicle maintenance and repair cost when moving from a good road condition to a fair or to a bad road condition, as well as the increase in the total logistics cost of a company as a result of worsening road conditions, can be seen in Table 5.8.

Table 5.8: Summary of Vehicle Maintenance and Repair Cost for Routes with Different IRIs

Company	Route Information	Average IRI (m/km)/[ft/mi]	Road Condition Rating	Average Maintenance and Repair Cost (ZAR/km)
A	Gauteng to Durban (N3)	2.7 [173]	Good	1.01
	Gauteng to Cape Town (N1)	3.6 [230]	Fair	1.30
B	Gauteng to Durban (N3)	2.7 [173]	Good	0.90
	Gauteng to Nelspruit (N4)	2.9 [186]	Fair	0.82
	Gauteng to Witbank (N12)	3.4 [218]	Fair	1.27
	Gauteng to Rustenburg (N4)	3.3 [211]	Fair	1.04
	Gauteng to Richardsbay (N17 and N2)	3.6 [230]	Fair	1.31
	Johannesburg to Vereeniging (R82)	3.6 [230]	Fair	1.57
	Gauteng to Cape Town (N12 and N1)	3.6 [230]	Fair	1.29
	Gauteng to Botswana (N4)	3.9 [250]	Fair	1.35
	Newcastle to Gauteng (N11 and N17)	4.2 [269]	Bad	2.09
	Gauteng to construction sites	4.3 [275]	Bad	2.13

Note: ZAR = South African Rand

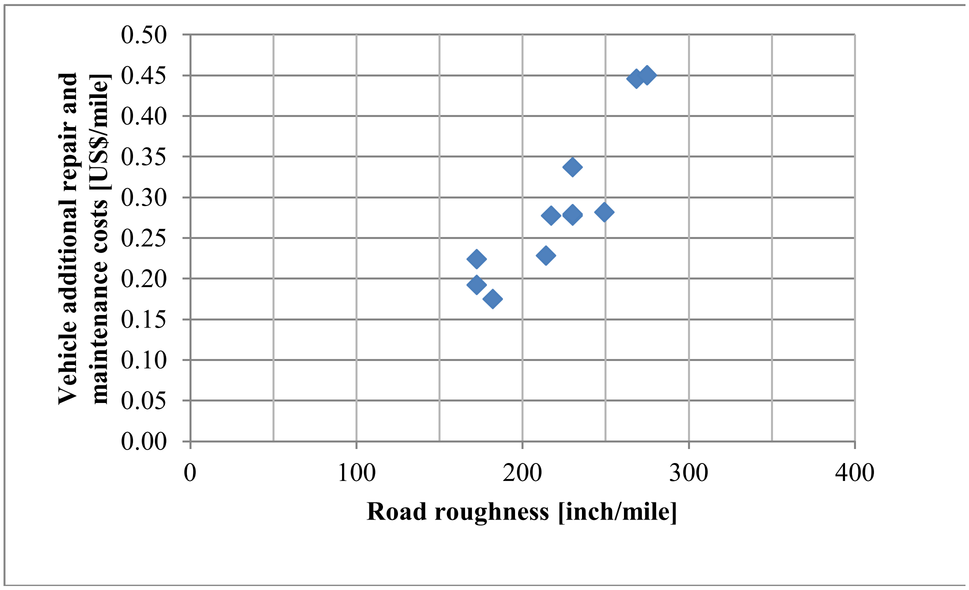

Figure 5.10: Potential increase in vehicle maintenance and repair cost due to bad roads.

Table 5.9: Summary of Potential Increases due to Worsening Road Conditions

Road Condition	Average Maintenance and Repair Cost (ZAR/km)	Average Percentage Increase in Truck Maintenance and Repair Cost	Average Percentage Increase in Company Logistics Cost
Good	0.96	–	–
Fair	1.24	30.24	2.60
Bad	2.11	120.94	10.40

Note: ZAR = South African Rand

The increase in internal logistics costs due to inadequate road conditions is experienced by most, if not all, transportation companies in a country. This figure eventually adds up to a massive increase in the logistics costs of the country as a whole. As the logistics costs of a country increase, the cost of its products in the global marketplace increases, which can have devastating effects on the global competitiveness of that country. It is therefore of critical importance to manage logistics costs effectively and to minimize unnecessary costs that can translate into higher product costs.

The Potential Effects of Deteriorating Road Quality and Maintenance in South Africa (35)

An evaluation of the potential negative effects of deteriorating road quality on transported cargo and the potential effects of road maintenance on companies were conducted. Even though it may be argued that the potential negative effects of bad roads warrant the proper maintenance and repair of the road network, it is important to consider the potential effects and cost of maintaining the roads before deciding how to deal with any unwanted effects.

International studies indicate a link between the condition of a road and the vibrations experienced in a truck traveling on that road. Different types of cargo (e.g., fresh produce and glass articles) are sensitive to different vibration ranges and magnitudes. The vehicle type, properties, and operating speed also affect potential damage to the cargo. Since excessive vibrations experienced by transported cargo can lead to cargo damage, it is important to investigate the actual effects that increased vibrations—caused by bad roads—can have on transported cargo.

The vibrations experienced at specific positions in trucks traveling on the South African road network were monitored to determine the relationship between damage to the transported cargo and road condition. The position of cargo in the truck is important, as the dimensions of the truck will affect the level to which vibrations are transposed to different areas in the truck. Current local and international investigations indicate that cargo situated at the uppermost location at the back of the truck's trailer experiences the highest levels of vibration and damage. An example of the damage to fresh produce transported in the back of a trailer over roads with high roughness is shown in Figure 5.11.

Figure 5.11: Typical damage to fresh produce cargo due to road roughness.

Analysis of satellite tracking data obtained from trucks operated on the route between Johannesburg and Port Elizabeth—a distance of approximately 1,000 km (620 mi)—during 2010 indicated the following interesting information. On a 50 km (31 mi) section of single-lane road where only one lane was available for traffic due to road maintenance, the truck had to stop 18 times (for at least 10 minutes each time), and attained an average speed of 20 km/h (12 mph). If the remainder of the road is assumed to be in a good condition and the truck can achieve an average speed of 60 km/h (37 mph) for the good section of the route, the delay increases the travel time from around 16.7 hours to 21.3 hours, a 27 percent increase in travel duration.

Even though the impacts of road repair and maintenance can be severe, the negative effects of these events can be mitigated. A balance between maintaining roads and traffic stoppages should be achieved with maintenance planned in such a way that traffic stoppages are minimized. Various models exist to enable the proper planning of road repair and maintenance. These models can help decision makers determine the most suitable alternative for road maintenance by considering various options, such as the use of bypasses and lane closures or using single-lane traffic over sections of the road.

In addition, these models also assist decision makers to determine the most suitable length of single-lane traffic sections from both maintenance and traffic flow viewpoints. This is important, as longer single-lane sections may be better in some instances, while shorter sections may allow traffic to flow quicker through the system in other instances, depending on traffic type, traffic volumes, and road geometry.

It is clear that there are many potential negative effects of bad roads, and finding an appropriate solution to the problem of bad roads is extremely important. It may be argued that the most obvious solution to this problem is to repair and maintain the condition of all roads, as that will address the root cause of the problem. However, the cost of repairing and maintaining roads can be extremely high, and the economic feasibility of this solution must be investigated before the best solution for the country can be identified. The road maintenance costs required to maintain good road quality on the Gauteng-Durban transport corridor were compared to the potential savings in vehicle maintenance and repair cost gained due to the improvement of the road quality, and the benefit-cost ratio of such an improvement was calculated.

To weigh the potential savings in vehicle maintenance and repair cost for transporting cargo on a good road with the cost of maintaining that road, the following assumptions were made:

- Annual road maintenance to maintain a good road condition
- Discount rate of 5 percent
- Exponential decrease in road condition after road maintenance if the road is not maintained on an annual basis
- Truck volume on the Gauteng-Durban corridor increases annually by 5 percent
- Road maintenance cost increases by 5 percent per year due to inflation

The minimum and maximum potential savings per kilometer were derived and compared with the estimated annual road maintenance cost per kilometer (Table 5.10).

Comparing the estimated annual road maintenance costs per kilometer with the potential savings in vehicle operating cost shows significant benefits that can be realized when keeping the road in a good condition. It is important to note that only truck traffic volumes were used in this analysis; therefore the actual benefit-cost ratios should be higher than the figures presented.

Table 5.10: Benefit-Cost Ratio of Keeping the Road in a Good Condition

Year	Road Maintenance Cost (ZAR/km)	Potential Savings (ZAR/km)		Benefit-Cost Ratio	
		Minimum	Maximum	Minimum	Maximum
1	600,000	(318,311)	(79,163)		
2	630,000	(156,763)	245,006		
3	661,500	21,736	601,790		
4	694,575	348,913	1,234,813		
5	729,304	777,232	2,056,250		
6	765,769	1,391,316	3,222,637		
7	804,057	2,215,862	4,779,711		
Total		4,279,985	12,061,043	1.88	3.47

Note: ZAR = South African Rand

The Potential Effects of Bad Roads on Transported Cargo(36)

This article presented two case studies that investigated the potential effects of deteriorating road quality on cargo damages and losses. The distribution of fresh produce in the agriculture sector requires extensive handling and transportation after harvesting—actions that can result in damage to and loss of products. This has significant economic impact on the agriculture sector, as damaged produce have reduced economic value and losses decrease revenue. The case studies investigated and quantified the additional damage to and loss of transported cargo incurred when fresh produce is transported on bad (as opposed to good) roads.

