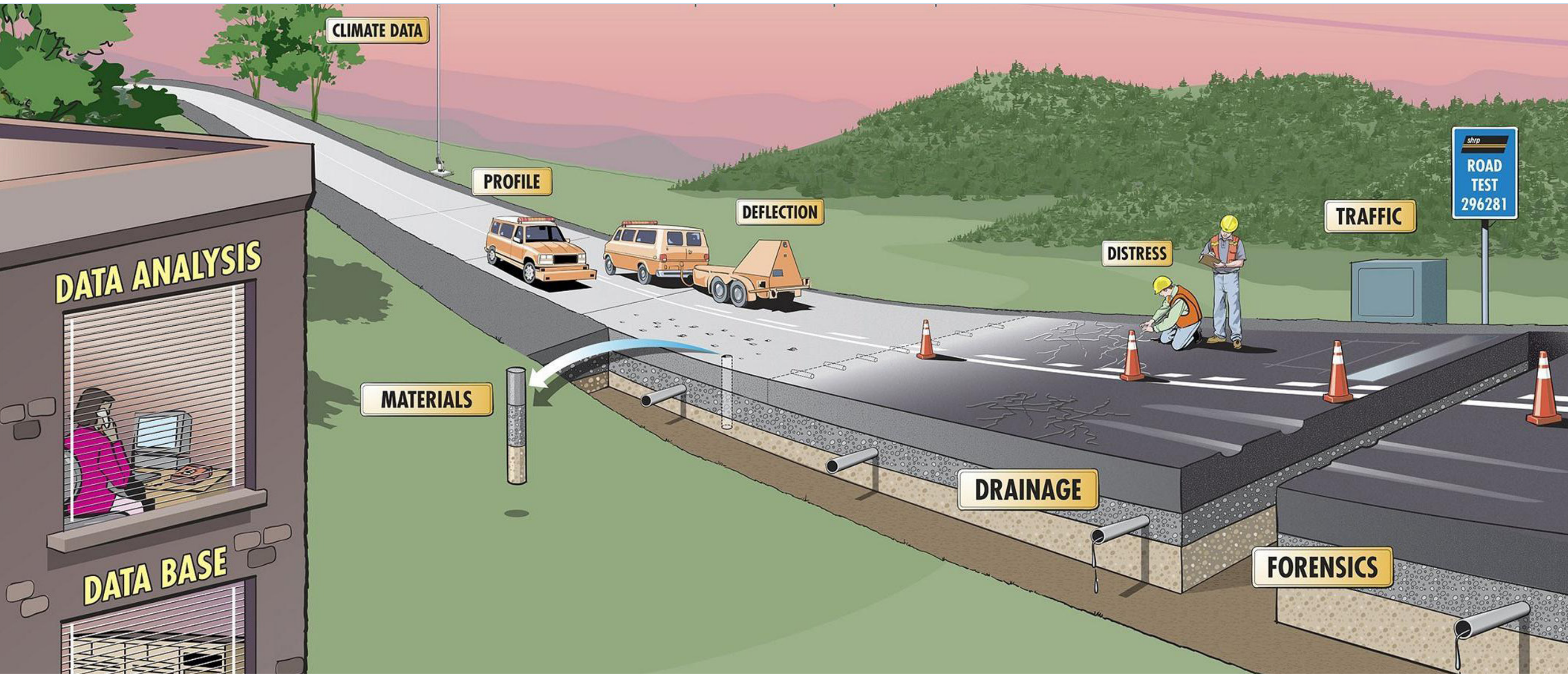
Estimating Design Lane Truck Volumes From HPMS Traffic Data for Long-Term Pavement Performance Analyses

PUBLICATION NO. FHWA-HRT-23-103 NOVEMBER 2023



U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

State highway agencies (SHAs) have large depositories of roadway and/or directional traffic data collected for Highway Performance Monitoring System (HPMS) data submissions. However, the HPMS traffic data are not detailed enough to be used with the Long-Term Pavement Performance (LTPP) or *Mechanistic-Empirical Pavement Design Guide* (MEPDG) models that require design lane-specific annual average daily truck traffic (AADTT). Depending on a model, design lane AADTT values by FHWA vehicle classification or for all heavy vehicle classes (trucks) combined may be needed.

This report documents the LTPP research study that developed methodologies and computational procedures to estimate AADTT in the design lane using HPMS data as inputs. SHAs that do not collect design lane-specific truck volumes, can use the computed parameter tables and equations described in this report to convert HPMS traffic data to design lane-specific AADTT for use with LTPP and MEPDG models to support statewide or network-level pavement performance analyses and pavement management decisions. However, site-specific truck data are still highly recommended for project-level pavement performance analysis and design.

The design lane-specific AADTT estimation methodologies presented in this report can be applied to HPMS datasets to help highway agencies increase use of HPMS data for pavement design, research, management, and forensic investigations. State and Federal agencies involved in the implementation of the LTPP and MEPDG models for pavement performance analysis will find theses methodologies and models presented in this report useful. Contractors, researchers, and consultants can also benefit from the product of this research.

Jean A. Nehme, Ph.D., P.E.
Director, Office of Infrastructure
Research and Development

TECHNICAL REPORT DOCUMENTATION PAGE

<table>
<tr><td>1. Report No.
FHWA-HRT-23-103</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient’s Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Estimating Design Lane Truck Volumes From HPMS Traffic Data for Long-Term Pavement Performance Analyses</td><td colspan="2">5. Report Date
November 2023</td></tr>
<tr><td colspan="2">6. Performing Organization Code:</td></tr>
<tr><td colspan="2">7. Author(s)
M. E. Hallenbeck (ORCID: 0000-0002-2298-0666), K. Verma (ORCID: 0000-0001-7793-4942), and O. I. Selezneva</td><td colspan="2">8. Performing Organization Report No.</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Applied Research Associates, Inc.
7184 Troy Hill Drive, Suite N
Elkridge, MD 21075-7056</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
DTFH61-14-C-00018</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
Office of Infrastructure Research and Development
Federal Highway Administration
6300 Georgetown Pike
McLean, VA 22101-2296</td><td colspan="2">13. Type of Report and Period Covered
Final Report; July 2014–January 2020</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code
HRDI-30</td></tr>
<tr><td colspan="4">15. Supplementary Notes
Deborah Walker (HRDI-30; ORCID: 0000-0002-3684-5190) served as the Contracting Officer’s Representative.</td></tr>
<tr><td colspan="4">16. Abstract
This report documents methodologies, predictive models, and computational procedures to estimate annual average daily truck traffic (AADTT) and AADTT by Federal Highway Administration (FHWA) vehicle classification in pavement design lane using Highway Performance Monitoring System (HPMS) data as inputs. The predictive models use as input variables roadway or directional annual average daily traffic (AADT), AADT of single-unit trucks, AADT of combination trucks, the functional classification of roadway, the number of lanes in the direction of travel, and the State identification. The models produce as output the design lane AADTT or AADTT by FHWA vehicle classification needed by the LTPP and Mechanistic-Empirical Pavement Design Guide (MEPDG) models. First, the Simple Default model parameters were computed for each State because truck types vary considerably from State to State due to differences in truck weight laws. Second, more detailed model parameters were developed for the States that supplied vehicle classification data to FHWA’s Travel Monitoring Analysis System (TMAS). For States that did not supply data to FHWA’s TMAS, model parameters were computed based on available vehicle classification data from the Long-Term Pavement Performance (LTPP) database. State highway agencies can use the computed parameter tables and equations described in this report to convert HPMS traffic data to design lane-specific AADTT by FHWA vehicle classification or for all heavy vehicle classes (trucks) combined for use with LTPP and MEPDG models to support statewide or network-level pavement performance analyses and pavement management decisions.</td></tr>
<tr><td colspan="2">17. Key Words
Traffic data, pavement design, Long-Term Pavement Performance, MEPDG, HPMS, AADTT, design lane</td><td colspan="2">18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.
https://www.ntis.gov</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
60</td><td>22. Price
N/A</td></tr>
</table>

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

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 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 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 (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

AADT	annual average daily traffic
AADTT	annual average daily truck traffic
CPT	computed parameter table
DOW	day of the week
FHWA	Federal Highway Administration
HCM	*Highway Capacity Manual*
HPMS	Highway Performance Monitoring System
LTPP	Long-Term Pavement Performance
MEPDG	*Mechanistic-Empirical Pavement Design Guide*
TLDF	truck lane distribution factor
TMAS	Travel Monitoring Analysis System
TMG	*Traffic Monitoring Guide*
VCDF	vehicle class distribution factor
WSDOT	Washington State Department of Transportation

CHAPTER 1. INTRODUCTION

BACKGROUND

Long-Term Pavement Performance (LTPP) program experiments were designed to analyze damage occurring on a specific pavement section against multiple independent variables collected to ensure those independent variables represented actual loading experienced by each pavement, actual environmental conditions experienced by each roadway test segment, and specific pavement attributes of each segment. LTPP models developed from these analyses were designed to compute pavement performance using truck volume and axle loading data given, by Federal Highway Administration (FHWA) vehicle classification, for the traffic lane being analyzed. The data and findings from LTPP studies were used to develop *Mechanistic-Empirical Pavement Design Guide* (MEPDG) methodologies and pavement performance models.(1)

Traffic Data for LTPP Lanes

As part of the LTPP experiment, it was specifically requested that participating highway agencies collect data on the volume of trucks—based on FHWA vehicle classification (using the 13-bin vehicle classification table presented in FHWA's *Traffic Monitoring Guide* [TMG])—physically crossing LTPP test pavements.(2) The TMG provides guidance to State highway agencies (SHAs) about the policies, standards, procedures, and equipment used in a traffic monitoring program.(2) The resulting LTPP pavement models were designed to compute pavement performance given the volume and nature of truck loads (inputted as axle loads) expected to pass over the lane being analyzed. The analysis lane was intended to be the lane experiencing the highest truck loading of all lanes within that roadway segment (i.e., if a four-lane road was under construction, the pavement was designed based on the one lane that would carry the largest number of heavy trucks).

In practice, SHAs frequently do not have the necessary detailed traffic data for the pavement design lane. The typical source of the traffic data at SHAs is the data collected for, or extracted from, the State Highway Performance Monitoring System (HPMS).(3) According to the 2016 *HPMS Field Manual,* each HPMS roadway segment that is part of HPMS' Full Extent dataset should contain two truck volume statistics: the annual average daily traffic (AADT) volume of single-unit trucks, and AADT volume of combination trucks.(4) These statistical parameters describe either two-way or directional truck volumes for HPMS roadway segments.

Relevant HPMS Tables

The HPMS database field names for the AADT volume of single-unit trucks and AADT volume of combination trucks parameters are AADT_Single_Unit and AADT_Combination, respectively. The HPMS Full Extent dataset also includes AADT statistics that describe two-way AADT volume for each HPMS roadway segment. In addition, HPMS includes the roadway functional classification (F_System) and the number of lanes (Through_Lanes) as required parameters for all roadway sections included in HPMS' Full Extent dataset.(4) These HPMS parameters and the computed parameter tables (CPTs) developed by the research team and documented in this report allow the estimation of design lane annual average daily truck traffic (AADTT), total and by FHWA vehicle class, for each of HPMS' Full Extent roadway sections.

PROBLEM STATEMENT

The HPMS dataset does not include lane-specific truck volumes by FHWA vehicle classification necessary for LTPP and MEPDG models.[1,3] Thus, it was necessary to create a methodology for SHAs to estimate design lane truck volume statistics using available HPMS data as inputs. This approach was deemed more suitable by the research team to building pavement performance equations using AADT as an input because the large variation in the relationship between AADT and traffic loading in the design lane would create models with limited statistical confidence.

Analysis Approach

The approach described in this report uses available HPMS data that all SHAs submit to FHWA annually and new CPTs introduced in this report to produce estimates of annual average daily truck volumes by FHWA vehicle classification specific to the design lane (i.e., the lane with the highest truck volume, typically the rightmost lane) needed by LTPP models. HPMS data used in the AADTT estimation models described in this report are available for any HPMS road section in minor arterial and larger roadway functional classifications, as part of the required HPMS Full Extent traffic data submittal to FHWA.[5]

Applicability

Because truck volume patterns are highly variable and the AADTT estimation models described in this chapter predict typical conditions, they will not accurately estimate unusual truck volume patterns. Thus, the models described in this chapter should be used only when detailed site-specific data are unavailable (e.g., actual vehicle classification counts performed in the design lane), as site-specific data will directly capture a specific road segment’s truck lane distribution and will therefore more accurately represent that site’s traffic flow, as opposed to a model estimating the mean condition for similar roadway segments.

CHAPTER 2. DATA SOURCES AND PREPARATION OF ANALYSIS INPUTS

Primary data used for model development come from FHWA's Travel Monitoring Analysis System (TMAS).[6] The data used for the analysis were through 2016. Data stored in the TMAS were collected using permanent vehicle classification counters operated by SHAs.[2]

DATA SOURCES USED AND DATA SELECTION CRITERIA

All vehicle classification records submitted to the TMAS in 2016 were exported from the TMAS database for further analysis. The research team also obtained station records for all traffic sites in the TMAS.[6] Station records include descriptions of the location (i.e., latitude and longitude) of each traffic site, the road name or road identification number on which it is located, the functional classification of the roadway at that point, and the number of lanes in each direction of travel at that location.

Vehicle classification data from the TMAS were obtained as hourly count records in FHWA's traditional hourly vehicle classification data format.[6] These records can include data for individual lanes, for all lanes in a single direction, or for all lanes in both directions of travel. TMAS codes included in the classification count record clarify which of these three options is used for each data submittal.

Only records submitted in "by lane" format using FHWA's TMG 13-bin vehicle classification system were used in the analysis.[2] Only days of data where data were available for all lanes at a site were used. Data for days where only a subset of hourly records was present were used in the analysis so long as the same number of hours of data was present for all lanes at the site for that day. A site needed 6 months of data to be used in the analysis. Data for 6 months or less are generally considered too small to accurately compute AADT, as it may allow for seasonal error in computation. But, since this analysis focused on the relationship of AADT to design lane volume, the research team decided this relationship should be reasonably stable throughout the year. Thus, errors in actual AADT computation from having only 6 months of data were acceptable, given that bias in AADT values would be mirrored in lane-specific volumes. The research team did not believe foregoing the use of sites with 6 months or less of data had a material impact on project results, but the team lacked the resources to test whether adding or deleting some of these sites materially impacted developed models.

Another data source was LTPP vehicle classification data. For SHAs that did not supply data to FHWA's TMAS, model parameters were computed based on available vehicle classification data from the LTPP database.[7]

COMPUTING INPUTS FOR ANALYSIS

The research team aggregated available records to compute AADT by vehicle classification by lane for each site and direction. The AADT computation method used is described on pages 3 to 97 of the 2016 FHWA TMG.[2] This process initially computed average hour-of-the-day values for each day of the week (DOW), for each month of the year, before computing average DOW volumes for each month, then computing average day of the month, and finally computing AADT. Annual average values by lane were added together to estimate directional AADT by vehicle class for each site, then AADT for all classes was computed by adding the 13 annual average daily vehicle class values together. These computations were all performed by lane.

AADT and AADT by vehicle class for both directions combined were computed by adding the directional values together. This step was complicated by the fact that many SHAs periodically use two different counting devices to collect data for the two different directions of travel. These separate pieces of equipment typically have different station IDs. Thus, it was not always easy to determine when two separate data-reporting stations were from a single roadway section on opposite sides of the roadway. Data from two different directional roadway station IDs were treated as a single site when one of the following conditions was met:

- Different station IDs, from the same State, were located within one-quarter of a mile of each other (based on the airline distance between the latitude and longitude for both sites).

- Those two station IDs contained either the same linear referencing system route ID or the same posted route signed number.

- Those different station IDs contained data from opposite directions (e.g., Direction is "1" and Direction is "5").

The data-processing task also computed single-unit truck (FHWA classes 4–7 combined AADT) and combination truck AADT volumes (FHWA classes 8–13 combined AADT) by lane by direction, for all lanes combined for each direction, and for all lanes in both directions.

Design lane truck volume was determined for each site and direction by comparing individual lane volumes in each direction. The lane with the largest volume of combination trucks (i.e., the sum of vehicles in FHWA classes 8–13 in each direction) was selected as the lane with the largest truck loading for that direction and was designated as the design lane. Therefore, separate design lane volumes exist for each direction of traffic. Since truck volumes differ by direction, this illustrates the inherent variation when estimating design lane truck volumes when AADTT by direction or for both directions combined is provided.

Some locations had data for only one direction of travel. Those sites were kept and used only for directional analyses.

DATA AVAILABILITY SUMMARY

The number of directional sites available for each State after data processing is shown in table 1.

Table 1. Number of directional sites by State and functional classification of roadway.