In this sector, trucks travel on a variety of road types before reaching their destination. In most cases the first stage of travel is on a gravel road from the farms where fresh produce is harvested. Gravel roads are generally in a worse condition and are rougher than paved national and provincial roads. Therefore the majority of damage to fresh produce and loss during transportation occurs while it is traveling on gravel roads.

The purpose of the fruit damage case study is to quantify the vibrations a truck and the fresh fruit it carries endure due to different road conditions when traveling from growers in the Limpopo Province to market distributors in Pretoria and Johannesburg. The vibrations generated during transport were then compared with vibration ranges known to cause damage to transported produce. The case study considered six similar trucks and four types of fruit. The trucks used in the case study traveled on national and provincial roads considered to be in good condition, with IRI values of 0.8–2.5 m/km (51–160 ft/mi), and conversely on gravel roads that had not been regraveled in the past eight years and had an IRI value of around 8 m/km (512 ft/mi).

The vertical acceleration experienced when traveling over rough road surfaces is what causes damage to vehicles, increased wear and tear and, potentially, damage to and loss of transported cargo. Vertical acceleration data were collected by installing accelerometers at different locations on the trucks and inside the packaging of transported fruit. Measurements from the truck body were compared to measurements from inside the packaging to investigate the damping and amplifying effect of packaging. As expected, measurements did not differ significantly among the six truck bodies, but differences were observed among different types of fruit cargo.

The dominant vertical acceleration frequencies experienced by the four types of fruit cargo were identified and compared with frequency ranges at which the different types of fruit are susceptible to damage. Figure 5.12 provides a visual comparison between the dominant frequencies experienced by the fruit cargo and the damage frequency range of the different fruits. The shaded area represents the overlap of dominant frequencies with the frequency range where different types of fruit are likely to be damaged. This overlap is an indication that some of the vibrations experienced during transportation may result in damage to transported produce.

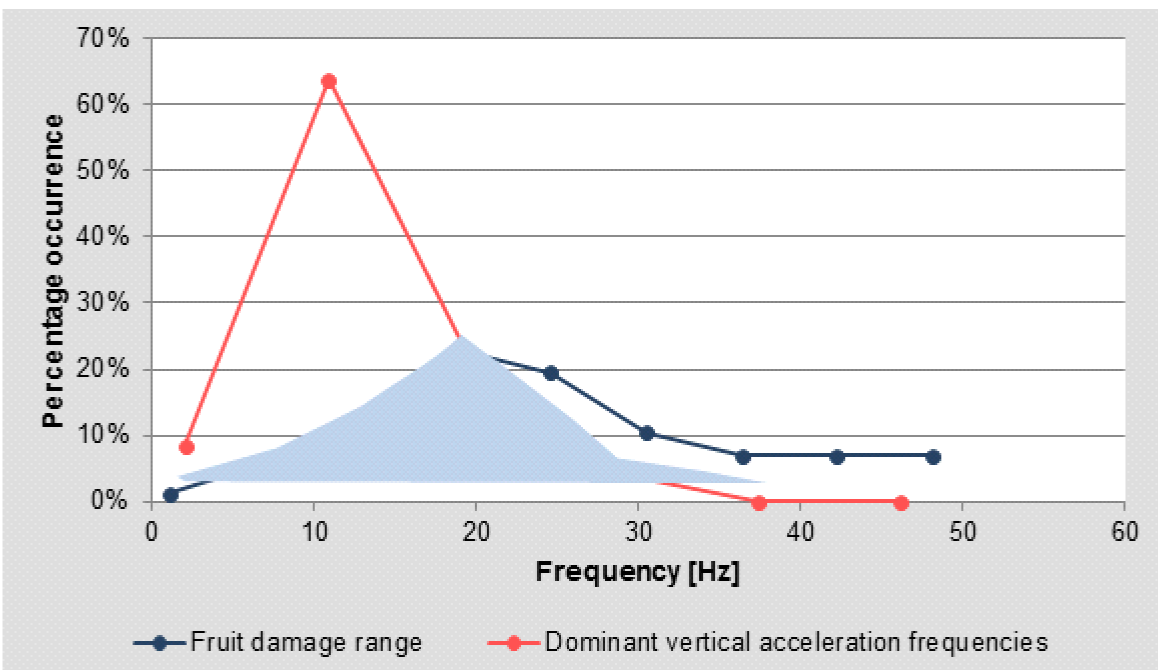

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Figure 5.12: Comparison between dominant frequencies experienced by fruit cargo and the vibration range that results in damage.

Different packing locations in a truck experience different magnitudes of vertical acceleration during transit. The range of vertical acceleration depends on factors such as tire pressure, truck suspension type, vehicle loading, and size of vehicle. Accelerometers were placed at different locations inside the truck within the pallets to compare the vertical acceleration experienced by cargo at different packing locations in the truck. In addition, the vertical acceleration experienced by the truck body was also measured. In general, pallets at the back of the truck and pallets on top of the pallet stacks in the front and middle of the truck experienced higher acceleration.

Figure 5.13 displays the normalized distributions of the vertical accelerations experienced at various packing levels in the front of the truck as well as on the truck body. The distributions for the accelerations experienced by the bottom and middle levels are very similar to that of the truck body. It is evident from the slightly lower mean value and variation of accelerations experienced in the bottom pallets compared to the truck body that the packaging does dampen the vertical acceleration. Fruit packaged on fiberboard pallets on the bottom level in the front of the truck were most protected against vibration damage incurred during transport.

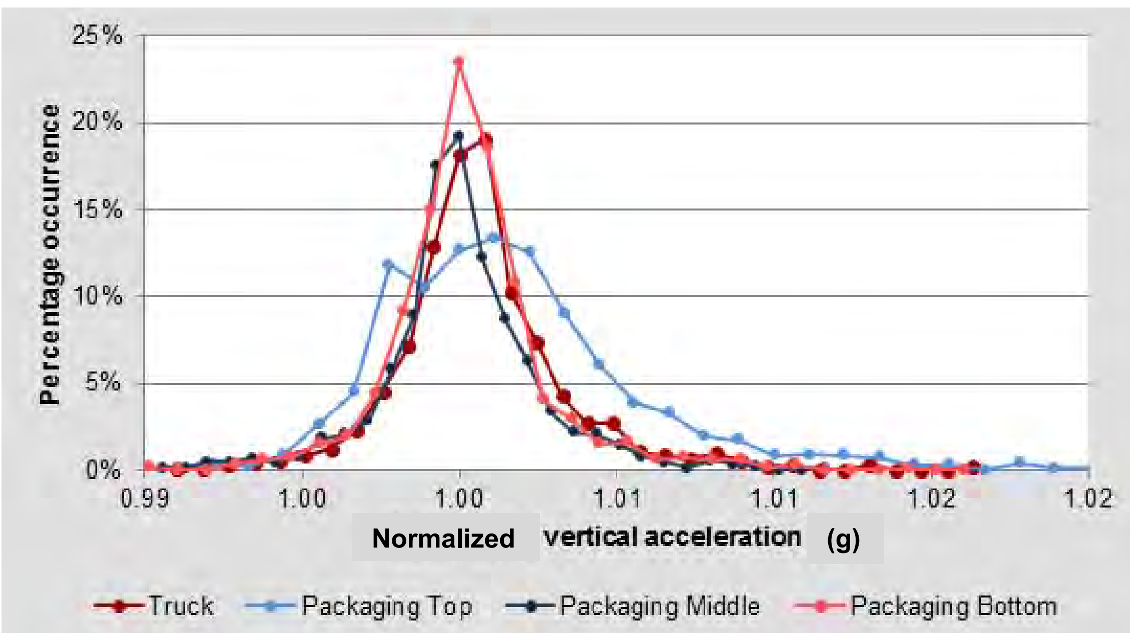

Figure 5.13: Normalized distributions of the vertical accelerations experienced within pallets at various packing levels at the front of the truck.

The economic impact of damaged agricultural cargo is absorbed differently by large- and small-scale farming operations. Large operations either use in-house fleets or outsource to transportation companies. In the former case, trucks can be customized for certain cargo or operational techniques can be enforced that mitigate damage due to vibration. In the latter case, service-level agreements and insurance safeguard the farmers' interests to a great extent. Small-scale farmers are typically more vulnerable, as they generally provide their own transport and thus are not safeguarded by service-level agreements or insurance and, unlike with large fleets, their vehicles, packaging, and operational procedures are not customized to moderate cargo damage.

Wheat has a fine granularity, making it a cargo susceptible to losses during transportation, especially on bad roads characterized by greater surface roughness. The grain loss case study investigated the potential wheat losses of a grain shipping company during transportation as a result of increased truck vibrations caused by bad roads in South Africa *(36)*.

Farm loads and silo-to-mill loads are two types of transportation contracts in the grain shipping industry. Shipping data from these two types of contracts between November 2010 and July 2011 were used for the case study. *Farm loads* refers to the transportation of wheat between farms and silos, which happens mainly via gravel roads. In other words, farm loads are generally transported along roads that are in bad condition. Silo-to-mill contracts transport loads mainly along paved roads in South Africa; these roads are mostly in a good condition. A similar mix of truck fleet is used to transport wheat for both types of transport contracts.

The shipping data analyzed in this case study provided the weight of individual wheat loads when loaded and unloaded. The difference between these two weights was the basis for calculating wheat loss during transit. After accounting for extreme causes of variation (such as vehicle accidents) it was assumed that the remaining variation was due to a variation in scale calibration, causing over- or underweighting, or a variation in the vibration experienced as a result of varying road quality conditions. It was assumed that the variation due to over- and underweighting canceled out across the data sample and was thus ignored.

Given that the truck fleet mix is the same for both contracts, it was concluded that wheat loss was 0.62 kg/ton higher, on average, when traveling on bad roads. The economic implications of these losses are quantified in Table 5.11 using the average wheat price between November 2010 and July 2011. The additional loss of 0.62 kg/ton translates to a loss in potential revenue of 1.34 South African rand (ZAR) per ton loaded. Given that 1.849 million tons of wheat are harvested annually in South Africa, this amounts to a potential revenue loss of ZAR 2.5 million.

The two case studies quantified the potential impacts that deteriorating road quality can have on transported cargo, and it is clear that the increased roughness on deteriorating roads greatly increases the risk of damage to fresh produce and loss of wheat during transit. Much can and should be done in terms of packaging, cargo handling, route planning, and driving techniques to reduce the effect of deteriorating road quality on transported cargo.

Table 5.11: Comparison of Average Wheat Loss on Good and Bad Roads

Wheat Loss by Weight							
Road Condition Rating	Load Weight (ton)	Loss per Load (kg)/[lb]	Loss per Ton Loaded (kg/ton)	Difference (kg/ton)	Road Condition Rating	Load Weight (ton)	Loss per Load (kg)/[lb]
Good	34.71	36.09 [79]	1.04	–	Good	34.71	36.09 [79]
Bad	22.86	37.85 [84]	1.66	0.62	Bad	22.86	37.85 [84]
Wheat Loss in Rand (average values)							
Road Condition Rating	**Wheat Price (ZAR/ton)**	**Loss per Ton Loaded (kg)**	**Value Lost per Ton Loaded (ZAR)**	**Difference (ZAR)**	**Road Condition Rating**	**Wheat Price (ZAR/ton)**	**Loss per Ton Loaded (kg)**
Good	2,167.82	1.04	2.25	–	Good	2,167.82	1.04
Bad	2,167.82	1.66	3.59	1.34	Bad	2,167.82	1.66

Notes: ton = metric ton (1,000 kg); ZAR = South African Rand

5.3.11 Other Regions and Corridors

Apart from the information presented in this section there was no substantial and detailed information found on regions or corridors apart from the San Joaquin Valley that could add to the discussions in this report.

5.4 Freight Logistics Analysis

5.4.1 Introduction to Freight Logistics and the Broader Supply Chain

A supply chain is more than just the operations required to move goods from one company to the next. More accurately, *supply chain* comprehensively describes the movement of materials from the source (raw materials) to the consumer/end customer (final products/services). Typically, a number of companies are involved in a supply chain, each fulfilling different operations or providing planning and management services to the supply chain. A supply chain encompasses purchasing, manufacturing, warehousing, transportation, customer service, demand planning, supply planning, information exchange, and management services. Considered in its entirety, a supply chain constitutes people, processes, materials, equipment, and information. Freight logistics is typically focused on the processes and elements in the supply chain that move materials from one geographic location in the supply chain to another. Although physical transportation is the greatest component of freight logistics, fleet management, transport planning, distribution strategies, transport packaging, route planning, freight inspection, and so forth are also constituents of the broader freight logistics function.

The Supply Chain Operations (SCOR®) Framework is a standard model used to map and describe supply chains. The SCOR Framework is a product of the Supply Chain Council (*www.supply-chain.org*) and is a recognized industry standard. Figure 5.14 is based on the SCOR model and shows a simplified schematic of a supply chain and its freight logistics interfaces. Consider, for example, the following simplified explanation of a tomato processing supply chain where the raw materials (fresh tomatoes) are grown in California and processed locally and then the final product (processed tomatoes) is sold in California or neighboring states.

- **Plan:** Supply chain planning coordinates demand and supply across the entire supply chain through information exchange. The planning function also evaluates supply chain performance in terms of cost efficiency and service delivery. Each company may execute its own planning, or the supply chain can coordinate its efforts and share the benefits.
- **Source:** Tomatoes are grown, harvested, sorted, and prepared for pickup by one or more farmers/suppliers.
    - *Freight logistics link 1:* Tomatoes are packed onto truck/rail car/intermodal container. Freight is transported to processing plant(s). Freight is offloaded.
- **Make:** Incoming tomatoes are inspected, and unusable tomatoes are separated from good tomatoes. Good tomatoes are transformed into various kinds of canned processed tomato products. Canned products are packed into boxes/pallets.
    - *Freight logistics link 2:* Boxes/pallets are loaded onto trucks and distributed to various retailers. Boxes/pallets are offloaded at retailers.
- **Delivery:** Incoming boxes/pallets are received. Product is inspected for damage. Unusable product is separated out. Product is stacked on shelves. Product is sold to consumer.
    - *Freight logistics link 3:* If the consumer requests home delivery of groceries, cans of processed tomato products would be loaded into a delivery vehicle and transported to the consumer's location. Damaged product would be returned by the consumer.
- **Return deliver:** Damaged product arriving at the retailers would be sent back to the processing plant(s) to be replaced.
    - *Freight logistics link 4:* Damaged product is loaded back onto the truck, transported back to the processing plant(s), and offloaded.
- **Return make:** If appropriate, bad tomatoes are returned to farmers/suppliers. Alternatively, bad tomatoes are disposed of.
    - *Freight logistics link 5:* If bad tomatoes are returned to the farmer/supplier the freight must be reloaded onto a(n) truck/rail car/intermodal container. Freight is transported to the farmer/supplier and offloaded.

Figure 5.14: Simplified schematic of a supply chain.

5.4.2 Freight Damage as a Result of V-PI

Each of the freight logistics links indicates a position in the supply chain where V-PI could potentially damage freight. Two primary types of freight damage are:

- **Freight damage due to vibration motion or sudden jolts.** This includes "mechanical failure, fatigue failure, cosmetic damage, undesirable settling of contents, breaking up between solid/liquid suspensions, static charge buildup, bottle-closure cap back-off and leaking fluids and powdered products" *(37)*.
- **Freight loss due to vibration.** This is relevant to grain, natural sands, and other mining related freight that can fall through cracks in the truck body, particularly when aggravated by abnormal vibration.

Steyn et al. *(36)* investigated both of these types of freight damage in the South African context through case studies published in the *Eighth State of Logistics*^{TM} *Survey for South Africa 2011* (see Section 5.3.10 for description and references).

A third potential impact could be that, under severe conditions, the equipment on the truck body intended to maintain freight integrity is damaged; for example, the cooling unit on a truck might be damaged by vibrations and jolts, affecting the integrity of the entire shipment. However, this is considered a high-impact, low-probability event.

The further along the supply chain, the more costly it is to write off freight. A pound of fresh tomatoes costs less to write off than a pound of processed product. Three typical supply chain responses to freight damage are:

- Product is sent back to the shipper for replacement, repair, or repackaging—placing a burden on the reverse supply chain (e.g., manufactured or electronic products);.Product is written off and must be disposed of by the receiver (e.g., damaged agricultural products).
- Product must be reclassified before selling (e.g., downgrading fruit).

All three of these freight damage responses require additional accounting and information exchange procedures, creating an additional administrative burden. The true cost of freight damage is thus the sum of the lost revenue and the cost of the operational repercussions caused.

There are many ways to prevent freight damage or mitigate the effects thereof. Protective packaging, freight insurance, customized trucks, and route avoidance (deliberately choosing alternative routes to avoid a particular stretch of road) are typical mechanisms employed.

Packaging engineering is an established discipline in which much attention is given to designing and testing packaging that protects products during transport and material handling. In the past few decades countless studies have been conducted to quantify the effect of transport vibrations on agricultural freight and compare the protection offered by various types of packaging. However, literature pertaining to the freight damage incurred by manufactured/processed goods and other nonagricultural commodities is scant. Agricultural freight is fragile and thus deserving of protective packaging, but it is a low-value, low-margin product that does not justify excessive spending on transport packaging. Therefore freight damage due to transport vibrations is a common occurrence in the agricultural industry. In fact, it is estimated that 30 to 40 percent of produce is discarded between the grower and consumer due to damage *(38)*. Manufacturers, on the other hand, go to great lengths to protect their final products through packaging—especially for high-value goods. The lack of freight damage literature related to manufactured goods could thus be because of the relatively low occurrence of freight damage during transport or because manufacturers do not want to publish research that could undermine their competitive advantage.

Studying the effects of V-PI on the freight logistics industry in California by quantifying the increase in vehicle operating costs and freight damage costs (both direct and indirect) holds significant value for industry players. Understanding these effects and having substantive proof of the relationship between pavement quality and supply chain costs could afford industry players the following benefits:

- Better-informed negotiations regarding freight insurance
- Better-informed supplier selection and contracting decisions
- Information for benefit-cost analyses related to transport packaging and customized vehicles
- Information for benefit-cost analyses related to route avoidance strategies (e.g., Is the cost of taking a longer route to avoid a bad stretch of road justified by the expected prevention of freight damage?)
- Better-informed fleet management strategies—incorporating VPI effects into decisions about suspension type and axles
- Guidelines on how to best load truck bodies or intermodal containers to prevent freight damage

5.4.3 Pilot Study Objectives

The purpose of this pilot study is to investigate and quantify vehicle operating and freight damage costs due to the VPI experienced on road surfaces of varying ride quality along freight routes within a specific area of California. In particular, the results of this pilot study should illustrate the value of conducting a similar statewide study that could inform road maintenance and repair planning. From a freight logistics point of view, it is implied that the pilot study should show how freight damage costs can be investigated and quantified for specific commodity flows within a study area.