State	Functional Classification of Roadway												Total
	1R	1U	2U	3R	3U	4R	4U	5R	5U	6R	7R	7U	
AK	31	10	—	18	27	8	20	4	6	—	—	—	124
AL	4	2	—	14	—	—	—	—	—	—	—	—	20
AR	18	8	6	30	2	14	4	12	—	—	—	—	94
CA	31	53	34	25	11	6	—	2	—	—	—	—	162
CO	28	22	18	60	22	30	2	4	—	—	—	—	186
DC	—	2	2	—	—	—	—	—	—	—	—	—	4
DE	—	—	—	14	6	—	—	10	4	4	—	—	38
FL	40	67	33	110	142	74	48	12	2	—	—	—	528
GA	62	76	12	46	44	32	42	34	20	—	—	4	372
HI	—	12	6	4	48	10	14	8	8	—	—	—	110
IA	44	20	2	10	42	6	10	—	2	—	—	—	136
ID	4	—	—	14	6	2	—	2	—	—	—	—	28
KS	31	26	—	24	22	10	—	24	—	—	—	—	137
KY	22	6	—	70	4	6	6	10	—	4	—	—	128
MA	2	19	1	—	6	2	2	—	—	—	—	—	32
MD	6	8	6	10	—	10	2	10	6	—	—	—	58
ME	6	—	—	8	—	14	—	4	—	—	—	—	32
MI	38	20	10	34	5	6	—	—	—	—	—	—	113
MN	5	12	2	40	14	20	10	16	—	—	2	2	123
MO	10	4	2	42	—	8	4	2	—	—	—	—	72
MS	32	18	8	54	12	12	12	14	6	6	—	—	174
MT	42	—	—	51	—	26	—	4	—	—	—	—	123
ND	16	5	—	64	6	23	—	12	—	—	—	—	126
NH	1	2	2	—	—	—	—	—	—	—	—	—	5
NM	12	2	—	28	4	16	—	2	—	—	—	—	64
NV	10	6	6	16	—	—	2	—	—	—	—	—	40
NY	18	16	14	24	18	14	18	13	4	—		2	141
OH	14	62	26	34	12	14	6	4	—	8	—	—	180
OK	—	—	2	4	—	—	—	—	—	—	—	—	6
PA	16	18	2	18	8	12	6	14	—	2	—	—	96
RI	2	6	8	10	2	6	2	2	—	—	2	—	40
VA	43	80	34	90	131	38	14	24	2	—	2	—	458
WA	46	50	53	104	4	24	2	11	—	—	—	—	294
WI	10	2	4	40	6	10	2	8	—	—	—	—	82
WV	25	12	2	30	16	14	12	22	2	2	2	—	139
WY	34	10	—	100	10	26	2	20	—	2	2	—	206
Total	703	656	295	1,240	630	493	242	304	62	28	10	8	4,671

—No data.

1R = Rural Interstate; 1U = Urban Interstate; 2U = Urban Principal Arterial - Other Freeways and Expressways; 3R = Rural Other Principal Arterial; 3U = Urban Other Principal Arterial; 4R = Rural Minor Arterial; 4U = Urban Minor Arterial; 5R = Rural Major Collector; 5U = Urban Major Collector; 6R = Rural Minor Collector; 7R = Rural Local; 7U = Urban Local.

As shown in table 1, TMAS data have relatively few sites classified as collector or local roads. Thus, equations produced by this project were weighted toward freeways and arterials.

Table 1 also shows that a number of SHAs did not submit vehicle classification data to the TMAS database.(6) It was not possible within the scope of this project to obtain vehicle classification data by lane for these States. Instead, for each State without data in the TMAS database, the representative vehicle classification percentage for each FHWA vehicle class 4–13 for each LTPP traffic site in the LTPP database was extracted from the TRF_REP table. The TRF_REP table can be obtained from the InfoPave™ web portal or by contacting the LTPP Customer Support Service Center (ltppinfo@dot.gov).(7) These data were used to provide default values for these States.

States without data in the TMAS database that required default equations are as follows: Arizona, Connecticut, Kansas, Kentucky, Louisiana, Nebraska, New Jersey, North Carolina, Oregon, South Carolina, South Dakota, Tennessee, Texas, Utah, and Vermont. Default equations were also used for New Hampshire, Oklahoma, and the District of Columbia because these States had too few stations in the TMAS to develop reliable State-specific equations. A minimum of six sites were needed to calibrate and test a State-specific model.

CHAPTER 3. FACTORS AFFECTING TRUCK VOLUME DISTRIBUTION BY LANE AND TRUCK BODY TYPE

Conversion of HPMS traffic statistics into design lane truck volumes by the FHWA vehicle classification requires two transformations: disaggregation of roadway truck volume into lane-specific volumes and disaggregation of truck volume into FHWA classes 4–13. The review of the TMAS data revealed that the fraction of trucks in any one lane of traffic on a multilane roadway is a highly variable quantity.(6) Similarly, the relationship between AADT of single-unit trucks ($AADT_{Single\text{-}unit}$) volumes, AADT of combination trucks ($AADT_{Combination}$) volumes, and annual average daily volumes in each of the 10 FHWA "truck" vehicle classes 4 through 13 ($AADT_{FHWA\text{-}n}$) is also highly variable. Factors affecting these relationships and their impacts are described in the following sections.

FACTORS IMPACTING TRUCK VOLUME DISTRIBUTIONS BY LANE

The distribution of trucks across different traffic lanes varies considerably from location to location because a wide variety of factors affect which lane a truck driver chooses to use. This variation is well known in the engineering community and has long been acknowledged in the *Highway Capacity Manual* (HCM).(8) For example, the last three versions of the HCM point out that the lane with the heaviest truck volume can be either the middle or rightmost lane of a three-lane freeway.

In general, as the number of lanes in a direction grows, the percentage of trucks in the design lane decreases. Often, the heaviest truck volume lane (i.e., the design lane for pavement design) is the rightmost lane of travel. However, a number of factors encourage heavy trucks to travel in a lane other than the right-hand lane; thus, the right-hand lane is not always the design lane.

Factors impacting truck lane choice include the following:

- Volume of traffic—As total traffic volume grows and congestion increases, trucks tend to move into less congested lanes, which lowers truck percentage in any one lane.

- Directional differences in truck traffic—On many roads, truck volumes are substantially different in one direction versus the other. When this occurs, dividing total truck volume reported for both directions in half results in overestimating one direction's truck traffic and underestimating truck traffic in the other direction.

- Proximity of on-ramps—The existence of merging traffic from on-ramps often encourages trucks to shift to the left on multilane roads to decrease the number of merge conflicts they experience, which both increases their own safety and lowers the impact merges have on their speed.

- Location and nature of off-ramps or roadway junctions—Truck lane distributions can be significantly affected when trucks need to occupy specific lanes to reach their destination (e.g., trucks move left to be in the correct lane when a freeway-to-freeway interchange or exit is located on the left-hand side).

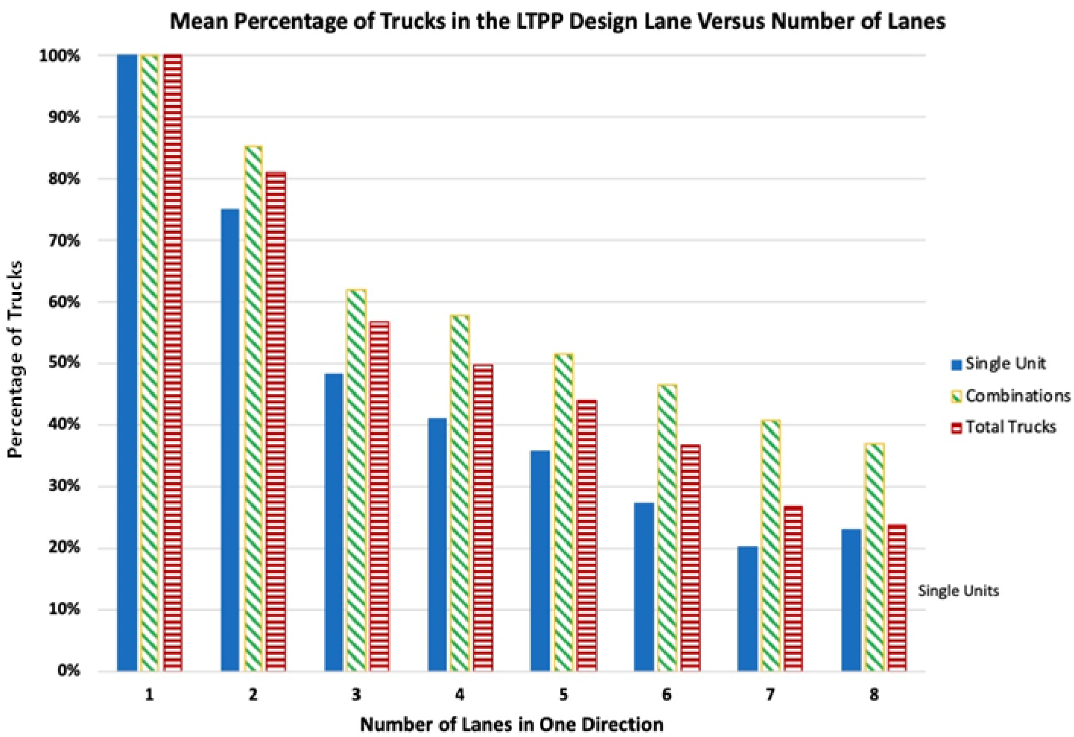
- Pavement condition—Poor pavement condition in one lane compared to other lanes encourages trucks to move to lanes with better ride quality.

- Grade—Steep grades typically result in heavy trucks moving to the right to allow faster vehicles to pass them and lighter trucks using other available lanes to pass slower moving vehicles.

Many of these factors—especially those that are lane-specific—are not data items captured in the HPMS database.[(3)] These factors are not routinely available in many SHA databases and were unavailable for this project analysis. The lack of information on these factors, combined with a lack of detailed research about the relative effects of these factors on truck volumes, is one of the causes of error in the models developed in this project.

Figure 1 shows the mean percentage of single-unit and combination trucks occupying the design lane (i.e., the lane with the largest volume of heavy trucks) given the number of lanes present in a single direction. Figure 1 shows that, for the average two-lane site in the project dataset, 85 percent of combination trucks and more than 80 percent of all trucks are found in the design lane; these percentages drop to 62 percent for combination trucks and 57 percent if there are three lanes in the direction of travel, respectively. The percentage of trucks in the design lane continues to drop as the number of lanes increases. The total volume of trucks typically grows as the number of lanes increases, so the drop in the percentage of trucks in the design lane does not necessarily correlate to a lowering of design lane truck volume.

While figure 1 shows the mean condition, there is considerable variation in these percentages among roadways. The standard deviation in the percentage of combination trucks in the design lane for two-lane roads (one direction of travel) is 13 percent. The standard deviation for three-lane roads is similar.



Source: FHWA.

Figure 1. Graph. Percentage of trucks in the LTPP design lane versus directional number of lanes.

Another way to look at truck lane use is to examine the frequency distribution of the percentage of trucks in the design lane. For two-lane roads (one direction of travel), more than 27 percent of the sites in this project's data sample had a design lane carrying more than 90 percent of total directional truck traffic (i.e., for over a quarter of sites, almost all trucks were found in the design lane). However, if only combination trucks are examined, that 27-percent value rises to 45 percent (i.e., for almost half of all two-lane roads (in one direction of travel), almost all combination trucks were found in the design lane). This finding most likely shows that single-unit trucks often travel in the fast lane (i.e., the leftmost lane), while heavier trucks stay to the right.

At the other end of the distribution of design lane truck traffic, 8 percent of two-lane sites (in one direction of travel) had less than 60 percent of directional total truck traffic in the design lane, and 6 percent of two-lane sites (in one direction of travel) had less than 60 percent of directional combination trucks in the design lane (i.e., while a majority of two-lane sites (in one direction of travel) saw the vast majority of trucks in the rightmost lane for each direction of travel, 6 to 8 percent of two-lane roads (in one direction of travel) had directional truck traffic almost evenly split between the two lanes). Unless available independent variables are used to identify these unusual sites, mathematical models will significantly overpredict design lane truck traffic for these 6 to 8 percent of cases.

Similar variations in the percentage of trucks in the design lane were found if more than two lanes of traffic (in one direction of travel) were present (i.e., 6 to 10 percent of sites had truck lane distribution patterns significantly lower than the normal percentage of trucks using the design lane).

Another factor affecting total truck volume estimates in the design lane is that there can be significant differences in directional truck volumes. Traffic engineers tend to think of volumes as roughly equal in both directions, although the timing of those volumes is commonly different (i.e., morning commute traffic is inbound in the a.m. and outbound in the p.m., but total daily inbound traffic is roughly equal to total daily outbound traffic). With truck volumes, these volumes are not always as closely linked.

Many trucking activities are not out-and-back trips. Freight delivery activities often follow circular routes (i.e., trucks travel from the primary terminal to destination 1 to destination 2 to destination 3 then back to the terminal). For this pattern, roads see truck volume in one direction but not the other. This situation results in different design lane volume for each direction of the roadway.

FACTORS IMPACTING DISAGGREGATING SINGLE-UNIT AND COMBINATION TRUCK VOLUMES INTO FHWA VEHICLE CLASSES

The second major aspect of converting HPMS traffic statistics to design lane inputs is disaggregating the simplified HPMS truck classification scheme (single-unit and combination trucks) into the more detailed FHWA TMG 13-bin vehicle classification scheme.[2,3] FHWA classes 4–7 are included in the HPMS single-unit truck category, while FHWA classes 8–13 are combination trucks. One advantage of this direct correlation is that HPMS truck volume statistics serve as control totals for the conversion. Thus, the only errors occurring in the disaggregation process are in determining the distribution of trucks within these two simplified classes—or when assigning a percentage of those volumes to the design lane.

The percentage of trucks in any one FHWA vehicle class can vary greatly from site to site, and even from one direction of travel to the other on a single road. The following two primary factors affect this distribution:

- The types of economic activities supported by a specific roadway greatly impact the types of loads (i.e., commodities) hauled.
- Size and weight laws for truck traffic determine truck characteristics—and thus truck classes—used to carry those commodities.

Each roadway may serve a specific set of economic activities:

- A farm-to-market road, bringing nearby farm products to processing plants or major distribution centers.
- A roadway serving as a means for getting raw materials to, and finished products from, an industrial facility.

- A local road serving only as a means for distributing goods to residents in a particular area.

- A rural interstate roadway serving as a through route, carrying goods from one community to another.

Economic activities supported by a given roadway determine the size and nature (e.g., weight, bulk) of cargo carried. Given the cargo that needs hauling, trucking companies select specific vehicle configurations based on the economics of those truck types. Vehicle economics change with State-specific size and weight laws; as a result, different vehicle types are often used to haul the same commodities in different States.

These same economic activities also affect the types of trucks observed. This situation is particularly true when one direction of travel is the loaded direction and the other is the empty direction. Many heavy-haul trucks use lift axles to legally carry heavier weights when fully loaded, and these trucks frequently change their FHWA vehicle classification when their lift axles are down versus up (e.g., a Pennsylvania coal truck might be FHWA class 6 (three-axle, single-unit) when empty but FHWA class 7 (four-plus-axle, single-unit) when loaded and with its lift axles down).(3) On a roadway where these trucks travel full in one direction and empty in the other, one direction of travel will observe many FHWA class 7 trucks and few FHWA class 6 trucks, while the other direction of travel will observe the opposite.

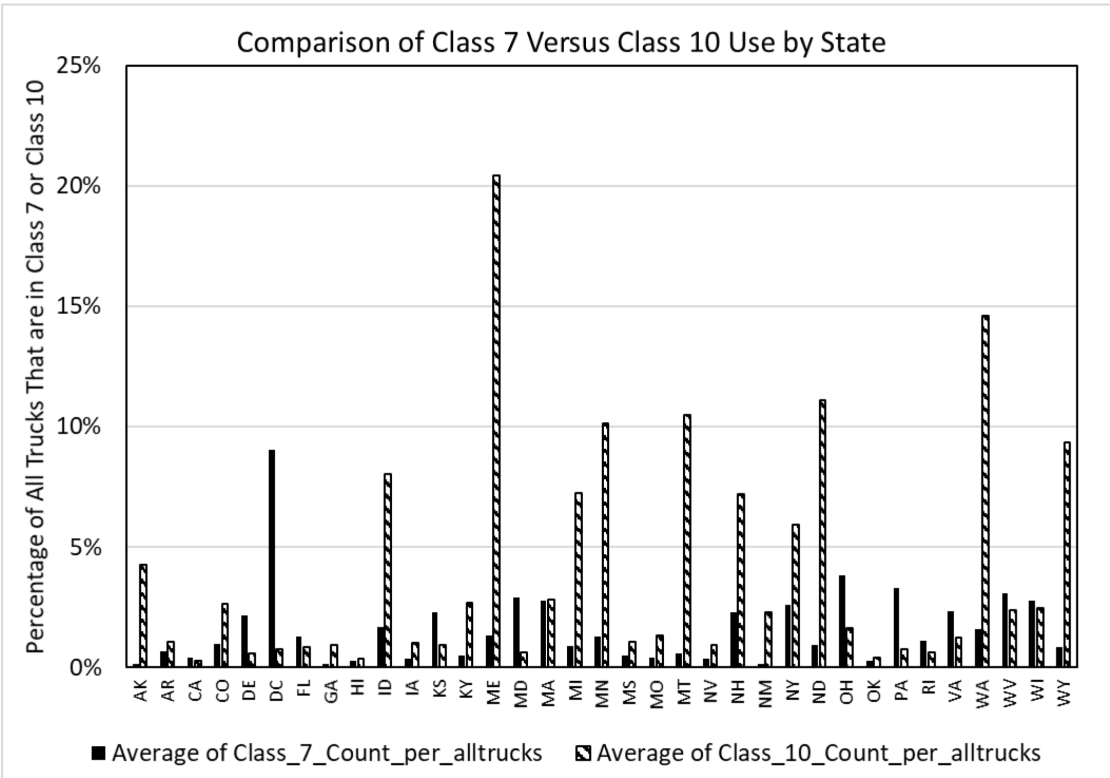
Each State refines their truck size and weight laws to support specific, important economic activities. Legislatures locally optimize those laws given the roadway network in the State and the specific interests of the legislature. In many cases, States adopt laws encouraging particular vehicle types in support of specific industries (e.g., many midwestern States with large coal industries have size and weight laws encouraging the use of large FHWA class 7 vehicles for hauling coal). In this case, five-plus-axle, single-unit trucks capable of carrying very heavy loads are used to move coal on the regional roadway network.

When this usage occurs, roadways in the States serving these industries exhibit a significant increase in the volume of these truck types relative to roadways in other States, or roadways elsewhere in the State where those commodities (e.g., coal) are not routinely hauled.

In contrast to the common use of FHWA class 7 single-unit trucks for hauling heavy natural resources like coal in some midwestern States, many western States adopted laws encouraging the use of FHWA class 10 combination trucks as their primary heavy-resource-hauling vehicles. Thus, many western States show higher FHWA class 10 volumes and lower FHWA class 7 volumes relative to States that adopted laws encouraging the use of FHWA class 7 trucks.

Overriding the relative split between the use of FHWA class 7 versus FHWA class 10 trucks is whether a given roadway actually serves an economic activity requiring moving heavy-natural-resource materials. Without such a need, the number of both FHWA classes 7 and 10 trucks observed using a given roadway can be quite small.

Figure 2 uses available TMAS data to show that data-collection sites in some States (e.g., California, Oklahoma) show relatively low FHWA classes 7 and 10 truck volumes relative to other truck classes.[6] In other States (e.g., Ohio, Pennsylvania, Maryland, and Washington, DC), reasonably high FHWA class 7 percentages are present, signaling lower FHWA class 10 use. In still other States (e.g., Maine, Washington, and Wyoming) FHWA class 10 use greatly outpaces FHWA class 7 use. Finally, some States (e.g., Massachusetts, West Virginia, Wyoming) have modest amounts of both FHWA classes 7 and 10 trucks. Part of this variation in the use of FHWA classes 7 and 10 trucks is a function of the State economy combined with size and weight laws, but some differences can be assigned to the locations selected for data collection by SHAs.

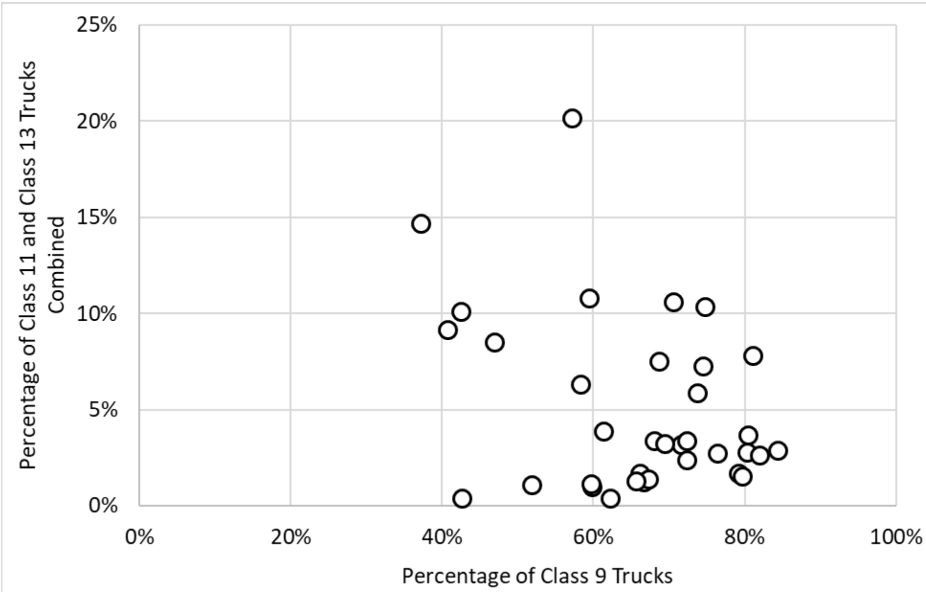


Source: FHWA.

Figure 2. Chart. Percentage of trucks in FHWA vehicle classes 7 and 10 by State (average across available TMAS sites).

Similar to the FHWA classes 7 and 10 relationship is the interrelationship between FHWA classes 9 and 11 and 13. Some States encourage the use of longer combination vehicles (most commonly FHWA classes 11 and 13) to increase trucking productivity, as FHWA classes 11 and 13 trucks allow carrying higher cubic volumes of freight with fewer vehicles. Triple-trailer combination trucks, one of several different FHWA class 13 vehicle configurations, are allowed by 13 Western States. Other States have laws discouraging larger, longer trucks over concerns about safety and maneuverability; in those States, triple-trailer vehicles are illegal.

Varying State laws result in traditional FHWA class 9 trucks (i.e., the class tractor plus semitrailer vehicle configuration) performing the majority of both long-haul and local heavy-freight movements. In other States, multitrailer trucks (specifically FHWA classes 11 and 13) carry a larger percentage of these high-volume freight movements. Figure 3 illustrates this relationship. For each State in the TMAS dataset, figure 3 shows the percentage of FHWA class 9 combination trucks versus the percentage of FHWA classes 11 and 13 combination trucks combined.[(6)] In general, the higher the fraction of FHWA classes 11 and 13 trucks, the lower the percentage of FHWA class 9 trucks; although a high variability is evident in figure 3.



Source: FHWA.

Figure 3. Chart. Correlation between FHWA classes 11 and 13 truck percentage and FHWA class 9 truck percentage .

While State size and weight laws significantly impact truck configurations in that State, many truck movements cross State lines, and such movements are impacted by multiple sets of size and weight laws. Where roadways serve long-haul trucking movements instead of local movements, Federal size and weight laws tend to govern truck configurations—rather than State-specific allowances above Federal limits permitted by individual States—as trucks making those interstate movements need to be legal in all States through which they pass.

The mix of trucks using a roadway is a result of the following:

- Differences in commodities being carried.
- Differences in truck configurations encouraged by State laws.
- Percentage of trips using roadways for long-haul, multistate trips versus in-State movements.

These factors result in considerable variation in the following:

- Number of trucks using any given roadway.
- Volume of trucks traveling in different directions on a given roadway.
- Types (i.e., classification) of trucks using any given roadway.
- Distribution of truck volumes across multiple lanes when more than one lane is present in any given direction of travel.

CHAPTER 4. ANALYSIS METHODOLOGY

Conversion of HPMS[3] traffic statistics into design lane truck volumes by the FHWA vehicle classification requires two transformations. The first transformation disaggregates combined roadway truck volume into lane-specific volumes so the truck volume in the most heavily used lane (in terms of heavy-truck volumes) can be identified and reported. The second transformation disaggregates single-unit truck volumes into FHWA classes 4–7 and combination truck volumes into FHWA classes 8–13. The two basic relationships (distribution of truck volume across lanes and distribution of truck volume across FHWA truck classes) were modeled in multiple ways as part of the analytical efforts in this project. In some models, the formula produced performed both tasks in one step; in other models, these two tasks were treated separately. Analytical modeling methods used in this project are briefly described in the following sections. The detailed description of the recommended model is provided in chapter 6.

INDEPENDENT VARIABLES TESTED IN THE MODELS

The modeling effort started with nine possible features (independent variables). These features included the following three descriptors of the station (roadway segment) itself:

- The functional classification of the roadway.
- That road section's rural or urban classification.
- The number of travel lanes (obtained both by direction and for both directions combined).

Six features, all describing site-specific traffic volume conditions available through the HPMS data, were then incorporated into the models. These six variables are as follows:

- AADT in both directions on this segment.
- Annual average daily number of single-unit trucks in both directions on this road segment.
- Annual average daily number of combination trucks in both directions on this road segment.
- The percentage of all vehicles that are single-unit trucks.
- The percentage of all vehicles that are combination trucks.
- The percentage of vehicles that are cars.

In addition, the State itself was treated as a "feature" in that separate models were developed for each State for which sufficient data were present. This step was done because the mix of trucks across FHWA classifications differs from State to State because of the differences in State truck size and weight laws.

SIMPLE DEFAULT MODEL

The simple model (also called the "Simple Default model") used mean values for national and State-specific truck patterns to compute factors for distributing roadway truck volume across travel lanes and across FHWA vehicle classes 4–13. This approach was developed based on the notion that factors causing truck drivers to select specific lanes are similar throughout the country, while State-specific size and weight laws have considerable impacts on truck classes found on roadways in specific States.

The simple model included development of two sets of factors that could be applied to estimate design lane AADTT and AADTT by FHWA vehicle classes 4–13 from roadway AADTT or roadway AADT of single-unit and combination trucks available for HPMS road sections. The first factor is used to estimate what fraction of the roadway truck traffic volume occurs in the pavement design lane. Mean national conditions were used to compute the default truck lane distribution factors (TLDFs) for roadways with different numbers of lanes. Therefore, the TLDF value is dependent on the number of lanes present in the selected direction of travel for a selected HPMS road section.

The second factor is the statewide average fraction (provided for all road functional classes or by aggregated road functional class for each State) of single-unit truck travel occurring within a selected FHWA vehicle classification. That is, for FHWA class 4, this factor is the average fraction of single-unit truck travel that is made up of FHWA class 4 trucks. For this project, the factors were developed using the State submitted TMAS data.(6) State-specific mean values by aggregated road functional class were used to compute default vehicle class distribution factors (VCDFs) for each FHWA vehicle class 4–13. SHAs that have permanent vehicle classifiers but have not submit those data to FHWA should use data collected from those traffic counting devices to develop their own statewide fractions.

MULTIPLE REGRESSION MODELS

The analysis approach selected for this project was multiple regression with best subset selection performed using the least absolute shrinkage and selection operator, or "LASSO," technique. Python® scripts were used to perform a series of *k*-fold cross validation checks of the data.

In this technique, the available data were divided into training and test datasets. The model was trained on a subset of the data, and the resulting models were then tested against the remaining set of the data. In the *k*-fold technique, this process is repeated multiple times using different subsets of the data for training and testing. This step allows the user to examine the effectiveness of multiple training runs, and the combined testing results provide more confidence in the estimated errors from the process. For this project, for each pass through the technique, two-thirds of the data were used to train each model, and the remaining one-third of the data were used to test those models.

Several multiple regression models were developed using the methodology discussed in the preceding sections. The following basic model formulations were attempted:

- Option No. 1: Models were constructed to estimate the fraction of trucks in each of the 10 FHWA vehicle classes that occur in the pavement design lane. The fractions estimated by the equations must then be multiplied by the annual average daily directional single unit and combination truck volumes to obtain the pavement design lane volumes by FHWA class.

- Option No. 2: Multivariate linear models were constructed using the available HPMS independent variables as inputs, which directly estimate the truck traffic volumes occurring within the pavement design lane.

- Option No. 3: Multivariate linear models were constructed using both the available HPMS independent variables, as well as interactive terms involving those same variables, as inputs (e.g., in addition to testing the use of the variables "number of lanes," and "AADT," the variable "AADT/number of lanes" was tested as an independent variable). These equations directly estimated the truck traffic volumes (by FHWA classification) occurring within the pavement design lane.

The first of these models was designed to improve on the Simple Default model described in the previous section that was built on the "State average" truck distribution by FHWA vehicle classes 4–13. The predicted (output) values must then be multiplied by directional truck volumes for the aggregated truck classes (i.e., the directional AADT for single-unit or combination truck). For this set of equations, the multivariate regression model predicts the fraction of the directional single-unit and combination truck volume occurring in the pavement design lane in each of the FHWA vehicle classes 4–13. This type of multivariate regression model formulation was selected because the large variation in volume between sites (i.e., some sites have very high truck volumes while other sites have very low truck volumes) can result in unintended overemphasis on the high-volume sites in the regression mathematics. Predicting a normalized variable (fraction of truck volume), rather than the actual volume of the individual FHWA classes, allowed this regression model to weigh the different test sites more evenly, rather than allowing larger absolute errors from higher volume roads to impact the model coefficient selection more heavily.

The regression models were tested and calibrated. The model calibration resulted in different sets of independent variables selected for the various equations for each vehicle class and State, as well as different coefficients selected for application against the independent variables, making practical application of these models highly complex. Regression models developed for individual States performed better than the Simple Default models, although not by significant amounts.

REGIONAL MODELS USING CLUSTER ANALYSIS

A series of "regional" models were also developed and tested. This series was the project team's attempt to define States with similar trucking characteristics, in order to both increase the sample size used to train models and to provide more widely applicable models that could be applied in States for which limited or no data were currently available for model training.

The "regional grouping" process tried to combine States through the use of cluster analysis, based on the fraction of single-unit trucks that are found in FHWA vehicle class 7, and the fraction of combination trucks that are in FHWA vehicle classes 10 and 13. The intent of the clustering process was to identify groups of States that encouraged or discouraged specific types of heavy vehicles: classes 7, 11, and 13. Slightly different cluster groupings were created based on the clustering technique used, whether the data input to the cluster process consisted of the individual stations or whether the statewide averages were used as inputs, as well as the number of clusters selected as a stopping point.

Unfortunately, the process of grouping States into clusters and then applying the regression models did not produce reliable results. In all cases, the regional models produced overall results that were less accurate than the Simple Default models produced by using the average statewide condition. The project team concluded that the data indicate that State-specific differences in the nature of trucks were large enough that it was better to compute models for each State.

CHAPTER 5. EVALUATION OF THE MODELS DEVELOPED FOR THIS PROJECT

The research team developed and tested both a simple model and several more complex models for predicting design-lane-specific truck volumes. The complex models used multivariate regression techniques as an attempt to predict design-lane-specific truck volumes more effectively. The simple model used mean values for national and State-specific truck patterns. Unfortunately, neither the simple nor complex models worked as well as desired. In some cases, the complex models worked slightly better than the simple models, but the differences were small, and the performance of these models was not consistent from one State to another. As a result, the research team concluded that the added benefits from using a more complex model structure, which required considerable time and data to calibrate, did not provide acceptable benefits. Consequently, the simple model was ultimately selected.

MODEL EVALUATION APPROACH

A number of complex multivariate regression models were developed for this project to predict design lane truck traffic volume from roadway truck traffic volume. These models were tested by predicting design lane truck traffic volume for over 4,500 directional roadway sites. The models were initially tested by dividing the sites into “model development” and “test” locations. The models developed from one set of sites were then evaluated by predicting design lane truck traffic volumes at the test sites. These procedures were repeated using different subsets of the 4,500 sites as “development” and “test” locations. Consequently, each effort produced slightly different models and evaluation results. Test results were averaged across all models, and the final models were developed based on the entire test dataset.

The results showed conclusively that data available in the HPMS[3] database lack sufficient explanatory power to effectively account for the multitude of factors affecting design lane truck volumes. As a result, the multivariate regression models developed for this project were moderately accurate at best. The results are unbiased in that the models both underestimate and overestimate design lane truck volumes by class in equal measure. Unfortunately, the estimates have large error bounds because of the high degree of variability in truck volume patterns on roadways in each State and across the nation. When used in statewide analyses (e.g., applied to a large number of sites in a State), the errors balance out (i.e., design lane truck volumes and volumes by class were overestimated for some individual roadway segments and underestimated for an equal number of others, but the estimate for any specific roadway segment was likely to be of modest quality). Model test results are described in more detail in the following sections.

ERROR STATISTICS USED

The initial statistic used to examine the effectiveness of the models was the absolute percentage error in the design lane truck estimates by vehicle classification. However, this statistic tended to overestimate the importance of errors in truck classes with low volumes (i.e., when volume in a given truck class is very low, relatively small absolute errors in predicted volume can result in large percentage errors).

Consequently, in addition to computing the absolute percentage error, the research team developed a hybrid performance statistic called failure percentage and its corollary called success percentage. These statistics were computed using both the absolute error associated with a predicted truck volume estimate and the percentage error associated with that absolute value.

The rationale behind this statistic is that when volumes in specific truck classes are very low, the best statistic to use when judging the quality of a prediction is the size of the absolute error. However, when volumes in a truck class are high, the best statistic for judging the quality of a prediction is the absolute percentage error.

Because the models under development predict truck volumes across all 10 truck classes and all roadways in a State—some of which are high volume and some of which are very low volume—a descriptive measure of model performance was selected to be a combination of absolute error and absolute percentage error. The resulting criterion is a simple binary statistic (success or failure) for each truck volume prediction. These statistics can also be computed for aggregated truck classes, such as the prediction of single-unit, combination, or multitrailer truck volumes.

EVALUATION RESULTS

Out of all models developed for this project, the following three models showed better results and were evaluated in more detail:

- The Simple Default model.
- The Design Lane Fraction Prediction model based on multiple regression.
- The Direct Volume Prediction model based on multiple regression.

To compare the various model outputs and explain the reliability of the resulting estimates, the project team resorted to examining the "failure criteria." The failure criteria determine the fraction of predictions made by a model formulation where both the absolute error in the prediction of a given FHWA vehicle class for a specific test site exceeds 10 vehicles and the absolute percentage error in that prediction exceeds 30 percent of the actual truck volume. This combination of error measurements is designed to indicate the number of "poor" design lane truck volume estimates.