It is important that the outcomes of this pilot study link with various ongoing studies and economic models as detailed in Sections 1 and 5.5.

The most prominent implication for the freight logistics aspect is the link to the Cal-B/C model described in Section 5.3.5. To perform a benefit-cost analysis of upgrading/repairing a certain stretch of road, potential freight damage savings accrued by the upgrade must be given as input into the Cal-B/C model. Therefore, the pilot study should develop a methodology whereby field measurements, stakeholder engagements, and existing data sources can be used to estimate freight damage savings along a certain stretch of road.

5.4.4 Information Requirements to Calculate Freight Damage Costs

To achieve the objectives discussed above requires cost calculations at a disaggregate level. Firstly, the expected freight damage cost incurred by a particular type of shipment must be quantified. Secondly the individual shipment costs must be aggregated to provide higher-level cost estimates. Performing the cost calculation at the disaggregate level requires the following steps:

- Quantifying the probability and extent of freight damage incurred by a shipment traveling on a road surface of a specific ride quality. This damage will depend on the vibration as influenced by road roughness, distance, traveling speed, load, suspension type and number of axles, as well as specific properties of the freight and its packaging *(39)*.
- Defining the indirect operational costs incurred due to freight damage. This will depend on the specific supply chain in question.
- Combining items 1 and 2 to obtain a total cost.

There is a significant body of knowledge relating to the freight damage caused by transport vibrations to specific agricultural products including the following products:

- Peaches
- Apples

- Pears
- Apricots
- Grapes
- Loquats
- Strawberries
- Tomatoes
- Potatoes
- Oranges
- Eggs

Unfortunately, the same cannot be said for manufactured and other nonagricultural goods. This means that in the case of agricultural commodities, results and findings from previous studies could be used to fill knowledge gaps in the data resulting from field measurements and industry interaction. In the case of nonagricultural or manufactured goods the project team would rely heavily on data collected through field measurement. During the field measurements, freight inspections at origin and destination would be required, in addition to the output from the accelerometers, GPS, and other onboard equipment.

The literature studied shows that the practice of using freight damage results generated from vibration table experiments instead of actual on-truck measurements is an acceptable methodology. The methodology is as follows:

1. Collect statistically significant data about the vibrations experienced by loaded truck bodies while traveling over varying pavement conditions through field measurements.
2. Create vibration profiles from these field measurements as input to the vibration table, which will emulate the vibration experienced on the floor of the truck body.
3. Stack freight onto the vibration table as it would be done in the truck (i.e., use the same packaging, stack height, etc.).
4. Vibrate the freight according to the vibration profiles.
5. Inspect freight and record freight damage.

This methodology can be repeated for many different kinds of freight, packaging methods, and stacking profiles, thus greatly reducing the number and variety of field measurements required. The University of Pretoria has vibration table equipment both in the civil and mechanical engineering faculties.

Addressing item 2 (above) will require extensive stakeholder interaction to understand the state of practice for various commodities in California and its neighboring states. This interaction could be achieved through interviews with logistics managers and/or observing logistics operations at shipping and receiving facilities.

Aggregating freight damage costs within a study area for a certain time period would require knowing the volumes of various types of freight transported over particular routes in a certain time period. Knowing the typical shipment characteristics along a particular route —such as packaging and loading variation—would also refine the damage and cost estimations, as these have a significant impact on the probability and degree of freight damage.

5.4.5 Selecting a Preferable Study Area and Freight Types for the Pilot Study

This section identifies a preferable study area and freight types from a freight logistics point of view based on information sources available to this pilot study (Section 5.3, Table 5.1 and Table 5.2).

Figure 5.15 is based on Table 5.1 (Summarized shipment characteristics by mode of transportation for state of origin–) and shows the percentage of the total ton-miles, tons, and monetary value attributed to each commodity. The commodities are sorted according to their ton-mile percentages. Table 5.12 lists the commodity descriptions associated with the index numbers on the x-axis. Those commodities that are known to be susceptible to damage due to bad road quality are italicized in the table. Mixed freight and miscellaneous manufactured products cover a broad range of items that may or may not be susceptible; therefore they are also highlighted (italicized).

From Figure 5.15 the following commodities (susceptible to damage) stand out:

- Other prepared foodstuffs and fats and oils—many tons and ton-miles shipped.
- Other agricultural products—many ton-miles shipped.
- Nonmetallic mineral products, gravel and crushed stone, coal and petroleum products—many tons shipped.
- Electronic and other electrical equipment and components and office equipment—high-value items. Damage to a small proportion of freight could have great monetary implications.

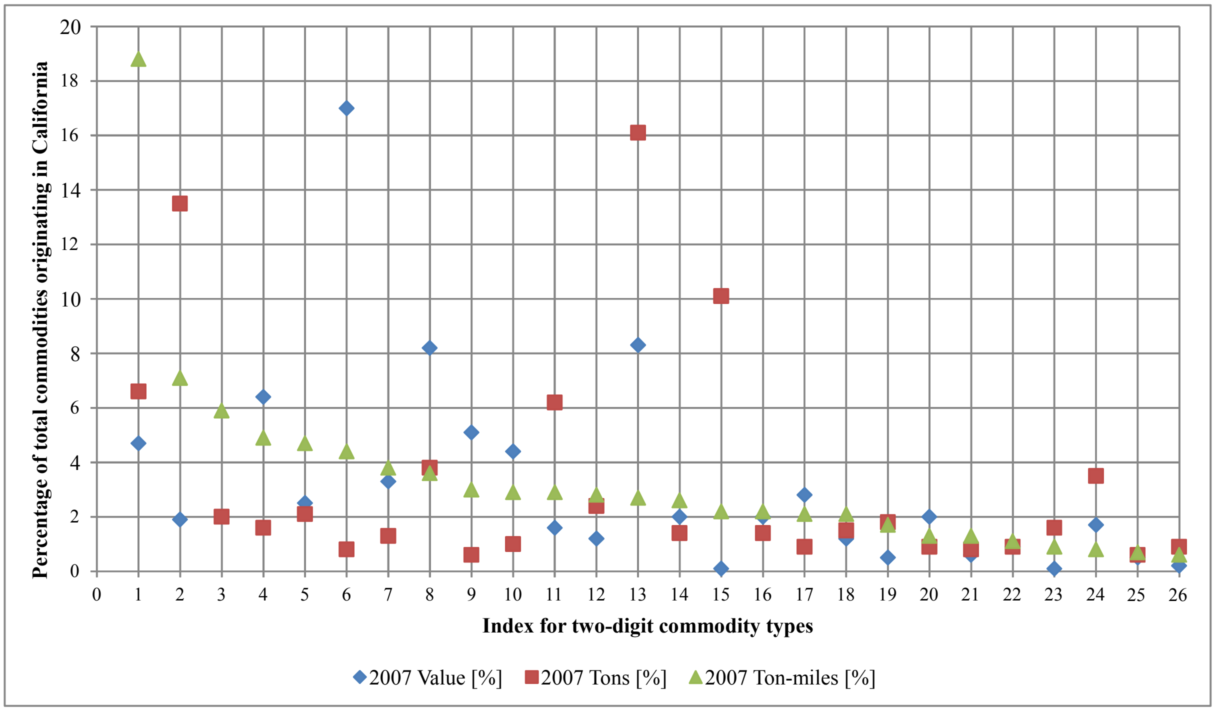

Figure 5.15: Comparison of different commodity shipments originating from California. (See Table 5.12 for description of index designations in this figure.)

Table 5.12: Commodity Classes Associated with Figure 5.15

Index	Description	Index	Description
1	*Other prepared foodstuffs and fats and oils*	14	Chemical products and preparations
2	Nonmetallic mineral products	*15*	*Gravel and crushed stone*
3	*Other agricultural products*	16	Base metal in primary or semifinished forms and in finished basic shapes
4	Motorized and other vehicles (including parts)	17	Articles of base metal
5	Alcoholic beverages	*18*	*Grains, alcohol, and tobacco products*
6	*Electronic and other electrical equipment and components and office equipment*	*19*	*Animal feed and products of animal origin*
7	Plastics and rubber	*20*	*Meat, fish, seafood, and their preparations*
8	*Mixed freight*	21	Basic chemicals
9	Textiles, leather, and articles of textile or leather	22	Paper or paperboard articles
10	*Miscellaneous manufactured products*	*23*	*Nonmetallic minerals*
11	*Coal and petroleum products*	24	Fuel oils
12	Wood products	25	Pulp, newsprint, paper, and paperboard
13	Gasoline and aviation turbine fuel	*26*	*Fertilizers*

A similar analysis was done using the categories listed in Table 5.2 which compares commodities shipped on truck for specified NCAIS-designated industries. The top 29 commodities (based on ton-miles) are shown in Figure 5.16 and Table 5.13. From Figure 5.16 the following commodities (susceptible to damage) stand out:

- Manufacturing, wholesale trade, merchant wholesalers, nondurable goods, food manufacturing—relatively high tons and ton-miles
- Nonmetallic mineral product manufacturing, mining (except oil and gas)—relatively many tons

Commodities that are known to be susceptible to damage due to bad road quality are highlighted (italicized) in Table 5.13.