For low-volume vehicle classes, the controlling statistic is an error that is greater than 10 vehicles. For low-volume truck classes, which can experience one or two trucks per day of some FHWA vehicle classes, the 10-truck-per-day error tends to result in a percentage error of more than 200 percent. Thus, for low-volume sites, even small absolute errors in the truck volume estimate—and which are typically irrelevant for pavement analysis—tend to result in very large percentage errors. These large percentage errors thus overstate the size of the error. Thus, a "bad" low-volume classification estimate occurs when the model predicts a volume that either overpredicts actual volume by 10 trucks per day, or underpredicts actual volume by 10 trucks per day. Sites with only small absolute volume errors are considered "acceptable" even if they have large percentage errors.

Conversely, for high-volume truck classes, the 10-truck-per-day criterion is too strict, as this small volume represents a small fraction of the volume of many truck classes within the design lane. For these roads, even a very good truck volume prediction can have an error of more than 10 trucks, as this may represent a small fraction of the expected daily design lane volume. Thus, for high volume truck classes, the controlling criteria is whether the predicted truck volume falls within 30 percent of the actual design lane volume.

Table 2 lists the computed “average failure criteria” (also called the “poor estimate rate”) for the three model approaches. That is, table 2 shows the percentage of predictions that would be considered “poor” given the dual criteria of the error both being greater than 30 percent and also being larger than 10 vehicles per day. (Note that table 2 through table 4 compare only the results from States for which all three models were computed. Data from States that did not upload truck volume counts to TMAS are not included in table 2 through table 4.)

In case the reader prefers to judge the various models on how frequently they work well, rather than how frequently they perform poorly, table 3 shows the percentage of predictions that fall within either 30 percent or 10 vehicles.

The failure criteria shown in table 2 are initially computed by State. The State values are then averaged to produce the values shown in table 2. Table 3 is computed by subtracting the values in table 2 from value of 1. Thus, these values show the “average” performance of the different models. The actual performance of these models varies for each FHWA vehicle class and each State. In fact, there is considerable variation in each performance of these models both within each of the individual FHWA vehicle classes and within States. The results reported in table 2 through table 4 also reflect the data samples available through TMAS.(6) Where the TMAS data samples are not representative of statewide conditions, the actual results experienced by each State will differ from the results shown in the tables.

Table 2. Relative performance of the three primary models (percentage of poor estimates).

Model	FHWA Class 4	FHWA Class 5	FHWA Class 6	FHWA Class 7	FHWA Class 8	FHWA Class 9	FHWA Class 10	FHWA Class 11	FHWA Class 12	FHWA Class 13
Design Lane Fraction Prediction (percent)	30	30	36	21	43	20	25	20	14	19
Simple Default (percent)	31	27	36	18	52	26	27	23	17	18
Direct Volume Prediction (percent)	38	47	47	25	40	47	37	30	21	28

Table 3. Relative performance of the three primary models (percentage of good estimates).

Model	FHWA Class 4	FHWA Class 5	FHWA Class 6	FHWA Class 7	FHWA Class 8	FHWA Class 9	FHWA Class 10	FHWA Class 11	FHWA Class 12	FHWA Class 13
Design Lane Fraction Prediction (percent)	70	70	64	79	57	80	75	80	86	81
Simple Default (percent)	69	73	64	82	48	74	73	77	83	82
Direct Volume Prediction (percent)	62	53	53	75	60	53	63	70	79	72

The variation in the performance of the model equations can be partially examined by looking at the standard deviation of the "failure criteria." Table 4 shows the standard deviation of the State statistics that make up the statistics shown in table 2.

Table 4. Standard deviation of the State-specific poor estimate rate.

Model	FHWA Class 4	FHWA Class 5	FHWA Class 6	FHWA Class 7	FHWA Class 8	FHWA Class 9	FHWA Class 10	FHWA Class 11	FHWA Class 12	FHWA Class 13
Design Lane Fraction Prediction (percent)	17	15	15	21	14	11	11	16	11	12
Simple Default (percent)	16	17	14	16	13	17	10	15	10	12
Direct Volume Prediction (percent)	28	27	23	29	25	22	27	29	22	25

As can be seen in table 4, the standard deviation of the failure criteria is generally between 10 percent and 25 percent. It is the combination of the modestly high percentage of "poor estimates" from the models, and the fairly high level of variation in those failure rates, which leads to the conclusion that none of these models works with a high degree of accuracy and precision.

When the performance of the three different model formulations were compared, it was determined that no one model formulation routinely outperformed the other two model formulations. However, the models do work reasonably well, more than they fail. They are, thus, considered a useful, if inexact, mechanism to applying LTPP models for statewide or network-level analyses within the HPMS framework.

CONCLUSIONS AND RECOMMENDATIONS

Complex multivariate regression models did not predict the volume of trucks by FHWA vehicle class in the design lane with appreciably better accuracy than the simple model based on the State mean percentage of trucks in each FHWA vehicle class within each aggregated truck class (i.e., aggregated single-unit or combination truck classes) combined with a nationwide estimate of the percentage of each aggregated truck class in the design lane for a given number of lanes of traffic in a single direction. Therefore, the simplified methodology using statewide statistics is recommended for estimating design lane AADTT using HPMS[3] data because of better transparency of how these statistics were developed and applied. The simplified methodology is applicable for statewide or network-level analyses where site-specific data are unavailable. Using this methodology, SHAs have the option of using mean values computed for all roadways or for subsets of roadways within different functional classifications. As an approach to selection of specific defaults, the best option varies from State to State based on how truck volumes vary across the State.

CHAPTER 6. RECOMMENDED FINAL MODEL AND PARAMETERS

The final design lane AADTT estimation model recommended by the research team for practical implementation uses parameters developed based on the mean values from the national and State-specific truck data collected by continuously counting traffic sites that were available through TMAS(6) at the time of this research study. Mean national conditions were used to determine the distribution of trucks across lanes, and State-specific means were computed to describe the classes of trucks present on different road functional classes within each State. These models assume that factors causing truck drivers to select specific lanes are similar throughout the country, while State-specific size and weight laws have considerable impacts on truck classes found on roadways in specific States.

DESCRIPTION OF SELECTED MODELS

Estimating Design Lane AADTT From HPMS Single-Unit and Combination Truck AADTs

If the SHA wishes to estimate AADTT in the design lane using HPMS data, the AADT_Single_Unit, AADT_Combination, and Through_Lanes parameters from HPMS' Full Extent dataset could be used in combination with the TLDFs for single-unit and combination trucks developed in this study and presented in the TRUCK_VOLUME_DESIGN_LANE_FRACTIONS table (see appendix table 12).(3) The following equation shows the computational process:

$$AADTT_{Design\ Lane} = \left(\frac{AADT_{Single-unit}}{2} \times TLDF_{Single-unit}\right) + \left(\frac{AADT_{Combination}}{2} \times TLDF_{Combination}\right) \quad (1)$$

Where:

$AADTT_{Design\ Lane}$ = the estimate of design lane AADTT for FHWA vehicle classes 4–13 combined.

$TLDF_{Single-unit}$ = the TLDF for single-unit trucks from the TRUCK_VOLUME_DESIGN_LANE_FRACTIONS table (see appendix table 12) for the number of lanes in the design direction of travel (Through_Lanes parameter from the HPMS) for the selected HPMS roadway segment.

$TLDF_{Combination}$ = the TLDF for combination trucks from TRUCK_VOLUME_DESIGN_LANE_FRACTIONS table (see appendix table 12) for the number of lanes in the design direction of travel (Through_Lanes parameter from the HPMS) for the selected HPMS roadway segment.

$AADT_{Single-unit}$ = the two-way AADTT for single-unit trucks for the selected HPMS roadway segment, stored as AADT_Single_Unit parameter in the HPMS dataset. (Because HPMS AADT_Single_Unit parameter values are for both directions combined, this value is divided by "2" in equation 1 to obtain a directional volume. If the HPMS roadway segment for which volume is produced is directional, do not divide by "2.")

$AADT_{Combination}$ = the two-way AADT for combination trucks for the selected HPMS roadway segment, stored as AADT_Combination parameter in the HPMS dataset. (Because HPMS AADT_Combination parameter values are for both directions combined, this value is divided by “2” in equation 1 to obtain a directional volume. If the HPMS roadway segment for which volume is produced is directional, do not divide by “2.”)

Estimating Design Lane AADTT for FHWA Vehicle Classes 4–13 From HPMS Single-Unit and Combination Truck AADTs

If the SHA wishes to estimate design lane AADTT for each of the FHWA vehicle classes 4–13 using HPMS roadway segment AADT values for single-unit and combination trucks, the following two equations could be used. If the HPMS roadway segment for which AADTT is estimated has only one direction of travel, do not divide $AADT_{Single\text{-}unit}$ or $AADT_{Combination}$ values by “2” in equations 2 and 3.

For single-unit trucks (FHWA classes 4–7):

$$AADTT_{FHWA-n} = \frac{AADT_{Single-unit}}{2} \times TLDF_{Single-unit} \times VCDF_{S-n} \tag{2}$$

Where:

$AADTT_{FHWA\text{-}n}$ = the estimate of design lane AADTT for FHWA vehicle class *n* (where in this case, *n* could be any FHWA class from 4 to 7).

$VCDF_{S\text{-}n}$ = the fraction of single-unit trucks expected in FHWA class *n* (where in this case, *n* could be any FHWA class from 4 to 7) obtained from State-specific defaults for all road types combined or from State-specific defaults based on the category of road for that HPMS section (e.g., the rural interstate category or the all roads other than interstates and expressways category) provided in the HPMS_FHWA_CLASSIFICATION_FRACTIONS table (see appendix table 13).

For combination trucks (FHWA classes 8–13):

$$AADTT_{FHWA-n} = \frac{AADT_{Combination}}{2} \times TLDF_{Combination} \times VCDF_{C-n} \tag{3}$$

Where:

$AADTT_{FHWA\text{-}n}$ = the estimate of design lane AADTT for FHWA vehicle class *n* (where in this case, *n* could be any FHWA class from 8 to 13).

$VCDF_{C\text{-}n}$ = the fraction of combination trucks expected to be found in the FHWA vehicle class *n* (where in this case, *n* could be any FHWA class from 8 to 13), obtained from State-specific defaults for all road types combined or from State-specific defaults based on the category of road for that site (e.g., the rural interstate category or the all roads other than interstates and expressways category) provided in the HPMS_FHWA_CLASSIFICATION_FRACTIONS table (see appendix table 13).

Estimating Design Lane AADTT and Design Lane AADTT by FHWA Vehicle Class Without Access to HPMS Single-Unit and Combination Truck AADT Statistics

Some SHAs may be working from a database that stores only roadway AADT and a percent truck value. In this case, the ALL_TRUCK_FHWA_CLASSIFICATION_FRACTIONS table (see appendix table 14) can be used to estimate design lane AADTT by vehicle class (for FHWA vehicle classes 4–13) in combination with AADT and percent truck values.

To estimate design lane AADTT by FHWA vehicle classification for a roadway segment, the following equation is used:

$$AADTT_{FHWA-n} = \frac{AADT}{2} \times \frac{Percent\ Trucks}{100} \times VCDF_n \times TLDF_{AllTrucks} \tag{4}$$

Where:

$AADTT_{FHWA\text{-}n}$ = the estimate of design lane AADTT for FHWA vehicle class *n* (where in this case, *n* could be any of the FHWA classes 4–13).

AADT = the two-way AADT for the selected roadway segment. If the HPMS roadway segment for which $AADTT_{FHWA\text{-}n}$ is being estimated has only one direction of travel, do not divide *AADT* values by “2” (two) in equation 4.

Percent Trucks = the percentage of AADT that is estimated to be trucks.

$VCDF_n$ = the VCDF for FHWA vehicle class *n* (i.e., the fraction of all trucks in FHWA classes 4–13 that fall within FHWA class *n*) taken from table 14, for the selected State, and the function classification of road category for the selected roadway segment.

$TLDF_{AllTrucks}$ = the TLDF taken from table 12 for all trucks combined for a given the number of through lanes in the design direction of travel for the selected roadway segment.

To estimate design lane AADTT for a roadway segment, the following equation is used:

$$AADTT_{Design\ lane} = \frac{AADT}{2} \times \frac{Percent\ Trucks}{100} \times TLDF_{AllTrucks} \tag{5}$$

DESCRIPTION OF MODEL PARAMETERS

The TLDFs for single-unit trucks ($TLDF_{Single\text{-}unit}$), combination ($TLDF_{Combination}$), and all trucks combined ($TLDF_{AllTrucks}$) were computed from logarithmic functions developed by the research team based on the relationships found within TMAS data extracted for this project. To determine the TLDFs, design lane volumes for single-unit trucks, combination trucks, and all trucks combined were computed, along with annual average (directional) single-unit truck, combination truck, and total truck volumes, for all lanes combined in that direction. The relationship between total volume and design lane volume was determined using linear, exponential, and logarithmic formulations. Logarithmic formulations provided the best results, with R^2 values of 0.79 for single-unit trucks and 0.66 for combination trucks.

The last column in table 12 shows the expected fraction of all trucks combined (in FHWA classes 4–13) in the design lane, given the number of lanes in the direction of travel. The last column in table 12 can be used by SHAs when performing non-HPMS-related analyses where $AADT_{single\text{-}unit}$ or $AADT_{combination}$ values are unavailable.

Vehicle Class Distribution Factors

The *VCDFs* were developed using TMAS data submitted by SHAs, and where data were unavailable, lane-specific traffic-monitoring data from the LTPP database were used.

For single-unit trucks (FHWA classes 4–7), $VCDF_{S\text{-}n}$ values are computed as shown in equation 6:

$$VCDF_{S-n} = \frac{FHWA_{S-n}}{FHWA_4 + FHWA_5 + FHWA_6 + FHWA_7} \tag{6}$$

Where $FHWA_{S\text{-}n}$ is the AADT of single-unit trucks in FHWA class n (n = 4, 5, 6, 7).

For combination trucks (FHWA classes 8–13), $VCDF_{C\text{-}n}$ values are computed as shown in equation 7:

$$VCDF_{C-n} = \frac{FHWA_{C-n}}{FHWA_8 + FHWA_9 + FHWA_{10} + FHWA_{11} + FHWA_{12} + FHWA_{13}} \tag{7}$$

Where $FHWA_{C\text{-}n}$ is the AADT of combination trucks in FHWA class n (n = 8, 9, 10, 11, 12, or 13).

For all trucks combined (FHWA classes 4–13), $VCDF_{C\text{-}n}$ values are computed as shown in equation 8:

$$VCDF_n = \frac{FHWA_n}{\sum_4^{13} FHWA_n} \tag{8}$$

Where $FHWA_n$ is the AADT of trucks in FHWA class n (n = 4, 5, 6, 7, 8, 9, 10, 11, 12, or 13).

First, $VCDF_{S\text{-}n}$, $VCDF_{C\text{-}n}$, and $VCDF_n$ values were computed at individual count locations around a State. Then, the mean value was computed across all locations within a State or for a defined subset of roadways within a State (e.g., rural interstates).

Additional $VCDF_{S\text{-}n}$, $VCDF_{C\text{-}n}$, and $VCDF_n$ values were computed as averages for specific aggregations of functional class roadways for each State (subject to TMAS data availability), such as only rural interstates. The computed $VCDF_{S\text{-}n}$ and $VCDF_{C\text{-}n}$ values are presented in table 13 in the appendix of this report. Up to five categories of $VCDF_{S\text{-}n}$ and $VCDF_{C\text{-}n}$ were developed for each State, including the following roadway categories: statewide averages, rural interstates, all roads except rural interstates, urban interstates and expressways, and all roads except interstates and expressways. Not all States have data in every category in table 13 because some data were unavailable to the research team. It is assumed that SHAs will select the category they wish to use (or supply their own), given the nature of truck traffic in their State. Whenever possible, SHAs are encouraged to develop their own $VCDF_{S\text{-}n}$ and $VCDF_{C\text{-}n}$ tables, as they have data resources unavailable for this project that could improve on the tables in this report.

Two approaches were selected for creating $VCDF_{S\text{-}n}$ and $VCDF_{C\text{-}n}$ default statistics for each State based on data availability. The first approach was for States that supplied more than six sites of truck volume data to the TMAS database.[6] For each TMAS site, annual average daily volume for each class of vehicles (i.e., $FHWA_n$) was computed using TMAS data. From these values, $VCDF_{S\text{-}n}$ and $VCDF_{C\text{-}n}$ were computed for that site using the formula defined in equations 6 and 7 for FHWA classes 4–7 and FHWA classes 8–13, respectively. A straight average of these site-specific values across all sites was computed for use as the statewide default.

The second approach was used when insufficient data were available in the TMAS database (fewer than six sites) for a State. In these cases, truck volume data present in the LTPP database were used in addition to TMAS data. For States that did not submit truck volume data to the TMAS database, State defaults were based entirely on LTPP data from the TRF_REP table. The TRF_REP table can be obtained from the InfoPave web portal or by contacting the LTPP Customer Support Service Center (ltppinfo@dot.gov).[7] In the TRF_REP table, a value is present for each LTPP test site indicating the percentage of trucks (FHWA classes 4–13) found in a given vehicle class at that site. These values were then converted to the required $VCDF_n$ statistics with the $VCDF_n$ value being set equal to the fraction of truck traffic in each of the FHWA class n (n = 4, 5, 6, 7, 8, 9, 10, 11, 12, 13). The mean value for each FHWA vehicle class n was computed across all sites in a State and presented in appendix table 14 as $VCDF_n$.