Therefore, when studying the effect of freight damage on road in California, the following commodities are most relevant:

- Various kinds of manufactured goods—particularly nondurable or electronic goods
- Agricultural and various other food products
- Mining products—coal, minerals, gravel

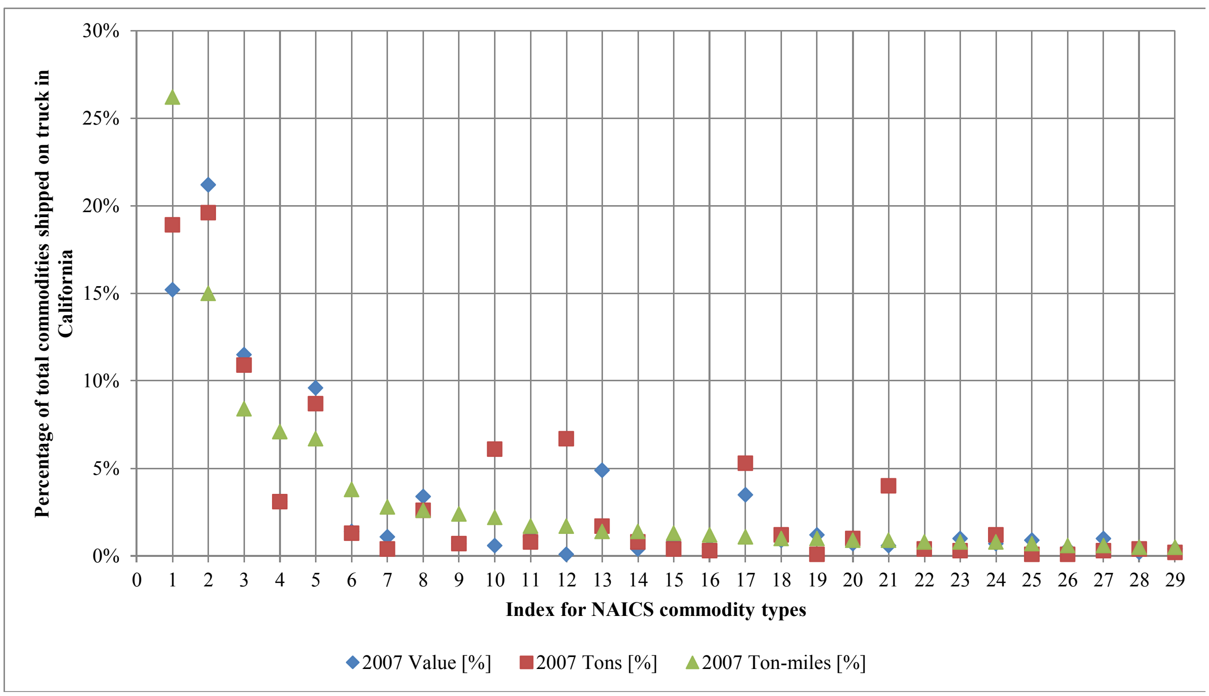

Figure 5.16: Comparison of different commodity shipments on truck in California.

Table 5.13: Commodity Types Associated with Figure 5.16

Index	Industry		Index	Industry
1	*Manufacturing*		16	Primary metal manufacturing
2	*Wholesale trade*		17	Petroleum and petroleum products merchant wholesalers
3	*Merchant wholesalers, nondurable goods*		*18*	*Miscellaneous nondurable goods merchant wholesalers*
4	*Food manufacturing*		*19*	*Transportation equipment manufacturing*
5	Merchant wholesalers, durable goods		*20*	*Beverage and tobacco product manufacturing*
6	Chemical manufacturing		*21*	*Petroleum and coal products manufacturing*
7	Miscellaneous durable goods merchant wholesalers		*22*	*Chemical and allied products merchant wholesalers*
8	*Grocery and related product merchant wholesalers*		23	Fabricated metal product manufacturing
9	Paper manufacturing		24	Lumber and other construction materials merchant wholesalers
10	*Nonmetallic mineral product manufacturing*		25	Machinery manufacturing
11	Corporate, subsidiary, and regional managing offices		*26*	*Electrical equipment, appliance, and component manufacturing*
12	*Mining (except oil and gas)*		*27*	*Machinery, equipment, and supplies merchant wholesalers*
13	Warehousing and storage		*28*	*Farm product raw material merchant wholesalers*
14	Wood product manufacturing		*29*	*Other industries*
15	Plastics and rubber products manufacturing			

From Table 5.1 it is also clear that for-hire trucks are responsible for a much greater proportion of ton-miles traveled than in-house fleets. It is thus recommended that targeting transport providers or third-party logistics providers (3PLs) (companies to which logistics processes are outsourced) for pilot study participation may be more fruitful than only targeting in-house fleets.

Detailed studies on the San Joaquin Valley (Section 5.3.3) show that this valley has large agricultural, mining, and manufacturing industries. In addition, almost half of the freight shipped in the valley has origin-destination pairs within the valley (i.e., internal shipments) which would make shipment inspections easier. The tomato-growing sector may be one sector to target, as tomatoes are fragile (soft) products. The dairy sector is not such an attractive research focus from a freight damage point of view, as highly regulated, customized trucks, and durable packaging make it unlikely that freight damage is incurred. However, from a VOC point of view it makes sense to investigate the dairy sector.

Some logistics-related issues that need to be dealt with during the planning of the remainder of the tasks in this pilot study include:

- The impact of the vertical vibrations on the truck body are very different when the truck is fully loaded as opposed to when the truck is empty or partially loaded *(40)*. Load consolidation, truckload (TL) vs. less-than-truckload (LTL), and empty backhauls are very important logistics issues that enjoy a lot of attention. Shippers may be interested to know just how much of a difference the loading of their trucks makes to the risk of cargo damage, fuel consumption, and maintenance costs.
- Reducing fuel consumption is a major focus area in the "greening" of logistics, and the quantification of differences in fuel consumption when traveling on roads with different roughness can add an extra data element to the modeling of the problem.
- From a business relationship point of view, it may be useful to understand "who pays" for the additional maintenance and freight damage in a certain industry. If transport is mostly outsourced it would be the trucking companies that incur the maintenance cost and then pass it on to their clients. If consignees take ownership of the cargo when it leaves the consignor's warehouse docks, the freight damage is incurred by the consignee and never by the consignor. These kinds of insights would be useful to a supply chain manager when planning upstream and downstream relationships.
- It may be useful to compare freight damage in truck bodies (semitrailers) to that of freight packed in intermodal containers that are then loaded onto truck trailers. Such insights and information could be very useful when assessing intermodal freight logistics (i.e., combinations of rail and road transport).

5.5 Links, Inputs, and Outputs

Many potential sources of information have been presented in Sections 3, 4, and 5 of this report. It is important to evaluate whether these sources link to each other and potentially support a uniform view of the issues around V-PI effects on the broader economy of California. In Section 6.2 this data consolidation view is provided by means of extracting major issues obtained from each of the sources and demonstrating how they link with each other and support the objectives of the pilot study.

In discussions with potential organizations and parties that may assist in providing information for the pilot study, a standard boilerplate was used as background to the study. This was mainly done to ensure that all parties outside of the pilot study team could get a detailed and complete picture of the objectives and focus of the pilot study.

6 DISCUSSION

6.1 Introduction

This section focuses on the consolidation of the data in the previous chapters, as well as the development of recommendations for further work in the project. Further, it allows for comments from the Caltrans project team regarding the recommendations and for documenting the final decision on the corridor/route on which the pilot study will be conducted.

6.2 Data Consolidation

6.2.1 Introduction

The data that were presented in discussed in Sections 3 to 5 of this document represent information sourced from a range of independent sources. Each of the sets of information has been discussed in detail individually. In this section a motivation is developed for the proposed Caltrans decision in Section 6.3 for a corridor/route to focus on during the next phase of this pilot project. Therefore, relevant bits of information from Sections 3 to 5 are combined to present a case. All the details from the specific data sets are not repeated, but reference is made to the relevant sources and locations in the report.

6.2.2 Report Issues

The purpose of this pilot study is to provide data and information that will provide input that supports Caltrans' freight program plans and related legislation with findings potentially contributing to economic evaluations; identification of challenges to stakeholders; and identification of problems, operational concerns, and strategies that "go beyond the pavement," including costs to the economy and the transportation network (delay, packaging, environment, etc.). Findings could lead to improved pavement policies and practices such as strategic recommendations that link pavement surface profile, design, construction, and preservation with V-PI. These findings also should provide information for evaluating the relationship between pavement ride quality (stemming from the pavement's condition), vehicle operating costs, freight damage, and logistics.

The overall objectives of this project are to enable Caltrans to better manage the risks of decisions regarding freight and the management and preservation of the pavement network, as the potential effects of such decisions (i.e., to resurface and improve ride quality earlier or delay such a decision for a specific pavement) will be quantifiable in economic terms. This objective will be reached through applying the principles of vehicle-pavement interaction (V-PI) and state-of-the-practice tools to simulate and measure peak loads and vertical acceleration of trucks and their freight on a selected range of typical pavement surface profiles on the State Highway System (SHS) for a specific region or Caltrans district.

The objectives of this report are to provide information on Tasks 1–6, and to provide guidance about the specific corridor or district on which the pilot study (Tasks 7–12) should be focused.

Road Inventory

The main outcome of Task 3 is to identify routes in each district and county for which ride quality data exists, as well as the actual ride quality for these routes (due to the volume of data, the actual data are kept only in electronic form). Routes in California have been identified, and a database containing actual road profiles and ride quality data is available for use in the remainder of the pilot project.