DESCRIPTION OF COMPUTED PARAMETER TABLES

The appendix included in this report contains the following three tables, described in the following sections. These tables provide SHA users of LTPP models with the default values necessary to compute design lane-specific truck volume inputs for HPMS segments included in a State's HPMS full-extent traffic statistics submittal.

- The TRUCK_VOLUME_DESIGN_LANE_FRACTIONS table contains default TLDFs to estimate truck traffic volume in the design lane (see table 12 in the appendix).

- The HPMS_FHWA_CLASSIFICATION_FRACTIONS table contains default $VCDF_{S\text{-}n}$ and $VCDF_{C\text{-}n}$ for each of the FHWA vehicle classes 4–13 to be used for design lane AADTT by vehicle class estimation with the HPMS AADT values for single-unit and combination trucks (see table 13 in the appendix).

- The ALL_TRUCK_FHWA_CLASSIFICATION_FRACTIONS table contains default $VCDF_n$ for each of the FHWA vehicle classes 4–13 to be used for design lane AADTT by vehicle class estimation with the HPMS AADT and truck percent values for roadway segments, when values for AADT_Single_Unit and AADT_Combination parameters are unavailable in the HPMS dataset (see table 14 in the appendix).

TRUCK_VOLUME_DESIGN_LANE_FRACTIONS Table

The TRUCK_VOLUME_DESIGN_LANE_FRACTIONS table is included in the appendix as table 12. This CPT describes the default mean fraction of trucks traveling in one direction that are likely to be found in the design lane, given the number of lanes on that roadway segment in that direction of travel. For example, for a four-lane road with two lanes northbound and two lanes southbound, the "number of lanes" value used as a look-up value in the table would be "2" (two). Three TLDF values are present in each row in the table. The first TLDF value describes the fraction of total directional single-unit trucks (i.e., vehicles in FHWA classes 4–7) expected to be in the design lane. The second TLDF value describes the fraction of directional combination trucks (i.e., vehicle in FHWA classes 8–13) expected to be in the design lane. The third TLDF value describes the fraction of all directional trucks (i.e., vehicles in FHWA classes 4–13) expected to be in the design lane. This last value should be used only when the user does not have access to roadway segment–specific AADT estimates of single-unit and combination trucks.

HPMS_FHWA_CLASSIFICATION_FRACTIONS Table

The HPMS_FHWA_CLASSIFICATION_FRACTIONS table is included in the appendix as table 13. This table provides the default expected mean fractions of single-unit or combination trucks for each FHWA vehicle class 4–13, as follows:

- The fraction of single-unit trucks that can be expected to fall within each of the FHWA classes 4–7.

- The fraction of combination trucks that can be expected to fall within each of the FHWA classes 8–13.

Data are extracted from this table by specifying the State of interest and the functional classification of road of interest for the roadway section.

Several additional default options are included in the CPT. These default options provide flexibility for the SHA to select a default that is more appropriate for its needs, given the trucking characteristic within that State. These defaults are provided for the following groups of road functional classifications:

- All roads in the State.
- Only rural interstates.
- All roads except rural interstates.
- Urban interstates and other expressways.
- Any road that is not an interstate or expressway.

Note that not all these categories are available for all States. Missing categories occur when SHAs have not submitted sufficient data to FHWA through the TMAS and when they do not have LTPP test sites associated with all functional classes of roads. SHAs are encouraged to develop their own default tables to use in place of table 13.

SHAs should also note that detailed design work should not use these default values. Actual pavement design work should use data collected at the site in question whenever possible because there is considerable variability in the truck traffic patterns, and the collection of site-specific data greatly reduces the potential for error in the design process. The table 13 defaults should be used only when better data are unavailable.

ALL_TRUCK_FHWA_CLASSIFICATION_FRACTIONS Table

Some SHAs do not explicitly separate single-unit trucks from combination trucks. Instead, they may store only two-way AADT and percentage of trucks values. These SHAs are limited in characterizing truck traffic in the design lane. The ALL_TRUCK_FHWA_CLASSIFICATION_FRACTIONS table, provided in the appendix table 14, aids SHAs in estimating design lane AADTT by FHWA vehicle classification when only roadway AADT and percentage of trucks information is available. This table contains estimated default distributions of truck volume by FHWA vehicle classes 4–13. In table 14, the default values for each of the FHWA vehicle class 4–13 are expressed as fractions of the total truck volume in FHWA vehicle classes 4–13 combined. The estimates in table 14 are organized by State name and the following aggregated road functional classifications:

- All roads in the State.
- Only rural interstates.
- All roads except rural interstates.
- Urban interstates and other expressways.
- Any road that is not an interstate or expressway.

CHAPTER 7. COMPUTATIONAL PROCEDURE AND EXAMPLE

The CPTs included in the appendix and equations described in chapter 6, along with the available HPMS traffic data that all SHAs annually submit to FHWA, could be used to estimate the design lane-specific AADTT volumes for individual FHWA vehicle classes 4–13 and for all tucks (FHWA vehicle classes 4–13) combined that are needed for the LTPP and MEPDG models.[1,3]

PROCEDURE

This procedure supports the use of LTPP and the MEPDG models by SHAs, which have limited traffic information for the pavement design lane (the lane with the highest truck volume, which is typically the rightmost lane, and also called the "truck" lane). Many State databases, such as those maintained by SHAs for HPMS data submissions, lack design lane-specific truck volumes by FHWA vehicle classification, which are needed by LTPP models and the MEPDG models. It is therefore necessary to estimate design lane AADTT using available HPMS data as inputs. The procedure for estimating AADTT by FHWA vehicle classification includes the following steps.

Step 1. Extract HPMS Data

To develop the design lane AADTT volume estimates, the user must first extract data from each roadway segment of interest from the HPMS database.[3] The following four HPMS parameters are required for each road segment:

- AADT_Single_Unit.
- AADT_Combination.
- F_System.
- Through_Lanes.

If AADT_Single_Unit and AADT_Combination parameters are unavailable, roadway segment AADT and percent truck information can be used as inputs for equations 4 and 5.

Step 2. Extract Data From TRUCK_VOLUME_DESIGN_LANE_FRACTIONS Table

The user should extract $TLDF_{Single\text{-}unit}$, $TLDF_{Combination}$, and $TLDF_{AllTrucks}$ parameters from the TRUCK_VOLUME_DESIGN_LANE_FRACTIONS table (appendix table 12) for the selected number of lanes in the direction of travel that includes the design lane.

Step 3. Extract Data From HPMS_FHWA_CLASSIFICATION_FRACTIONS Table

If AADT_Single_Unit and AADT_Combination parameters are available in the SHA HPMS dataset, $VCDF_{S\text{-}n}$ and $VCDF_{C\text{-}n}$ parameters should be extracted from the HPMS_FHWA_CLASSIFICATION_FRACTIONS table included in appendix table 13 for a selected State and road functional type. After these parameters are extracted, the user should proceed to step 5.

Step 4. Extract Data From ALL_TRUCK_FHWA_CLASSIFICATION_FRACTIONS Table

If AADT_Single_Unit and AADT_Combination parameters are unavailable in the SHA HPMS dataset, the user should extract $VCDF_n$ parameters from the ALL_TRUCK_FHWA_CLASSIFICATION_FRACTIONS table included in appendix table 14.

Step 5. Compute Design Lane AADTT for FHWA Vehicle Classes 4–13

The extracted $VCDF_{S\text{-}n}$ and $VCDF_{C\text{-}n}$ parameters should be used as inputs to equations 2 and 3 to compute design lane AADTT for each FHWA vehicle class 4–13.

Alternatively, if AADT_Single_Unit and AADT_Combination parameters are unavailable, the extracted $VCDF_n$ parameters should be used as inputs to equation 4, along with the roadway segment AADT and percent truck parameters, to compute design lane AADTT for each FHWA vehicle class 4–13.

Step 6. Compute Design Lane AADTT for FHWA Vehicle Classes 4–13 Combined (Optional)

To estimate design lane AADTT for a roadway segment for FHWA vehicle classes 4–13 combined, extract $TLDF_{AllTrucks}$ from table 12 for the applicable number of lanes in the direction of travel and use equation 5, along with the roadway segment AADT and percent truck information.

EXAMPLE

For example, if the Washington State Department of Transportation (WSDOT) wishes to use LTPP or MEPDG models to examine pavement performance for the entire I–90 corridor and needs design lane AADTT values for FHWA classes 4–13, WSDOT would need to extract data for the four HPMS parameters (AADT_Single_Unit, AADTT_Combination, F_System, and Through_Lanes) for each HPMS segment of I–90. Two examples of the extracted HPMS data are shown in table 5. The first example is from western Washington, near milepost 42, outside of the Seattle metropolitan region but still on the western slope of the Cascade Mountains. The second example comes from near milepost 206, in eastern Washington, approximately two-thirds of the way from Seattle to Spokane. Both locations are functionally classified as rural interstates.

Table 5. Example of data extracted from HPMS.

I–90 Location	Site 1	Site 2
Milepost	42	206
AADTT_Single_Unit	1,050	440
AADTT_Combination	4,900	1,870
F_System	1R	1R
Through_Lanes	3	2

1R = rural interstate.

Next, WSDOT would need to download the records from the TRUCK_VOLUME_DESIGN_LANE_FRACTIONS and FHWA_CLASSIFICATION_FRACTIONS tables included in this report, as shown in table 6 and table 7 (STATE_CODE = 53, number of lanes = 2 and 3).

Table 6. TLDFs for Washington State.

Number of Lanes	$TLDF_{Single\text{-}unit}$	$TLDF_{Combination}$	$TLDF_{AllTrucks}$
2	0.72	0.81	0.78
3	0.56	0.70	0.64

Table 7. $VCDF_{S\text{-}n}$ and $VCDF_{C\text{-}n}$ for Washington State.

ROAD_GROUP	VCDF _S4	VCDF _S5	VCDF _S6	VCDF _S7	VCDF _C8	VCDF _C9	VCDF _C10	VCDF _C11	VCDF _C12	VCDF _C13
StateAvg	0.083	0.738	0.145	0.033	0.183	0.425	0.271	0.02	0.02	0.081
RuralInterstate	0.115	0.751	0.111	0.022	0.1	0.552	0.231	0.025	0.024	0.068
AllButRuralInt	0.078	0.736	0.151	0.035	0.197	0.404	0.278	0.019	0.019	0.083
UrbanInt& Expressways	0.095	0.732	0.134	0.04	0.177	0.453	0.267	0.019	0.021	0.064
Non-Interstate OrExpressway	0.063	0.74	0.167	0.03	0.215	0.36	0.288	0.019	0.017	0.102

Avg = average; Int = interstate.

Because this analysis is focused on an interstate freeway, the RuralInterstate option from table 7 should be used to obtain the VCDF values for all rural I–90 road segments. Based on the selected ROAD_GROUP option, FHWA class 9 will make up 55.2 percent of the combination trucks on the rural portions of I–90.

The extracted data then should be used as inputs to equations 2 and 3 to estimate design lane-specific AADTT volumes by FHWA classification ($AADTT_{FHWA\text{-}n}$). Table 8 through table 11 show the values taken from table 12 and table 13 and the computed design lane AADTT volumes by FHWA classification for the two sites on I–90.

Table 8. Example of computation of design lane AADTT by FHWA vehicle classification for I–90, site 1, single-unit trucks.

FHWA Vehicle Class	$AADT_{Single\text{-}unit}$	$TLDF_{Single\text{-}unit}$	$VCDF_{S\text{-}n}$	$AADTT_{FHWA\text{-}n}$
4	1,050	0.56	0.1150	34
5	1,050	0.56	0.7510	221
6	1,050	0.56	0.1110	33
7	1,050	0.56	0.0220	6

Table 9. Example of computation of design lane AADTT by FHWA vehicle classification for I–90, site 1, combination trucks.

FHWA Vehicle Class	$AADT_{Combination}$	$TLDF_{Combination}$	$VCDF_{C\text{-}n}$	$AADTT_{FHWA\text{-}n}$
8	4,900	0.7	0.1000	172
9	4,900	0.7	0.5520	947
10	4,900	0.7	0.2310	396
11	4,900	0.7	0.0250	43
12	4,900	0.7	0.0240	41
13	4,900	0.7	0.0680	117

Table 10. Example of computation of design lane AADTT by FHWA vehicle classification for I–90, site 2, single-unit trucks.

FHWA Vehicle Class	$AADT_{Single\text{-}unit}$	$TLDF_{Single\text{-}unit}$	$VCDF_{S\text{-}n}$	$AADTT_{FHWA\text{-}n}$
4	440	0.72	0.1150	18
5	440	0.72	0.7510	119
6	440	0.72	0.1110	18
7	440	0.72	0.0220	3

Table 11. Example of computation of design lane AADTT by FHWA vehicle classification for I–90, site 2, combination trucks.

FHWA Vehicle Class	$AADT_{Combination}$	$TLDF_{Combination}$	$VCDF_{C\text{-}n}$	$AADTT_{FHWA\text{-}n}$
8	1,870	0.81	0.1000	76
9	1,870	0.81	0.5520	418
10	1,870	0.81	0.2310	175
11	1,870	0.81	0.0250	19
12	1,870	0.81	0.0240	18
13	1,870	0.81	0.0680	51

CHAPTER 8. CONCLUSIONS AND LIMITATIONS

CONCLUSIONS

The findings from the review of truck volume distributions across different States and road functional classes and the results of predictive modeling of design lane truck volumes led to the following conclusions:

- Truck volume patterns are highly diverse, both in terms of the variation in the percentage of trucks using the design lane from site to site and the percentage of trucks in any one FHWA vehicle class.

- A number of factors encourage heavy trucks to travel in a lane other than the right-hand lane; thus, the right-hand lane is not always the design lane. Factors impacting truck lane choice include volume of traffic, directional differences in truck traffic, proximity of on- and off-ramps, roadway junctions, pavement condition, and steep grades. Many of these factors were unavailable for this analysis project. The lack of information on these factors, combined with a lack of detailed research about the relative effects of these factors on truck volumes, is one of the causes of error in the models developed in this project.

- Independent variables available through the HPMS[3] database lack strong explanatory power to control sources of variation when estimating design lane truck volumes.

- Models developed in this study using HPMS[3] data to predict design lane truck volumes had modest levels of accuracy and reliability at best, even though those models produced unbiased estimates of design lane truck volumes by FHWA vehicle class.

- When examining model performance, the research team found many of the largest errors in model performance occurred when directional truck volumes were very different for both directions at a site. The model can make only one prediction for a site, and when two directions of travel show very different truck travel patterns, any model will produce substantial errors when predicting those two directional movements.

- Complex multivariate regression models did not predict the volume of trucks by class in the design lane with appreciably better accuracy than the simple model based on the State mean percentage of FHWA class trucks within each aggregated truck class (i.e., single-unit or combination truck classes), combined with a nationwide estimate of the percentage of each aggregated truck class in the design lane for a given number of lanes of traffic in a single direction.

- The simplified methodology using statewide statistics was selected for estimating design lane AADTT using HPMS data because of better transparency of how these statistics were developed and applied. This methodology is applicable for statewide or network-level analyses where site-specific data are unavailable. States have the option of using mean values computed for all roadways or for subsets of roadways within different functional classifications. As an approach to default selection, the best option varies from State to State based on how truck volumes vary across the State.

LIMITATIONS

The limitations of the predictive models described in this report strongly indicate that, while modeled predictions can provide unbiased results, the level of accuracy needed for high-quality pavement analyses requires collecting site- and lane-specific truck volume data. Default equations developed to convert available HPMS(3) data into LTPP design lane inputs should be used only when site-specific values are unavailable for analyses.

Given the current state of traffic monitoring equipment capabilities and data storage resources, it is highly recommended that each SHA report and store traffic data by FHWA vehicle classification for each individual travel lane.

APPENDIX. COMPUTED PARAMETER TABLES

Table 12 provides default truck volume distribution factors for the design lane ("truck" lane) for road facilities with the number of lanes in the direction of travel ranging between 1 and 8.

Table 12. TRUCK_VOLUME_DESIGN_LANE_FRACTIONS table.

Number of Lanes	Fraction of Single-Unit Trucks in the Design Lane ($TLDF_{Single\text{-}unit}$)	Fraction of Combination Trucks in the Design Lane ($TLDF_{Combination}$)	Fraction of All Trucks in the Design Lane ($TLDF_{AllTrucks}$)
1	1.00	1.00	1.00
2	0.72	0.81	0.78
3	0.56	0.70	0.64
4	0.44	0.62	0.54
5	0.35	0.55	0.47
6	0.27	0.50	0.40
7	0.21	0.46	0.35
8	0.15	0.42	0.31

Table 13 provides default truck percentages, expressed either as a percentage of single-unit trucks (for FHWA vehicle classed 4–7) or combination trucks (for FHWA vehicle classes 8–13).

Table 14 provides default percentages of truck AADT for each of the FHWA vehicle classes 4–13, expressed as fractions of total truck volume (FHWA vehicle classes 4–13 combined).

Table 13. HPMS_FHWA_CLASS_FRACTIONS table.