Vehicle Inventory

The deliverable for Task 4 is a table of current vehicle population per standard FHWA vehicle classifications for Caltrans. Based on the various sources used in this task (FWHA truck classifications, commodity flow analysis, and WIM data), the following was identified:

- The most common truck types are FHWA Class 9 and 12 (up to 48 percent of the trucks on selected routes), followed by Class 5.
- High truck flows are experienced in District 6 – part of the San Joaquin Valley.
- Axle load spectra are heavier at night than in the daytime.
- Axle load spectra and truck type distribution show very little seasonal variation.
- Axle load spectra are much higher in the Central Valley than in the Bay Area and Southern California, particularly for tandem axles.
- More than 90 percent of the truck traffic traveled in the outside or two outside lanes, on two- and three-lane highways, respectively.
- Truck speeds typically fall within the range of 50–75 mph (80–120 km/h).
- Leaf springs are predominantly used in steering axles, with drive axles using air suspension and trail axles using leaf suspension.

Information Review

Task 5 focuses on evaluating the data obtained from the various resources for Tasks 3–4, as well as additional relevant information that may add to the project. The deliverable for Task 5 is a detailed understanding and input to the progress report on the available data sources and required analyses for the project, inclusive of indications of the potential links between the outputs from this project and the inputs for the various economic and planning models.

California Statewide Freight Planning

The purpose of the California Statewide Freight Planning (CSFF) model is to provide a policy-sensitive model to forecast commodity flows and commercial vehicle flows within California, addressing socioeconomic conditions, land-use policies related to freight, environmental policies, and multimodal infrastructure investments. It requires appropriate information and data about freight movements and costs to enable accurate modeling.

Commodity Flow Survey

It is evident that truck-based transportation dominates the freight transportation scene in California. Eighty-two percent of the freight tons shipped from California utilizes only trucks. The data indicate that the highest percentage of commodities and industries (in terms of value, tons, and ton-miles) transported by truck are manufacturing goods, wholesale trade, and nondurable goods for the whole of California. No specific information for commodity flows into California (destination California) could be identified in this pilot study.

San Joaquin Information

The San Joaquin Valley is composed of eight counties and 62 cities. It has a diverse internal economy and also plays a major role in the distribution of agricultural materials throughout California, the United States, and the world. Trucks are the dominant mode choice, with more than 450 million tons of goods moved by truck into, out of, or within the San Joaquin Valley in 2007—more than 85 percent of all tonnage associated with these types of moves in the San Joaquin Valley. Truck movement in the San Joaquin Valley relies on a combination of all levels of highways and roads in the area. Key regional highways include the primary north-south corridors (I-5 and SR 99) and east-west corridors (I-580, SR 152, SR 41, SR 46, and SR 58) and in total constitute more than 31,000 lane-miles. There are more than 2,700 lane-miles of truck routes in the San Joaquin Valley region, with in excess of 80 percent designated STAA National Truck Routes.

Farm products are the dominant commodity carried outbound from the San Joaquin Valley, comprising 33 percent of the total outbound movements. This consists of fresh field crops (vegetables, fruit and nuts, cereal grains, and animal feed). Stone and aggregates account for 18 percent of the total, food and tobacco products around 10 percent, and waste and mixed freight 6 percent and 4 percent of the total tonnage, respectively.

The region accounts for over 8 percent of the total GDP for the state of California. However, the region accounts for a much higher proportion of output within sectors such as agriculture (nearly 50 percent) and mining and mineral extraction (25 percent). The San Joaquin Valley includes 6 of the top 10 counties in California for total value of agricultural production.

Goods Movement Action Plan

The California Goods Movement Action Plan (GMAP) includes a compiled inventory of existing and proposed goods movement infrastructure projects, including previously identified projects in various regional transportation plans and regional transportation improvement programs prepared by metropolitan planning organizations, regional transportation planning agencies, and county transportation commissions. One of the four priority regions and corridors identified in the GMAP is the Central Valley region that includes the San Joaquin Valley.

California Life-Cycle Benefit/Cost Analysis Model

Caltrans uses the California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C) to conduct investment analyses of projects proposed for the interregional portion of the State Transportation Improvement Program (STIP), the State Highway Operations and Protection Program (SHOPP), and other ad hoc analyses requiring benefit-cost analysis. The following required inputs are deemed to be potentially affected by the work conducted in this pilot study: roadway type, number of general traffic lanes, number of HOV lanes, HOV restriction, highway free-flow speed, current and forecast average annual daily traffic (AADT), hourly HOV/HOT volumes, percent trucks, truck speed, and pavement condition.

Industry

Potential involvement of industry in Task 8 activities includes:

- GPS tracking and acceleration measurements on selected trucks traveling on designated State Highway segments—need for trucks, trailers and freight
- Truck trailer information as input into computer simulations of vehicles traveling over a range of pavements

Models for Rolling Resistance In Road Infrastructure Asset Management Systems Project

The objective of the Models for rolling resistance In Road Infrastructure Asset Management systems (MIRIAM) project is to conduct research to provide sustainable and environmentally friendly road infrastructure, mainly by reducing vehicle rolling resistance, and consequently lowering CO_2 emissions and increasing energy efficiency. Potential links between the MIRIAM project and the pilot study mainly lie in the potential use of selected rolling resistance models originating from MIRIAM in the evaluation of the effects of pavement roughness on vehicle energy use, emissions, and rolling resistance. Initial MIRIAM studies indicated that:

- Rolling resistance is a property of tires and the pavement surface.
- Tentative source model for the pavement influence on rolling resistance should contain the mean profile depth (MPD), pavement roughness (IRI), and pavement stiffness as significant pavement parameters.
- For light vehicles, the pavement roughness effect on rolling resistance is probably around a third of that of the effect of MPD, and it appears to be higher for heavy vehicles.

California Inter-Regional Intermodal System

The California Inter-Regional Intermodal System (CIRIS) was envisioned as an umbrella concept for rail intermodal service between the Port of Oakland and the rest of Northern California. The increased use of rail options for these transportation options will affect truck volumes and deterioration of the pavement infrastructure.

I-5/SR 99 Origin and Destination Truck Study

This study indicated that:

- Traffic volumes within the study area were found to be consistent for both fall and spring seasons, with some exceptions, while overall truck percentages were higher in spring compared to fall, with a few exceptions.
- Little variance was observed in truck travel patterns between the fall and spring.
- The majority of trucks (83.8 percent) were 5-axle double-unit type.
- 70 percent of the trucks were based within California. Of these, 47 percent were based in the San Joaquin Valley region and 34 percent in the Southern California region.
- The top five categories and commodity types by percentage are food and related products (21 percent), empty trucks (18 percent), farm products (14 percent), miscellaneous freight (12 percent), and transportation equipment (4 percent).

State of Logistics South Africa

The ride quality of a road has, for many years, been used as the primary indication of the quality of a road—mainly due to findings that the most of the deterioration in the road structure ultimately translates into a decrease in the riding quality of the road. Various studies about the effect of the ride quality of roads on the vibrations and responses in vehicles have been conducted, with the main conclusions indicating that a decrease in the ride quality of a road is a major cause of increased vibrations and subsequent structural damage to vehicles. These increased vibrations and structural damage to vehicles can have many negative effects on the transportation cost of companies and the broader economy of a country.

The increase in internal logistics costs due to inadequate road conditions is experienced by most, if not all, transportation companies in a country. This figure eventually adds up to a massive increase in the logistics costs of the country as a whole. As the logistics costs of a country increases, the cost of its products in the global marketplace increases, which can have devastating effects on the global competitiveness of that country. It is therefore of critical importance to manage logistics costs effectively and to minimize unnecessary costs that can translate into higher product costs.

Comparing the estimated annual road maintenance costs per kilometer with the potential savings in vehicle operating costs shows significant benefits that can be realized when keeping the road in a good condition.

The vertical acceleration experienced when traveling over rough road surfaces is what causes damage to vehicles, increased wear and tear and, potentially, damages to and loss of transported cargo. The economic impact of damaged agricultural cargo is absorbed differently by large- and small-scale farming operations.

Freight Logistics

When freight is damaged it results in both direct and indirect losses in potential revenue through effects on logistical operations. These operational repercussions depend on the type of freight, as well as the standard operating procedures of shipper and receiver, and include:

- Product is sent back to the shipper for replacement, repair or repackaging – placing burden on the reverse supply chain.
- Product is "written off" and must be disposed of by the receiver.
- Product must be reclassified before selling.

The most prominent implications for the freight logistics aspect is the link to the Cal-B/C model. To perform a benefit-cost analysis of upgrading/repairing a certain stretch of road, potential freight damage savings accrued by the upgrade must be given as input into the Cal-B/C model. Therefore, the pilot study should develop a methodology whereby field measurements, stakeholder engagements, and existing data sources can be used to estimate freight damage savings along a certain stretch of road.

To achieve the objectives discussed above requires cost calculations at a disaggregate level. Firstly, the expected freight damage cost incurred by a particular type of shipment must be quantified. Secondly, the individual shipment costs must be aggregated to provide higher-level cost estimates.

Based on the available information, the following commodities should be most relevant for this pilot study:

- Various kinds of manufactured goods—particularly nondurable or electronic goods
- Agricultural and various other food products
- Mining products—coal, minerals, gravel

Summary

Based on the information in Section 6.2.2, there exists a good understanding of the pavement conditions in terms of ride quality in California, as well as the major truck types and operational conditions on these pavements. The major commodities being transported have been identified, and the potential links with models such as the Cal-B/C model are apparent. Most of the information on commodity flows and truck operations are available for the San Joaquin Valley, which forms a major corridor for transport of agricultural and related freight.

6.2.3 Motivational Reasons for Recommended Region/Corridor

The information presented in this report provides a good basis of information to describe the freight movement and transport infrastructure conditions in the San Joaquin Valley region in California.