STATE _CODE	ROAD_GROUP	$VCDF_{S-4}$	$VCDF_{S-5}$	$VCDF_{S-6}$	$VCDF_{S-7}$	$VCDF_{C-8}$	$VCDF_{C-9}$	$VCDF_{C-10}$	$VCDF_{C-11}$	$VCDF_{C-12}$	$VCDF_{C-13}$
1	StateAvg	0.026	0.393	0.089	0.012	0.091	0.614	0.020	0.017	0.006	0.002
2	StateAvg	0.054	0.827	0.117	0.002	0.285	0.372	0.195	0.000	0.000	0.146
4	StateAvg	0.016	0.170	0.034	0.004	0.080	0.626	0.007	0.045	0.012	0.007
5	StateAvg	0.129	0.770	0.089	0.013	0.223	0.717	0.024	0.020	0.005	0.012
6	StateAvg	0.043	0.850	0.099	0.008	0.090	0.812	0.005	0.076	0.016	0.002
8	StateAvg	0.131	0.543	0.292	0.035	0.143	0.738	0.042	0.017	0.018	0.042
9	StateAvg	0.026	0.366	0.085	0.024	0.084	0.378	0.008	0.025	0.003	0.001
10	StateAvg	0.150	0.680	0.136	0.034	0.295	0.667	0.022	0.007	0.004	0.006
11	StateAvg	0.124	0.541	0.175	0.086	0.257	0.483	0.035	0.003	0.000	0.046
12	StateAvg	0.053	0.770	0.150	0.027	0.450	0.519	0.015	0.008	0.005	0.002
13	StateAvg	0.152	0.705	0.140	0.002	0.293	0.662	0.022	0.011	0.006	0.006
15	StateAvg	0.086	0.818	0.093	0.003	0.344	0.599	0.044	0.007	0.005	0.003
16	StateAvg	0.059	0.835	0.081	0.024	0.301	0.407	0.192	0.006	0.008	0.086
17	StateAvg	0.140	0.591	0.257	0.012	0.150	0.746	0.016	0.019	0.016	0.054
18	StateAvg	0.094	0.617	0.227	0.061	0.142	0.804	0.017	0.025	0.009	0.002
19	StateAvg	0.125	0.731	0.131	0.013	0.155	0.765	0.047	0.012	0.006	0.015
20	StateAvg	0.037	0.280	0.110	0.008	0.074	0.438	0.014	0.028	0.007	0.004
21	StateAvg	0.051	0.221	0.104	0.042	0.120	0.401	0.037	0.016	0.003	0.005
22	StateAvg	0.030	0.267	0.046	0.003	0.106	0.503	0.021	0.016	0.005	0.003
23	StateAvg	0.138	0.715	0.122	0.026	0.199	0.426	0.371	0.003	0.001	0.001
24	StateAvg	0.147	0.709	0.103	0.042	0.284	0.673	0.024	0.008	0.004	0.005
25	StateAvg	0.116	0.557	0.266	0.062	0.168	0.687	0.055	0.017	0.014	0.058
26	StateAvg	0.092	0.664	0.213	0.031	0.074	0.706	0.106	0.013	0.007	0.093
27	StateAvg	0.212	0.559	0.199	0.030	0.205	0.598	0.182	0.007	0.004	0.004
28	StateAvg	0.031	0.805	0.153	0.011	0.253	0.680	0.020	0.026	0.013	0.008
29	StateAvg	0.106	0.677	0.205	0.011	0.098	0.844	0.021	0.023	0.008	0.006
30	StateAvg	0.188	0.638	0.156	0.018	0.060	0.572	0.155	0.005	0.012	0.196
31	StateAvg	0.011	0.078	0.065	0.008	0.105	0.634	0.054	0.025	0.008	0.012
32	StateAvg	0.164	0.710	0.116	0.009	0.110	0.749	0.017	0.041	0.022	0.062
33	StateAvg	0.131	0.559	0.122	0.028	0.160	0.568	0.176	0.003	0.001	0.001
34	StateAvg	0.033	0.363	0.115	0.050	0.065	0.360	0.008	0.005	0.001	0.000
35	StateAvg	0.089	0.842	0.066	0.003	0.222	0.695	0.042	0.017	0.008	0.015
36	StateAvg	0.109	0.577	0.251	0.063	0.227	0.614	0.109	0.016	0.012	0.023
37	StateAvg	0.038	0.221	0.090	0.011	0.098	0.489	0.013	0.019	0.005	0.015
38	StateAvg	0.094	0.700	0.179	0.028	0.270	0.469	0.170	0.003	0.005	0.081
39	StateAvg	0.058	0.547	0.285	0.109	0.118	0.805	0.029	0.028	0.012	0.008
40	StateAvg	0.026	0.351	0.063	0.004	0.121	0.513	0.012	0.014	0.005	0.006
41	StateAvg	0.025	0.185	0.038	0.004	0.069	0.435	0.073	0.035	0.003	0.134
42	StateAvg	0.059	0.646	0.218	0.076	0.216	0.724	0.015	0.023	0.011	0.011

STATE _CODE	ROAD_GROUP	$VCDF_{S-4}$	$VCDF_{S-5}$	$VCDF_{S-6}$	$VCDF_{S-7}$	$VCDF_{C-8}$	$VCDF_{C-9}$	$VCDF_{C-10}$	$VCDF_{C-11}$	$VCDF_{C-12}$	$VCDF_{C-13}$
44	StateAvg	0.044	0.836	0.102	0.018	0.227	0.725	0.021	0.007	0.004	0.017
45	StateAvg	0.018	0.266	0.112	0.038	0.086	0.446	0.007	0.018	0.005	0.003
46	StateAvg	0.009	0.174	0.052	0.011	0.138	0.395	0.109	0.017	0.004	0.091
47	StateAvg	0.013	0.281	0.075	0.016	0.116	0.464	0.007	0.017	0.005	0.005
48	StateAvg	0.036	0.229	0.070	0.004	0.119	0.498	0.014	0.018	0.006	0.006
49	StateAvg	0.016	0.318	0.022	0.000	0.094	0.360	0.005	0.007	0.040	0.139
50	StateAvg	0.025	0.362	0.092	0.014	0.087	0.387	0.028	0.003	0.002	0.001
51	StateAvg	0.293	0.376	0.277	0.054	0.158	0.792	0.025	0.016	0.008	0.000
53	StateAvg	0.083	0.738	0.145	0.033	0.183	0.425	0.271	0.020	0.020	0.081
54	StateAvg	0.186	0.581	0.178	0.055	0.126	0.797	0.055	0.014	0.006	0.001
55	StateAvg	0.175	0.626	0.140	0.059	0.279	0.657	0.045	0.009	0.006	0.004
56	StateAvg	0.141	0.556	0.267	0.036	0.154	0.595	0.133	0.006	0.010	0.102
1	RuralInterstate	0.019	0.318	0.050	0.001	0.049	0.745	0.005	0.026	0.007	0.001
2	RuralInterstate	0.058	0.857	0.083	0.002	0.190	0.432	0.191	0.000	0.001	0.186
4	RuralInterstate	0.012	0.119	0.026	0.002	0.064	0.702	0.008	0.049	0.014	0.006
5	RuralInterstate	0.213	0.707	0.075	0.005	0.108	0.822	0.013	0.036	0.016	0.005
6	RuralInterstate	0.043	0.879	0.075	0.004	0.048	0.858	0.005	0.068	0.019	0.002
8	RuralInterstate	0.261	0.487	0.206	0.045	0.099	0.733	0.024	0.029	0.043	0.072
12	RuralInterstate	0.078	0.768	0.139	0.015	0.163	0.792	0.008	0.021	0.014	0.002
13	RuralInterstate	0.211	0.647	0.141	0.002	0.157	0.779	0.012	0.024	0.014	0.014
16	RuralInterstate	0.069	0.838	0.083	0.011	0.099	0.646	0.115	0.013	0.019	0.108
17	RuralInterstate	0.198	0.554	0.233	0.015	0.075	0.849	0.011	0.022	0.020	0.023
18	RuralInterstate	0.154	0.600	0.213	0.034	0.067	0.877	0.008	0.029	0.014	0.005
19	RuralInterstate	0.177	0.702	0.114	0.007	0.070	0.869	0.015	0.031	0.014	0.001
20	RuralInterstate	0.027	0.187	0.130	0.004	0.061	0.509	0.008	0.055	0.015	0.003
21	RuralInterstate	0.020	0.081	0.038	0.019	0.122	0.662	0.011	0.038	0.007	0.002
22	RuralInterstate	0.038	0.213	0.040	0.002	0.126	0.534	0.017	0.020	0.006	0.004
23	RuralInterstate	0.177	0.724	0.085	0.014	0.134	0.681	0.171	0.010	0.003	0.002
24	RuralInterstate	0.190	0.693	0.097	0.020	0.092	0.860	0.013	0.020	0.013	0.003
25	RuralInterstate	0.101	0.617	0.257	0.025	0.117	0.780	0.034	0.029	0.012	0.029
26	RuralInterstate	0.105	0.693	0.183	0.020	0.057	0.782	0.079	0.014	0.008	0.060
27	RuralInterstate	0.174	0.586	0.225	0.015	0.053	0.859	0.038	0.030	0.010	0.010
28	RuralInterstate	0.039	0.829	0.126	0.005	0.130	0.793	0.011	0.043	0.019	0.004
29	RuralInterstate	0.130	0.664	0.202	0.004	0.033	0.905	0.007	0.036	0.018	0.002
30	RuralInterstate	0.204	0.681	0.105	0.011	0.029	0.750	0.082	0.010	0.020	0.110
31	RuralInterstate	0.007	0.041	0.020	0.002	0.077	0.767	0.020	0.050	0.011	0.005
32	RuralInterstate	0.145	0.765	0.085	0.004	0.057	0.797	0.012	0.027	0.023	0.085
33	RuralInterstate	0.226	0.601	0.158	0.016	0.135	0.700	0.159	0.005	0.001	0.000
34	RuralInterstate	0.043	0.377	0.115	0.049	0.069	0.335	0.006	0.005	0.001	0.000
35	RuralInterstate	0.134	0.781	0.081	0.004	0.106	0.791	0.026	0.036	0.024	0.017
36	RuralInterstate	0.152	0.498	0.255	0.095	0.076	0.825	0.069	0.017	0.008	0.006

STATE _CODE	ROAD_GROUP	***VCDF**$_{S-4}$*	***VCDF**$_{S-5}$*	***VCDF**$_{S-6}$*	***VCDF**$_{S-7}$*	***VCDF**$_{C-8}$*	***VCDF**$_{C-9}$*	***VCDF**$_{C-10}$*	***VCDF**$_{C-11}$*	***VCDF**$_{C-12}$*	***VCDF**$_{C-13}$*
37	RuralInterstate	0.024	0.078	0.041	0.002	0.064	0.727	0.006	0.035	0.010	0.012
38	RuralInterstate	0.113	0.709	0.168	0.009	0.258	0.609	0.074	0.008	0.012	0.038
39	RuralInterstate	0.047	0.529	0.293	0.131	0.042	0.893	0.013	0.038	0.012	0.003
40	RuralInterstate	0.018	0.153	0.067	0.002	0.081	0.628	0.009	0.021	0.010	0.012
41	RuralInterstate	0.019	0.132	0.030	0.004	0.063	0.505	0.084	0.039	0.003	0.123
42	RuralInterstate	0.064	0.652	0.212	0.072	0.050	0.877	0.008	0.041	0.020	0.004
44	RuralInterstate	0.066	0.842	0.075	0.017	0.092	0.870	0.008	0.023	0.007	0.000
45	RuralInterstate	0.013	0.123	0.034	0.002	0.080	0.689	0.006	0.040	0.011	0.002
46	RuralInterstate	0.012	0.167	0.042	0.012	0.137	0.475	0.042	0.020	0.004	0.088
47	RuralInterstate	0.009	0.088	0.022	0.004	0.052	0.758	0.005	0.049	0.012	0.001
48	RuralInterstate	0.024	0.093	0.022	0.002	0.124	0.667	0.016	0.037	0.011	0.005
49	RuralInterstate	0.016	0.153	0.022	0.000	0.094	0.599	0.014	0.013	0.020	0.069
51	RuralInterstate	0.333	0.365	0.271	0.031	0.050	0.891	0.010	0.032	0.017	0.000
53	RuralInterstate	0.115	0.751	0.111	0.022	0.100	0.552	0.231	0.025	0.024	0.068
54	RuralInterstate	0.208	0.570	0.188	0.034	0.037	0.907	0.014	0.029	0.012	0.001
55	RuralInterstate	0.254	0.609	0.107	0.031	0.091	0.860	0.013	0.025	0.010	0.001
56	RuralInterstate	0.148	0.586	0.228	0.038	0.045	0.792	0.063	0.017	0.026	0.056
1	AllButRuralInt	0.028	0.417	0.101	0.016	0.104	0.571	0.025	0.015	0.006	0.003
2	AllButRuralInt	0.052	0.817	0.129	0.002	0.317	0.353	0.196	0.000	0.000	0.133
4	AllButRuralInt	0.027	0.331	0.059	0.009	0.129	0.388	0.006	0.032	0.008	0.011
5	AllButRuralInt	0.109	0.785	0.092	0.015	0.250	0.692	0.027	0.016	0.002	0.013
6	AllButRuralInt	0.043	0.843	0.105	0.009	0.100	0.800	0.005	0.078	0.015	0.002
8	AllButRuralInt	0.097	0.557	0.314	0.032	0.155	0.739	0.047	0.014	0.011	0.034
9	AllButRuralInt	0.026	0.366	0.085	0.024	0.084	0.378	0.008	0.025	0.003	0.001
10	AllButRuralInt	0.150	0.680	0.136	0.034	0.295	0.667	0.022	0.007	0.004	0.006
11	AllButRuralInt	0.124	0.541	0.175	0.086	0.257	0.483	0.035	0.003	0.000	0.046
12	AllButRuralInt	0.051	0.770	0.151	0.028	0.473	0.497	0.016	0.007	0.004	0.002
13	AllButRuralInt	0.140	0.717	0.140	0.003	0.320	0.639	0.024	0.008	0.004	0.004
15	AllButRuralInt	0.086	0.818	0.093	0.003	0.344	0.599	0.044	0.007	0.005	0.003
16	AllButRuralInt	0.058	0.835	0.081	0.026	0.335	0.367	0.205	0.005	0.006	0.082
17	AllButRuralInt	0.112	0.609	0.268	0.011	0.184	0.698	0.018	0.017	0.014	0.068
18	AllButRuralInt	0.076	0.623	0.232	0.070	0.164	0.782	0.020	0.024	0.008	0.002
19	AllButRuralInt	0.114	0.737	0.134	0.015	0.173	0.743	0.054	0.008	0.004	0.018
20	AllButRuralInt	0.039	0.303	0.105	0.008	0.078	0.421	0.015	0.022	0.005	0.005
21	AllButRuralInt	0.064	0.277	0.130	0.051	0.119	0.296	0.048	0.007	0.002	0.006
22	AllButRuralInt	0.006	0.431	0.064	0.004	0.045	0.411	0.034	0.004	0.002	0.000
23	AllButRuralInt	0.128	0.712	0.130	0.029	0.213	0.368	0.417	0.001	0.001	0.001
24	AllButRuralInt	0.142	0.710	0.104	0.044	0.307	0.652	0.026	0.007	0.003	0.006
25	AllButRuralInt	0.117	0.552	0.266	0.064	0.172	0.681	0.056	0.016	0.014	0.060
26	AllButRuralInt	0.085	0.649	0.229	0.037	0.083	0.669	0.120	0.013	0.007	0.109
27	AllButRuralInt	0.214	0.557	0.198	0.031	0.213	0.585	0.189	0.006	0.004	0.004