Transportation and logistics in this corridor is being studied in detail in various studies, supporting the notion that the region is important for the economy of California. This idea is also supported by data indicating that a large proportion of freight originates, passes through, or is destined for companies and markets in this region.

Based on the information provided in this report, it is thus recommended that routes in the San Joaquin Valley be the focus of the remainder of this pilot study. Specific routes, commodities, and trucks in the valley need to be identified for the details of Tasks7–8.

6.3 Vehicle Field Study Parameters

6.3.1 Field Work Objective

The field work for the pilot study is described in Task 8 of the proposal: Measurements of vertical, horizontal, and longitudinal accelerations of selected California trucks on selected locations of specific routes.

The deliverable for Task 8 is: Field data used for the validation of simulation data. Data will be collected through a selection of private trucks or Caltrans trucks or rental trucks—rental trucks will be focused on local haul trucks for pilot study. If actual maintenance costs are not available, models developed for studies such as the U.S. State of Logistics, South African State of Logistics, and HDM-4 (the World Bank's Highway Development and Management Model), and for the National Cooperative Highway Research Program (NCHRP) on typical U.S trucks will be evaluated to obtain acceptable models.

The field work consists of two different sets of data. The first data set focuses on the responses measured on a specific truck as well as the freight being transported, and the second data set focuses on historical data on VOCs (typically fuel, general maintenance, tire, repair and damage costs) for a fleet of vehicles.

The first data set focuses on the collection of the vehicle-specific data (location, speed, and operational data in line with OBD-II compliance [see definition in Section 6.3.5] [i.e., fuel consumption]) and response data (vertical, horizontal, and longitudinal accelerations of truck and freight) due to the truck traveling over selected routes. The objective of this data set is to provide the range of accelerations being experienced by the vehicle and the freight during standard operations, in order to develop an understanding of potential damage caused to the vehicle and the freight during transportation.

6.3.2 Field Work Requirements

To conduct the required field work, the following requirements are set for the equipment involved:

- Commercial trucks (and drivers) as per FHWA Classes 5, 9, and/or 11 should be used.
- Trucks should be OBD-II compliant.
- Trucks would preferably travel on some of the selected routes as a normal travel pattern.
- Acceleration sensors will be supplied as part of the pilot study. They are self-contained and only need to be fixed to the truck and the freight using duct tape.
- GPS equipment and video cameras will be supplied as part of the pilot study. They are self-contained and only need to travel in the cabin of the truck when measurements are being taken.
- OBD-II sensors will be supplied as part of the pilot study. They need to fit the trucks' OBD-II plug. All current U.S. trucks are OBD-II compliant.
- A basic field form must be completed by the driver.

The methodology for the data collection will entail the following general steps by researchers:

- Instrumentation of the truck and freight, as well as placement of GPS, video, and OBD-II sensors
- Inspection and documentation of freight condition before trip commences
- Data collection on the designated route
- Retrieval of sensors, GPS, video camera, and OBD-II sensors at the end of the trip
- Inspection and documentation of freight condition at the end of the trip
- Collection of data on sensitivity of the specific freight to ranges of accelerations (existing literature and other sources as available)
- Data analysis of collected data in conjunction with road condition data (based on Caltrans and other data sources) and sensitive ranges of accelerations
- Reporting

A member of the pilot study team will follow the specific truck being monitored during the trip to be available during the measurement process, and will also be responsible for the installation and retrieval of the equipment.

6.3.3 Route Requirements

The routes indicated in Table 6.1 are recommended candidates for the measurements. The routes are recommended subject to a final decision on the corridor in which the pilot study will be conducted (Section 6.4). These routes are located in the San Joaquin Valley. It is recommended that final route and segment selection be conducted in consultation with the truck owners to keep to existing routes on the State Highway System as far as possible, and to aim for routes on which historical truck operating costs are available.

The objective in selecting the routes is to enable a range of ride qualities to be observed over a specific route segment (outer truck lane only) using the same truck and freight. A distribution of the range of average ride qualities measured for a sample of 40 percent of these routes is shown in Figure 6.1 (the remaining 60 percent of the sections are currently being analyzed). The average of this distribution is 109 in./mi (1.7 m/km); however, when analyzing the whole set of data, maximum ride quality values of up to 986 in./mi (15.4 m/km) were observed. The detailed analysis of the data set will be completed once routes are selected that can practically be used for the V-PI response analyses.

Table 6.1: Potential Routes for Field Measurements

District	County	Route Number*
6	Fresno (FRE)	5, 33, 41, 43, 63, 99, 145, 168, 180, 198, 201, 245, 269, 168S, 180S
	Kern (KER)	5, 14, 33, 41, 43, 46, 58, 65, 99, 119, 155, 178, 204, 223, 395, 058U, 178S
	Kings (KIN)	5, 33, 41, 43, 137, 198, 269
	Madera (MAD)	41, 49, 59, 99, 145, 152, 233
10	Tulare (TUL)	43, 63, 65, 99, 137, 180, 198, 201, 216, 245
	Merced (MER)	5, 33, 59, 99, 140, 152, 165
	San Joaquin (SJ)	4, 5, 12, 26, 33, 88, 99, 120, 132, 205, 580

To enable these measurements to be taken, the following equipment will be used:

- Acceleration sensors attached to designated locations on the truck (as shown in Figure 6.2) (approximately six locations, dependent on truck geometry) and freight (approximately six locations, dependent on truck geometry) using duct tape; no wiring required
- OBD-II sensor (plugs into standard truck OBD-II plug)
- GPS equipment (unattached, in truck cabin)
- Video camera (attached to dashboard using suction cup to monitor road for later referencing)

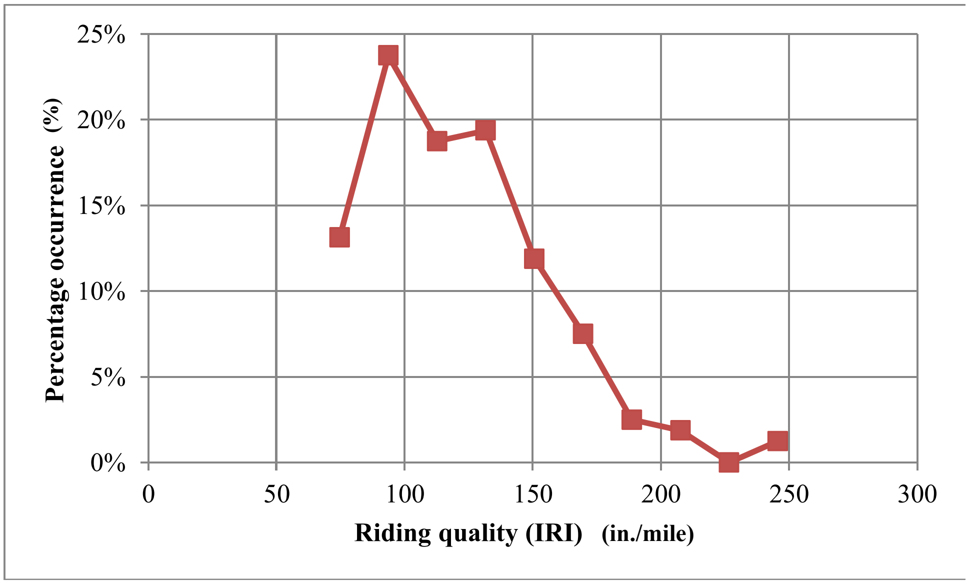

Figure 6.1: Distribution of average ride qualities on routes identified in Table 6.1.

The second data set focuses on the collection of data on maintenance records for specific trucks being operated on specific routes to enable development of a relationship between ride quality and VOCs. For this data set a larger number of trucks will typically be required (similar type of trucks, large number for statistical representativeness—preferably in excess of 50); however, no sensors will be attached to these trucks and data set will consist only of historical company-collected data. The collection of this data set is not part of the planned field work during September 2012. The data collected for this second data set will enable the vehicle maintenance and operations costs on specific routes to be determined and analyzed relatively to the route ride qualities.

Figure 6.2: Typical location of accelerometers on typical South African truck.

6.3.4 Experimental Design

Based on the objective and the deliverable for Task 8, the experimental design in Table 6.2 has been developed. It is anticipated that the agricultural freight measurements will be conducted during September 2012 and the nonagricultural freight during either September 2012 (dependent on logistics around arrangements) or January 2013.

Table 6.2: Experimental Design for Pilot Study

Variables	Ideal Number	Notes
Truck types	1 x FHWA Class 9 or 11 (5-axle), 58% of traffic District 6, 66% of traffic District 10 1 x FHWA Class 5 (2-axle) 30% of traffic District 6, 21% of traffic District 10	Class 9 or 11 truck main priority Class 5 truck if available
Tire types	1	Standard tires as used by company; no changes required. Condition and details only will be monitored.
Suspension types	1	Standard suspension as used by company; no changes required. Will probably be air.
Freight	2 from agricultural and 2 from nonagricultural origin	Agricultural (ideally 2 different types of produce that are prone to transport-related damage (i.e., tomatoes) and losses (i.e., grains if possible)
Routes	1 or more with a range of at least three different distinct roughness levels. Refer to Table 3.1.	

- FHWA Class 5 truck—2-axle, 6-tire, single-unit trucks
- FHWA Class 9 truck—5-axle single trailer trucks, all 5-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit
- FHWA Class 11 truck—5-axle (or fewer) multitrailer trucks. All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit

The experimental design thus requires a minimum of two trucks with two types of agricultural produce and two types of nonagricultural freight to travel on at least one route with a range of roughness levels (thus at least eight truck trips). It is preferable to keep the driver and the company constants in the pilot experiment. The details will be finalized once the actual routes are identified and the types of trucks used for specific freight are identified.