STATE _CODE	ROAD_GROUP	$VCDF_{S-4}$	$VCDF_{S-5}$	$VCDF_{S-6}$	$VCDF_{S-7}$	$VCDF_{C-8}$	$VCDF_{C-9}$	$VCDF_{C-10}$	$VCDF_{C-11}$	$VCDF_{C-12}$	$VCDF_{C-13}$
28	AllButRuralInt	0.029	0.799	0.159	0.013	0.282	0.654	0.022	0.022	0.011	0.008
29	AllButRuralInt	0.102	0.679	0.206	0.013	0.109	0.834	0.024	0.021	0.006	0.006
30	AllButRuralInt	0.179	0.615	0.183	0.022	0.076	0.481	0.192	0.003	0.009	0.240
31	AllButRuralInt	0.013	0.098	0.090	0.012	0.120	0.562	0.072	0.012	0.006	0.016
32	AllButRuralInt	0.171	0.692	0.126	0.011	0.127	0.732	0.019	0.045	0.021	0.055
33	AllButRuralInt	0.099	0.546	0.110	0.032	0.169	0.524	0.181	0.003	0.001	0.002
34	AllButRuralInt	0.029	0.356	0.116	0.051	0.064	0.371	0.008	0.004	0.000	0.000
35	AllButRuralInt	0.078	0.856	0.063	0.003	0.249	0.673	0.046	0.013	0.004	0.014
36	AllButRuralInt	0.103	0.589	0.251	0.058	0.249	0.583	0.114	0.016	0.013	0.025
37	AllButRuralInt	0.040	0.239	0.097	0.013	0.102	0.458	0.014	0.016	0.005	0.016
38	AllButRuralInt	0.091	0.698	0.180	0.030	0.272	0.449	0.184	0.003	0.004	0.088
39	AllButRuralInt	0.059	0.549	0.285	0.108	0.124	0.798	0.030	0.028	0.012	0.009
40	AllButRuralInt	0.027	0.367	0.063	0.005	0.124	0.504	0.012	0.013	0.004	0.006
41	AllButRuralInt	0.052	0.450	0.079	0.004	0.096	0.084	0.023	0.020	0.001	0.190
42	AllButRuralInt	0.058	0.645	0.220	0.077	0.249	0.693	0.017	0.019	0.009	0.012
44	AllButRuralInt	0.042	0.836	0.103	0.019	0.234	0.717	0.022	0.006	0.004	0.018
45	AllButRuralInt	0.021	0.380	0.175	0.068	0.091	0.251	0.008	0.001	0.000	0.004
46	AllButRuralInt	0.006	0.182	0.063	0.011	0.139	0.303	0.185	0.014	0.003	0.094
47	AllButRuralInt	0.015	0.345	0.092	0.020	0.138	0.366	0.007	0.007	0.002	0.007
48	AllButRuralInt	0.038	0.262	0.082	0.005	0.118	0.457	0.014	0.013	0.004	0.006
49	AllButRuralInt	0.017	0.363	0.022	0.000	0.094	0.294	0.002	0.005	0.045	0.158
50	AllButRuralInt	0.025	0.362	0.092	0.014	0.087	0.387	0.028	0.003	0.002	0.001
51	AllButRuralInt	0.286	0.378	0.278	0.057	0.177	0.775	0.028	0.014	0.007	0.000
53	AllButRuralInt	0.078	0.736	0.151	0.035	0.197	0.404	0.278	0.019	0.019	0.083
54	AllButRuralInt	0.181	0.584	0.176	0.060	0.146	0.772	0.065	0.011	0.005	0.001
55	AllButRuralInt	0.163	0.628	0.145	0.063	0.306	0.627	0.050	0.006	0.006	0.004
56	AllButRuralInt	0.140	0.550	0.275	0.035	0.175	0.556	0.147	0.003	0.007	0.111
1	UrbanInt&Expressways	0.015	0.362	0.161	0.011	0.050	0.535	0.033	0.019	0.009	0.005
2	UrbanInt&Expressways	0.037	0.830	0.131	0.002	0.389	0.284	0.176	0.000	0.000	0.150
4	UrbanInt&Expressways	0.009	0.408	0.108	0.039	0.094	0.286	0.006	0.022	0.003	0.024
5	UrbanInt&Expressways	0.123	0.782	0.078	0.017	0.238	0.714	0.013	0.027	0.004	0.004
6	UrbanInt&Expressways	0.049	0.837	0.103	0.011	0.104	0.803	0.006	0.071	0.014	0.002
8	UrbanInt&Expressways	0.102	0.559	0.311	0.027	0.174	0.731	0.027	0.014	0.015	0.039
9	UrbanInt&Expressways	0.021	0.276	0.062	0.016	0.094	0.476	0.010	0.040	0.005	0.001
11	UrbanInt&Expressways	0.124	0.541	0.175	0.086	0.257	0.483	0.035	0.003	0.000	0.046
12	UrbanInt&Expressways	0.063	0.748	0.155	0.034	0.279	0.677	0.012	0.018	0.010	0.004
13	UrbanInt&Expressways	0.167	0.674	0.157	0.002	0.233	0.715	0.017	0.018	0.009	0.009
15	UrbanInt&Expressways	0.116	0.797	0.080	0.006	0.462	0.479	0.029	0.020	0.005	0.005
17	UrbanInt&Expressways	0.121	0.587	0.283	0.009	0.093	0.832	0.012	0.020	0.015	0.027
18	UrbanInt&Expressways	0.086	0.761	0.127	0.025	0.080	0.859	0.011	0.033	0.016	0.002
19	UrbanInt&Expressways	0.150	0.678	0.163	0.009	0.128	0.817	0.019	0.024	0.011	0.001

STATE _CODE	ROAD_GROUP	$VCDF_{S-4}$	$VCDF_{S-5}$	$VCDF_{S-6}$	$VCDF_{S-7}$	$VCDF_{C-8}$	$VCDF_{C-9}$	$VCDF_{C-10}$	$VCDF_{C-11}$	$VCDF_{C-12}$	$VCDF_{C-13}$
20	UrbanInt&Expressways	0.040	0.270	0.153	0.010	0.103	0.377	0.008	0.026	0.005	0.008
21	UrbanInt&Expressways	0.056	0.313	0.118	0.152	0.102	0.233	0.011	0.012	0.002	0.001
24	UrbanInt&Expressways	0.177	0.668	0.114	0.042	0.181	0.780	0.015	0.014	0.008	0.002
25	UrbanInt&Expressways	0.141	0.537	0.253	0.069	0.171	0.687	0.048	0.017	0.014	0.063
26	UrbanInt&Expressways	0.079	0.664	0.224	0.033	0.063	0.749	0.093	0.014	0.008	0.074
27	UrbanInt&Expressways	0.162	0.556	0.243	0.038	0.139	0.760	0.075	0.020	0.003	0.003
28	UrbanInt&Expressways	0.051	0.775	0.170	0.004	0.183	0.752	0.011	0.036	0.015	0.002
29	UrbanInt&Expressways	0.103	0.653	0.222	0.022	0.064	0.890	0.011	0.018	0.015	0.002
31	UrbanInt&Expressways	0.021	0.153	0.177	0.018	0.113	0.444	0.047	0.007	0.003	0.017
32	UrbanInt&Expressways	0.192	0.654	0.139	0.015	0.117	0.727	0.025	0.041	0.020	0.069
33	UrbanInt&Expressways	0.099	0.546	0.110	0.032	0.169	0.524	0.181	0.003	0.001	0.002
34	UrbanInt&Expressways	0.016	0.296	0.096	0.048	0.066	0.461	0.010	0.006	0.000	0.000
35	UrbanInt&Expressways	0.051	0.916	0.032	0.001	0.293	0.636	0.028	0.039	0.001	0.003
36	UrbanInt&Expressways	0.217	0.544	0.200	0.038	0.214	0.614	0.081	0.027	0.032	0.032
37	UrbanInt&Expressways	0.040	0.152	0.066	0.009	0.112	0.566	0.014	0.024	0.007	0.012
38	UrbanInt&Expressways	0.158	0.569	0.249	0.025	0.196	0.674	0.068	0.010	0.010	0.041
39	UrbanInt&Expressways	0.078	0.541	0.290	0.092	0.079	0.835	0.030	0.037	0.013	0.007
40	UrbanInt&Expressways	0.036	0.552	0.085	0.007	0.171	0.442	0.013	0.013	0.004	0.010
42	UrbanInt&Expressways	0.104	0.514	0.303	0.078	0.092	0.799	0.013	0.049	0.027	0.020
44	UrbanInt&Expressways	0.052	0.801	0.126	0.021	0.186	0.752	0.021	0.011	0.005	0.025
48	UrbanInt&Expressways	0.040	0.272	0.121	0.003	0.099	0.432	0.009	0.015	0.005	0.004
49	UrbanInt&Expressways	0.014	0.313	0.020	0.000	0.128	0.377	0.006	0.009	0.033	0.100
51	UrbanInt&Expressways	0.303	0.359	0.285	0.052	0.115	0.832	0.019	0.022	0.011	0.000
53	UrbanInt&Expressways	0.095	0.732	0.134	0.040	0.177	0.453	0.267	0.019	0.021	0.064
54	UrbanInt&Expressways	0.224	0.556	0.182	0.038	0.043	0.886	0.009	0.042	0.020	0.001
55	UrbanInt&Expressways	0.145	0.559	0.178	0.118	0.221	0.729	0.028	0.014	0.006	0.001
56	UrbanInt&Expressways	0.155	0.586	0.232	0.026	0.037	0.778	0.055	0.019	0.030	0.080
1	Non-InterstateOrExpressway	0.051	0.624	0.127	0.020	0.143	0.686	0.026	0.014	0.007	0.001
2	Non-InterstateOrExpressway	0.054	0.816	0.129	0.002	0.309	0.361	0.199	0.000	0.000	0.131
4	Non-InterstateOrExpressway	0.016	0.457	0.083	0.007	0.151	0.252	0.005	0.016	0.004	0.009
5	Non-InterstateOrExpressway	0.105	0.785	0.095	0.014	0.253	0.686	0.030	0.014	0.002	0.016
6	Non-InterstateOrExpressway	0.031	0.855	0.109	0.006	0.090	0.795	0.004	0.092	0.018	0.002
8	Non-InterstateOrExpressway	0.096	0.556	0.314	0.034	0.149	0.742	0.053	0.014	0.010	0.032
9	Non-InterstateOrExpressway	0.031	0.674	0.136	0.062	0.038	0.055	0.004	0.001	0.000	0.000
10	Non-InterstateOrExpressway	0.150	0.680	0.136	0.034	0.295	0.667	0.022	0.007	0.004	0.006
12	Non-InterstateOrExpressway	0.047	0.776	0.151	0.026	0.525	0.450	0.016	0.004	0.003	0.002
13	Non-InterstateOrExpressway	0.130	0.734	0.133	0.003	0.355	0.609	0.027	0.005	0.002	0.002
15	Non-InterstateOrExpressway	0.081	0.822	0.095	0.002	0.326	0.617	0.046	0.005	0.004	0.002
16	Non-InterstateOrExpressway	0.058	0.835	0.081	0.026	0.335	0.367	0.205	0.005	0.006	0.082
17	Non-InterstateOrExpressway	0.109	0.617	0.262	0.012	0.216	0.651	0.021	0.016	0.014	0.082
18	Non-InterstateOrExpressway	0.073	0.578	0.265	0.084	0.192	0.757	0.022	0.021	0.006	0.002

STATE _CODE	ROAD_GROUP	$VCDF_{S-4}$	$VCDF_{S-5}$	$VCDF_{S-6}$	$VCDF_{S-7}$	$VCDF_{C-8}$	$VCDF_{C-9}$	$VCDF_{C-10}$	$VCDF_{C-11}$	$VCDF_{C-12}$	$VCDF_{C-13}$
19	Non-InterstateOrExpressway	0.112	0.741	0.132	0.015	0.176	0.739	0.056	0.007	0.003	0.019
20	Non-InterstateOrExpressway	0.048	0.342	0.077	0.006	0.085	0.400	0.007	0.030	0.002	0.003
21	Non-InterstateOrExpressway	0.106	0.442	0.169	0.044	0.102	0.116	0.021	0.000	0.000	0.000
23	Non-InterstateOrExpressway	0.128	0.712	0.130	0.029	0.213	0.368	0.417	0.001	0.001	0.001
24	Non-InterstateOrExpressway	0.129	0.726	0.100	0.045	0.353	0.604	0.030	0.005	0.001	0.007
25	Non-InterstateOrExpressway	0.058	0.591	0.299	0.053	0.175	0.666	0.077	0.013	0.015	0.053
26	Non-InterstateOrExpressway	0.089	0.639	0.232	0.040	0.096	0.617	0.137	0.012	0.006	0.132
27	Non-InterstateOrExpressway	0.221	0.558	0.192	0.030	0.222	0.561	0.205	0.004	0.004	0.004
28	Non-InterstateOrExpressway	0.024	0.805	0.156	0.015	0.305	0.632	0.024	0.019	0.010	0.010
29	Non-InterstateOrExpressway	0.102	0.682	0.204	0.012	0.114	0.828	0.025	0.021	0.005	0.007
30	Non-InterstateOrExpressway	0.179	0.615	0.183	0.022	0.076	0.481	0.192	0.003	0.009	0.240
31	Non-InterstateOrExpressway	0.024	0.104	0.121	0.014	0.146	0.470	0.075	0.014	0.005	0.029
32	Non-InterstateOrExpressway	0.157	0.718	0.117	0.008	0.134	0.736	0.015	0.048	0.022	0.045
34	Non-InterstateOrExpressway	0.051	0.424	0.126	0.041	0.064	0.284	0.006	0.004	0.001	0.000
35	Non-InterstateOrExpressway	0.079	0.853	0.064	0.003	0.247	0.675	0.047	0.012	0.004	0.015
36	Non-InterstateOrExpressway	0.066	0.603	0.267	0.064	0.261	0.573	0.125	0.012	0.007	0.023
37	Non-InterstateOrExpressway	0.055	0.387	0.115	0.024	0.106	0.264	0.012	0.011	0.003	0.023
38	Non-InterstateOrExpressway	0.087	0.706	0.176	0.031	0.276	0.437	0.191	0.002	0.004	0.090
39	Non-InterstateOrExpressway	0.037	0.558	0.279	0.126	0.175	0.756	0.030	0.017	0.011	0.011
40	Non-InterstateOrExpressway	0.035	0.494	0.106	0.008	0.084	0.529	0.014	0.011	0.004	0.003
42	Non-InterstateOrExpressway	0.043	0.688	0.192	0.077	0.302	0.658	0.018	0.009	0.003	0.010
44	Non-InterstateOrExpressway	0.036	0.859	0.088	0.017	0.266	0.694	0.022	0.002	0.003	0.013
45	Non-InterstateOrExpressway	0.026	0.431	0.137	0.010	0.105	0.279	0.009	0.001	0.000	0.002
46	Non-InterstateOrExpressway	0.005	0.185	0.067	0.010	0.150	0.249	0.234	0.008	0.002	0.091
47	Non-InterstateOrExpressway	0.026	0.650	0.107	0.038	0.131	0.026	0.012	0.000	0.000	0.012
48	Non-InterstateOrExpressway	0.050	0.335	0.098	0.007	0.121	0.358	0.014	0.009	0.004	0.005
49	Non-InterstateOrExpressway	0.019	0.413	0.025	0.000	0.094	0.297	0.001	0.005	0.036	0.110
51	Non-InterstateOrExpressway	0.276	0.390	0.274	0.060	0.215	0.740	0.033	0.009	0.004	0.000
53	Non-InterstateOrExpressway	0.063	0.740	0.167	0.030	0.215	0.360	0.288	0.019	0.017	0.102
54	Non-InterstateOrExpressway	0.174	0.588	0.175	0.063	0.162	0.754	0.074	0.006	0.003	0.001
55	Non-InterstateOrExpressway	0.165	0.635	0.142	0.058	0.315	0.618	0.052	0.006	0.006	0.004
56	Non-InterstateOrExpressway	0.139	0.548	0.277	0.036	0.184	0.543	0.152	0.002	0.005	0.113

Avg = average; Int = interstate.

Table 14. ALL_TRUCK_FHWA_CLASSIFICATION_FRACTIONS table.

STATE _CODE	ROAD_GROUP	$VCDF_4$	$VCDF_5$	$VCDF_6$	$VCDF_7$	$VCDF_8$	$VCDF_9$	$VCDF_{10}$	$VCDF_{11}$	$VCDF_{12}$	$VCDF_{13}$
1	StateAvg	0.015	0.256	0.068	0.010	0.077	0.534	0.018	0.016	0.005	0.002
2	StateAvg	0.040	0.651	0.089	0.001	0.057	0.080	0.042	0.000	0.000	0.039
4	StateAvg	0.016	0.170	0.034	0.004	0.080	0.626	0.007	0.045	0.012	0.007
5	StateAvg	0.052	0.352	0.041	0.007	0.112	0.406	0.011	0.013	0.003	0.004
6	StateAvg	0.019	0.391	0.042	0.004	0.039	0.452	0.003	0.040	0.010	0.001
8	StateAvg	0.064	0.181	0.095	0.010	0.084	0.485	0.026	0.012	0.013	0.029
9	StateAvg	0.026	0.366	0.085	0.024	0.084	0.378	0.008	0.025	0.003	0.001
10	StateAvg	0.099	0.460	0.085	0.021	0.075	0.247	0.006	0.003	0.001	0.001
11	StateAvg	0.101	0.431	0.142	0.070	0.116	0.116	0.006	0.002	0.000	0.016
12	StateAvg	0.026	0.372	0.068	0.013	0.202	0.301	0.008	0.005	0.003	0.001
13	StateAvg	0.077	0.383	0.068	0.001	0.098	0.348	0.009	0.007	0.004	0.004
15	StateAvg	0.079	0.747	0.081	0.003	0.021	0.065	0.004	0.001	0.000	0.000
16	StateAvg	0.035	0.480	0.046	0.017	0.104	0.189	0.080	0.003	0.004	0.042
17	StateAvg	0.040	0.216	0.081	0.003	0.083	0.514	0.010	0.013	0.011	0.029
18	StateAvg	0.027	0.250	0.080	0.023	0.069	0.518	0.009	0.016	0.006	0.002
19	StateAvg	0.039	0.275	0.045	0.005	0.081	0.509	0.027	0.008	0.004	0.009
20	StateAvg	0.037	0.280	0.110	0.008	0.074	0.438	0.014	0.028	0.007	0.004
21	StateAvg	0.051	0.221	0.104	0.042	0.120	0.401	0.037	0.016	0.003	0.005
22	StateAvg	0.030	0.267	0.046	0.003	0.106	0.503	0.021	0.016	0.005	0.003
23	StateAvg	0.062	0.345	0.058	0.013	0.086	0.229	0.204	0.001	0.001	0.000
24	StateAvg	0.096	0.495	0.070	0.029	0.056	0.241	0.006	0.004	0.002	0.001
25	StateAvg	0.051	0.243	0.112	0.028	0.091	0.400	0.028	0.010	0.008	0.029
26	StateAvg	0.021	0.183	0.054	0.009	0.051	0.531	0.072	0.010	0.005	0.064
27	StateAvg	0.086	0.244	0.080	0.013	0.099	0.367	0.101	0.005	0.002	0.002
28	StateAvg	0.010	0.311	0.056	0.005	0.118	0.460	0.011	0.018	0.008	0.004
29	StateAvg	0.032	0.226	0.067	0.004	0.057	0.574	0.013	0.017	0.006	0.004
30	StateAvg	0.053	0.197	0.047	0.006	0.032	0.411	0.105	0.004	0.009	0.137
31	StateAvg	0.011	0.078	0.065	0.008	0.105	0.634	0.054	0.025	0.008	0.012
32	StateAvg	0.046	0.290	0.035	0.003	0.048	0.490	0.009	0.025	0.013	0.040
33	StateAvg	0.082	0.393	0.086	0.019	0.083	0.266	0.066	0.003	0.001	0.000
34	StateAvg	0.033	0.363	0.115	0.050	0.065	0.360	0.008	0.005	0.001	0.000
35	StateAvg	0.036	0.398	0.027	0.001	0.101	0.390	0.023	0.010	0.005	0.009
36	StateAvg	0.046	0.278	0.111	0.026	0.100	0.351	0.059	0.010	0.008	0.011
37	StateAvg	0.038	0.221	0.090	0.011	0.098	0.489	0.013	0.019	0.005	0.015
38	StateAvg	0.028	0.242	0.056	0.009	0.173	0.319	0.111	0.002	0.004	0.055
39	StateAvg	0.021	0.198	0.097	0.038	0.058	0.541	0.016	0.017	0.008	0.005
40	StateAvg	0.020	0.309	0.049	0.004	0.111	0.473	0.011	0.013	0.005	0.006
41	StateAvg	0.025	0.185	0.038	0.004	0.069	0.435	0.073	0.035	0.003	0.134
42	StateAvg	0.018	0.298	0.082	0.033	0.078	0.449	0.007	0.018	0.009	0.007