6.3.5 General Notes

Onboard diagnostics (OBD) is a generic term referring to a vehicle's self-diagnostic and reporting capability. OBD systems provide access to the functional status of various vehicle subsystems. The OBD-II standard specifies the type of diagnostic connector, the electrical signaling protocols available, and the messaging format. It also provides a candidate list of vehicle parameters to monitor along with how to encode the data for each. There is a pin in the connector that provides power for the scan tool from the vehicle battery, which eliminates the need to connect a scan tool to a power source separately. Finally, the OBD-II standard provides an extensible list of diagnostic trouble codes (DTCs). As a result of this standardization, a single device can query the onboard computer(s) in any vehicle. Most manufacturers have made the OBD-II Data Link Connector the only one in the vehicle, through which all systems are diagnosed and programmed *(41)*.

6.4 Caltrans Decision

Based on the information presented in this report, as well as the discussions on the data and the analyses and syntheses in Sections 5 and 6, it is recommended that the San Joaquin Valley be used as the pilot region for this project.

The I-5, SR 58, and SR 99 routes are recommended as preferred routes for the pilot study. However, if vehicles that travel on other, similar routes are the only vehicles available for the pilot study, their routes may be used in the pilot analyses instead.

7 CONCLUSIONS AND RECOMMENDATIONS

This section only contains the major conclusions and recommendations from this project to date. Section 6.2 provides a detailed overview of the information obtained from the project, and Section 6.3 contains details on the anticipated field work for Task 8.

7.1 Conclusions

The following conclusions are drawn based on the information provided and discussed in this report:

- Ample information exists to enable the objectives of this pilot study to be met through analyzing the V-PI and logistics situation in a selected corridor in California.
- The San Joaquin Valley corridor is a major production and transportation corridor in California and well-suited to serve as pilot area for the purposes of the remainder of this project.

7.2 Recommendations

The following recommendations are made based on the information provided and discussed in this report:

- The San Joaquin Valley should be targeted as the pilot study area for the purposes of the remaining tasks in this pilot project.
- The work anticipated for Tasks 7–12 should commence once this report has been accepted and approved by the client.

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TECHNICAL APPENDICES

APPENDIX A: MINUTES OF PROJECT KICKOFF MEETING

A.1. Introduction

This appendix contains a copy of the minutes of the kickoff meeting held on 2 February 2012 in Sacramento, California.

Division of Research and Innovation February 2, 2012

Office of Materials and Infrastructure

SPR Part 1 Special Study – DRAFT Contact List

Recorder – B. Nokes

Meeting Summary – Project Kickoff for SPR Part I Special Study: "Pilot Study Investigating the Interaction and Effects for State Highway Pavements, Trucks, Freight, and Logistics"

The meeting Sign-in Sheet and Agenda are shown below. Discussions followed the meeting agenda. Handouts at the meeting included: (1) names and contact information for project members (updated Contact List is included in final page of this summary) and (2) project proposal/workplan. The meeting started at 10:00 am and adjourned at 11:35 am.

Discussions and follow-up actions are highlighted here.

- Rose is the project lead contact at DOTP. Bill is the project lead contact at DRISI (task manager for this task within for the UCPRC contract). Joe is the UCPRC contract manager in DRISI.
- Wynand showed the webpage link to get copies of South Africa State of Logistics reports.
- Wynand will email his MS PowerPoint file to DOTP/DRISI.
- The location (region as opposed to a specific Caltrans District) for road profile and truck analysis and truck instrumentation will be investigated and then decided by Task 6. Potential locations discussed included the South Coast and Bay Area. South Coast (District 7) efforts and good sources of information also include potential coordination with SCAG and UC Irvine, which are developing new models. Bay Area (District 4) could provide linkages to more local sites (e.g., Port of Oakland, agricultural producers in District 3) that may be better suited to this pilot study.
- The type of freight (e.g., agriculture, electronics) suitable to focus on in this pilot study also will be decided by Task 6.
- The location and freight sector for instrumentation of trucks will be decided by the project team after identifying road and vehicle inventory data, gathering other necessary information including

private-sector contacts, and completing technical discussions, which are expected to culminate in a decision by June 2012.

- The risk of not obtaining in-service trucks for instrumentation may be mitigated by starting now to (1) identify contacts in various sectors (e.g., Caltrans and outside professional contacts, electronics/computer, agribusiness associations, local farmers) and (2) investigate potential coordination of this task with related UCPRC projects that may provide access to trucks.
- Other potential Caltrans contacts to follow-up with who may be helpful for the project include (1) Joanne McDermott (DOTP Freight Planning) to identify possible industry contacts for instrumentation of trucks and (2) Sarah Chesebro (Transportation Systems Information, TSI, Travel Forecasting and Analysis Office) and Doug MacIvor (TSI, Transportation/Freight Modeling & Data Branch). Alfredo suggested potential contacts with the farming sector may be achieved through contact with UC Extension.
- Jackie shared a sample of SPR Part I Annual Report form the DOTP submits to the FHWA. Wynand & Louw offered to follow its format in their monthly project updates. Jackie will email the forms to all.
- Communication and feedback were emphasized as priorities. Virtual meetings, e.g., using WebEx, will be planned in the coming months to keep up project team communication and feedback. Austin is a resource in DOTP to help set up WebEx meetings. Wynand and Louw can easily shift their schedules for WebEx meetings so that the 9–10 hour time zone difference will not be a barrier to communications.

Caltrans Division of Research & Innovation

Sign-in Sheet

Kickoff Meeting

SPR Part 1 Special Study –

"Pilot Study Investigating the Interaction and Effects for State Highway Pavements, Trucks, Freight, and Logistics"

Tuesday January 31, 2012 10:00 a.m. – 12:00 p.m. 1101 R Street Conference Room

Name	Organization/Division	Phone	Email
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Austin Hicks	DOTP/EAB	916 653-0709	austin_hicks@dot.ca.gov
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AL ARANA	DOTP	916-653-5827	alarana@dot.ca.gov
Joe Holland	DRI	916-227-5825	t.joe.holland@dot.ca.gov
Bill Nokes	DRI	(916) 324-2904	bill.nokes@dot.ca.gov

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Agenda

Kickoff Meeting for SPR Part 1 Special Study:
"Pilot Study Investigating the Interaction and Effects for State Highway Pavements, Trucks, Freight, and Logistics"

Tuesday January 31, 2012 10:00 a.m. – 12:00 p.m. 1101 R Street

Meeting Moderator: DRI - Joe Holand/Bill Nokes
Participants:
Caltrans (Divisions) -
Transportation Planning (DOTP): Economic Analysis - Barry Padilla, Rose Agacer; SPR Part 1 - Jacqueline Hodaly; and Transportation System Analysis - Al Arana
Research & Innovation (DRI): Materials & Infrastructure - Nick Burmas, Joe Holand, Bill Nokes
Contract Team -
Principal Investigator: Prof. Wynand Steyn (University of Pretoria, UP)
CSIR: Louw du Plessis
UC Pavement Research Center (UCPRC): Jim Signore (Director of UCPRC at UC Berkeley campus)

Desired Meeting Outcomes: (1) Overall understanding and expectations of this project's purpose, objectives, workplan/schedule, and deliverables, (2) Knowledge of the project's team members and their roles as well as currently identified project customers and stakeholders, and (3) Agreement on follow-up actions.

Item	**Responsible**
Welcome and Introductions	Joe & All
I. Project Staff/Contacts & Organizational Structure	
Contract Team Background: UCPRC, CSIR, & UP	Joe/Bill, UCPRC, CSIR, & UP
Caltrans Sponsor, Staff & Advisor(s)	DOTP
DRI Staff	DRI
Project Customers & Stakeholders	DRI/DOTP
II. Project Overview & Discussion	
Description: Purpose, Objectives, Deliverables	DRI/DOTP
Workplan: Tasks, Schedule, Milestones, Resources	Contract Team
Risk & Quality Management: Opportunities & Threats, Quality Control/Assurance	DRI/DOTP & Contract Team
III. Communications	
Scheduled Progress Reports	DRI/DOTP & Contract Team
Meetings	Contract Team
Encouraging & Enabling Feedback	DRI/DOTP & Contract Team
IV. Roundtable – Q&A	All
V. Review Follow-up Action Assignments	Joe/Bill & All
Adjourn	Joe

Organization and Name	Role in Project	Email	Phone
DOTP – Office of State Planning (Economic Analysis Branch)			
Barry Padilla	**DOTP Project Mgr**	**barry_padilla@dot.ca.gov**	**916-653-9248**
Rose Agacer	**DOTP Project Lead Contact**	**rose_agacer@dot.ca.gov**	**916-651-6014**
Austin Hicks	**DOTP Project Assistant**	**austin_hicks@dot.ca.gov**	**916-653-0709**
DOTP – Office of Resources, Administration, & SPR			
Al Arana	**DOTP Engineering Advisor**	**al_arana@dot.ca.gov**	**916-653-5827**
DRI – Office of Materials & Infrastructure			
Joe Holland	**DRI (UCPRC) Contract Mgr**	**t_joe_holland@dot.ca.gov**	**916-227-5825**
Bill Nokes	**DRI Task Mgr**	**bill_nokes@dot.ca.gov**	**916-324-2904**
Contract Team			
Prof. Wynand Steyn	**Principal Investigator**		
Louw du Plessis	**Project Assistant (CSIR)**		
Jim Signore	**UCPRC Contact (Berkeley)**		