STATE _CODE	ROAD_GROUP	$VCDF_4$	$VCDF_5$	$VCDF_6$	$VCDF_7$	$VCDF_8$	$VCDF_9$	$VCDF_{10}$	$VCDF_{11}$	$VCDF_{12}$	$VCDF_{13}$
44	StateAvg	0.029	0.602	0.063	0.011	0.052	0.224	0.006	0.003	0.002	0.008
45	StateAvg	0.018	0.266	0.112	0.038	0.086	0.446	0.007	0.018	0.005	0.003
46	StateAvg	0.009	0.174	0.052	0.011	0.138	0.395	0.109	0.017	0.004	0.091
47	StateAvg	0.013	0.281	0.075	0.016	0.116	0.464	0.007	0.017	0.005	0.005
48	StateAvg	0.036	0.229	0.070	0.004	0.119	0.498	0.014	0.018	0.006	0.006
49	StateAvg	0.016	0.318	0.022	0.000	0.094	0.360	0.005	0.007	0.040	0.139
50	StateAvg	0.025	0.362	0.092	0.014	0.087	0.387	0.028	0.003	0.002	0.001
51	StateAvg	0.130	0.167	0.107	0.023	0.057	0.484	0.012	0.013	0.006	0.000
53	StateAvg	0.034	0.331	0.066	0.016	0.085	0.252	0.146	0.012	0.011	0.046
54	StateAvg	0.089	0.304	0.086	0.031	0.036	0.417	0.024	0.010	0.004	0.000
55	StateAvg	0.071	0.277	0.062	0.028	0.132	0.394	0.025	0.006	0.004	0.002
56	StateAvg	0.039	0.156	0.071	0.008	0.085	0.458	0.094	0.005	0.008	0.077
1	RuralInterstate	0.008	0.188	0.039	0.001	0.042	0.686	0.005	0.025	0.006	0.001
2	RuralInterstate	0.035	0.572	0.054	0.001	0.064	0.146	0.063	0.000	0.000	0.064
4	RuralInterstate	0.012	0.119	0.026	0.002	0.064	0.702	0.008	0.049	0.014	0.006
5	RuralInterstate	0.041	0.148	0.014	0.001	0.084	0.655	0.011	0.029	0.013	0.004
6	RuralInterstate	0.013	0.270	0.023	0.001	0.032	0.596	0.003	0.047	0.014	0.001
8	RuralInterstate	0.127	0.087	0.038	0.007	0.074	0.533	0.018	0.023	0.031	0.062
12	RuralInterstate	0.016	0.166	0.028	0.004	0.125	0.624	0.006	0.017	0.011	0.001
13	RuralInterstate	0.039	0.121	0.025	0.000	0.126	0.636	0.009	0.020	0.012	0.012
16	RuralInterstate	0.015	0.187	0.019	0.002	0.077	0.502	0.089	0.010	0.015	0.084
17	RuralInterstate	0.024	0.092	0.033	0.002	0.063	0.721	0.009	0.019	0.017	0.020
18	RuralInterstate	0.026	0.114	0.037	0.005	0.054	0.719	0.006	0.024	0.011	0.004
19	RuralInterstate	0.032	0.131	0.021	0.001	0.056	0.708	0.011	0.026	0.012	0.001
20	RuralInterstate	0.027	0.187	0.130	0.004	0.061	0.509	0.008	0.055	0.015	0.003
21	RuralInterstate	0.020	0.081	0.038	0.019	0.122	0.662	0.011	0.038	0.007	0.002
22	RuralInterstate	0.038	0.213	0.040	0.002	0.126	0.534	0.017	0.020	0.006	0.004
23	RuralInterstate	0.060	0.242	0.029	0.005	0.088	0.452	0.115	0.006	0.002	0.001
24	RuralInterstate	0.048	0.178	0.025	0.005	0.068	0.640	0.010	0.015	0.010	0.002
25	RuralInterstate	0.022	0.134	0.056	0.006	0.092	0.610	0.026	0.022	0.009	0.023
26	RuralInterstate	0.018	0.155	0.033	0.004	0.042	0.633	0.056	0.011	0.006	0.042
27	RuralInterstate	0.029	0.101	0.037	0.003	0.044	0.713	0.031	0.025	0.008	0.008
28	RuralInterstate	0.008	0.191	0.025	0.001	0.093	0.622	0.008	0.034	0.016	0.003
29	RuralInterstate	0.016	0.080	0.022	0.001	0.028	0.797	0.007	0.031	0.016	0.001
30	RuralInterstate	0.053	0.140	0.019	0.002	0.020	0.593	0.064	0.007	0.015	0.085
31	RuralInterstate	0.007	0.041	0.020	0.002	0.077	0.767	0.020	0.050	0.011	0.005
32	RuralInterstate	0.034	0.195	0.021	0.001	0.035	0.606	0.009	0.018	0.017	0.064
33	RuralInterstate	0.118	0.313	0.082	0.008	0.065	0.335	0.076	0.003	0.000	0.000
34	RuralInterstate	0.043	0.377	0.115	0.049	0.069	0.335	0.006	0.005	0.001	0.000
35	RuralInterstate	0.025	0.163	0.015	0.001	0.078	0.634	0.022	0.027	0.020	0.015
36	RuralInterstate	0.023	0.079	0.039	0.013	0.061	0.702	0.058	0.014	0.007	0.005

STATE _CODE	ROAD_GROUP	*$VCDF_4$*	*$VCDF_5$*	*$VCDF_6$*	*$VCDF_7$*	*$VCDF_8$*	*$VCDF_9$*	*$VCDF_{10}$*	*$VCDF_{11}$*	*$VCDF_{12}$*	*$VCDF_{13}$*
37	RuralInterstate	0.024	0.078	0.041	0.002	0.064	0.727	0.006	0.035	0.010	0.012
38	RuralInterstate	0.017	0.142	0.027	0.002	0.206	0.498	0.060	0.006	0.010	0.032
39	RuralInterstate	0.009	0.128	0.065	0.034	0.032	0.683	0.010	0.029	0.010	0.002
40	RuralInterstate	0.018	0.153	0.067	0.002	0.081	0.628	0.009	0.021	0.010	0.012
41	RuralInterstate	0.019	0.132	0.030	0.004	0.063	0.505	0.084	0.039	0.003	0.123
42	RuralInterstate	0.010	0.102	0.034	0.013	0.041	0.739	0.007	0.035	0.017	0.004
44	RuralInterstate	0.027	0.342	0.031	0.007	0.055	0.516	0.005	0.013	0.004	0.000
45	RuralInterstate	0.013	0.123	0.034	0.002	0.080	0.689	0.006	0.040	0.011	0.002
46	RuralInterstate	0.012	0.167	0.042	0.012	0.137	0.475	0.042	0.020	0.004	0.088
47	RuralInterstate	0.009	0.088	0.022	0.004	0.052	0.758	0.005	0.049	0.012	0.001
48	RuralInterstate	0.024	0.093	0.022	0.002	0.124	0.667	0.016	0.037	0.011	0.005
49	RuralInterstate	0.016	0.153	0.022	0.000	0.094	0.599	0.014	0.013	0.020	0.069
51	RuralInterstate	0.056	0.066	0.041	0.005	0.038	0.744	0.009	0.028	0.014	0.000
53	RuralInterstate	0.029	0.200	0.029	0.006	0.068	0.417	0.166	0.019	0.018	0.048
54	RuralInterstate	0.052	0.138	0.049	0.010	0.027	0.682	0.010	0.022	0.009	0.001
55	RuralInterstate	0.053	0.122	0.022	0.006	0.072	0.685	0.010	0.020	0.008	0.001
56	RuralInterstate	0.014	0.058	0.022	0.004	0.039	0.720	0.055	0.016	0.024	0.049
1	AllButRuralInt	0.017	0.278	0.077	0.012	0.089	0.485	0.022	0.013	0.004	0.002
2	AllButRuralInt	0.042	0.677	0.101	0.001	0.054	0.058	0.035	0.000	0.000	0.031
4	AllButRuralInt	0.027	0.331	0.059	0.009	0.129	0.388	0.006	0.032	0.008	0.011
5	AllButRuralInt	0.054	0.400	0.047	0.008	0.118	0.347	0.011	0.009	0.001	0.005
6	AllButRuralInt	0.021	0.420	0.047	0.005	0.040	0.417	0.002	0.038	0.009	0.001
8	AllButRuralInt	0.048	0.205	0.109	0.011	0.087	0.473	0.028	0.010	0.008	0.021
9	AllButRuralInt	0.026	0.366	0.085	0.024	0.084	0.378	0.008	0.025	0.003	0.001
10	AllButRuralInt	0.099	0.460	0.085	0.021	0.075	0.247	0.006	0.003	0.001	0.001
11	AllButRuralInt	0.101	0.431	0.142	0.070	0.116	0.116	0.006	0.002	0.000	0.016
12	AllButRuralInt	0.027	0.389	0.072	0.014	0.208	0.274	0.008	0.004	0.003	0.001
13	AllButRuralInt	0.085	0.435	0.077	0.002	0.092	0.290	0.009	0.005	0.002	0.002
15	AllButRuralInt	0.079	0.747	0.081	0.003	0.021	0.065	0.004	0.001	0.000	0.000
16	AllButRuralInt	0.039	0.529	0.051	0.019	0.109	0.137	0.079	0.002	0.002	0.035
17	AllButRuralInt	0.047	0.273	0.104	0.004	0.092	0.417	0.010	0.011	0.008	0.033
18	AllButRuralInt	0.028	0.291	0.092	0.028	0.074	0.457	0.010	0.014	0.005	0.001
19	AllButRuralInt	0.040	0.304	0.050	0.006	0.086	0.467	0.030	0.005	0.002	0.010
20	AllButRuralInt	0.039	0.303	0.105	0.008	0.078	0.421	0.015	0.022	0.005	0.005
21	AllButRuralInt	0.064	0.277	0.130	0.051	0.119	0.296	0.048	0.007	0.002	0.006
22	AllButRuralInt	0.006	0.431	0.064	0.004	0.045	0.411	0.034	0.004	0.002	0.000
23	AllButRuralInt	0.062	0.369	0.065	0.015	0.086	0.177	0.225	0.000	0.000	0.000
24	AllButRuralInt	0.102	0.531	0.075	0.032	0.055	0.195	0.006	0.003	0.001	0.001
25	AllButRuralInt	0.053	0.250	0.116	0.029	0.091	0.386	0.028	0.009	0.007	0.030
26	AllButRuralInt	0.023	0.197	0.064	0.012	0.056	0.480	0.080	0.010	0.005	0.074
27	AllButRuralInt	0.089	0.251	0.082	0.013	0.102	0.350	0.105	0.004	0.002	0.002

STATE _CODE	ROAD_GROUP	$VCDF_4$	$VCDF_5$	$VCDF_6$	$VCDF_7$	$VCDF_8$	$VCDF_9$	$VCDF_{10}$	$VCDF_{11}$	$VCDF_{12}$	$VCDF_{13}$
28	AllButRuralInt	0.010	0.339	0.063	0.006	0.124	0.422	0.011	0.014	0.006	0.004
29	AllButRuralInt	0.035	0.249	0.074	0.005	0.062	0.538	0.014	0.014	0.005	0.004
30	AllButRuralInt	0.053	0.226	0.061	0.008	0.038	0.318	0.126	0.002	0.005	0.163
31	AllButRuralInt	0.013	0.098	0.090	0.012	0.120	0.562	0.072	0.012	0.006	0.016
32	AllButRuralInt	0.049	0.322	0.040	0.004	0.052	0.452	0.010	0.027	0.012	0.032
33	AllButRuralInt	0.071	0.420	0.088	0.023	0.089	0.243	0.062	0.003	0.001	0.001
34	AllButRuralInt	0.029	0.356	0.116	0.051	0.064	0.371	0.008	0.004	0.000	0.000
35	AllButRuralInt	0.038	0.453	0.029	0.001	0.107	0.333	0.023	0.006	0.002	0.007
36	AllButRuralInt	0.049	0.307	0.121	0.028	0.105	0.301	0.060	0.009	0.008	0.012
37	AllButRuralInt	0.040	0.239	0.097	0.013	0.102	0.458	0.014	0.016	0.005	0.016
38	AllButRuralInt	0.030	0.257	0.061	0.011	0.168	0.293	0.118	0.002	0.003	0.058
39	AllButRuralInt	0.022	0.204	0.099	0.039	0.060	0.530	0.017	0.016	0.008	0.006
40	AllButRuralInt	0.020	0.322	0.047	0.004	0.113	0.460	0.012	0.013	0.004	0.005
41	AllButRuralInt	0.052	0.450	0.079	0.004	0.096	0.084	0.023	0.020	0.001	0.190
42	AllButRuralInt	0.020	0.337	0.092	0.037	0.086	0.391	0.008	0.014	0.007	0.008
44	AllButRuralInt	0.029	0.615	0.065	0.011	0.052	0.209	0.006	0.003	0.002	0.008
45	AllButRuralInt	0.021	0.380	0.175	0.068	0.091	0.251	0.008	0.001	0.000	0.004
46	AllButRuralInt	0.006	0.182	0.063	0.011	0.139	0.303	0.185	0.014	0.003	0.094
47	AllButRuralInt	0.015	0.345	0.092	0.020	0.138	0.366	0.007	0.007	0.002	0.007
48	AllButRuralInt	0.038	0.262	0.082	0.005	0.118	0.457	0.014	0.013	0.004	0.006
49	AllButRuralInt	0.017	0.363	0.022	0.000	0.094	0.294	0.002	0.005	0.045	0.158
50	AllButRuralInt	0.025	0.362	0.092	0.014	0.087	0.387	0.028	0.003	0.002	0.001
51	AllButRuralInt	0.142	0.185	0.119	0.026	0.061	0.439	0.013	0.010	0.005	0.000
53	AllButRuralInt	0.035	0.353	0.072	0.018	0.088	0.225	0.143	0.010	0.010	0.046
54	AllButRuralInt	0.097	0.342	0.094	0.035	0.038	0.357	0.027	0.007	0.003	0.000
55	AllButRuralInt	0.074	0.300	0.067	0.031	0.141	0.351	0.027	0.004	0.003	0.002
56	AllButRuralInt	0.044	0.175	0.080	0.009	0.094	0.407	0.101	0.003	0.005	0.082
1	UrbanInt&Expressways	0.008	0.243	0.147	0.010	0.046	0.482	0.032	0.018	0.008	0.005
2	UrbanInt&Expressways	0.030	0.663	0.100	0.002	0.080	0.059	0.036	0.000	0.000	0.031
4	UrbanInt&Expressways	0.009	0.408	0.108	0.039	0.094	0.286	0.006	0.022	0.003	0.024
5	UrbanInt&Expressways	0.059	0.375	0.038	0.008	0.118	0.376	0.007	0.014	0.002	0.002
6	UrbanInt&Expressways	0.025	0.432	0.049	0.006	0.042	0.401	0.003	0.033	0.008	0.001
8	UrbanInt&Expressways	0.040	0.204	0.105	0.008	0.097	0.475	0.018	0.010	0.012	0.031
9	UrbanInt&Expressways	0.021	0.276	0.062	0.016	0.094	0.476	0.010	0.040	0.005	0.001
11	UrbanInt&Expressways	0.101	0.431	0.142	0.070	0.116	0.116	0.006	0.002	0.000	0.016
12	UrbanInt&Expressways	0.029	0.336	0.069	0.017	0.137	0.386	0.006	0.011	0.006	0.002
13	UrbanInt&Expressways	0.079	0.319	0.070	0.001	0.108	0.392	0.008	0.011	0.006	0.006
15	UrbanInt&Expressways	0.109	0.748	0.075	0.005	0.025	0.034	0.002	0.001	0.000	0.000
17	UrbanInt&Expressways	0.029	0.180	0.064	0.002	0.060	0.610	0.009	0.016	0.012	0.019
18	UrbanInt&Expressways	0.019	0.263	0.029	0.006	0.048	0.595	0.008	0.021	0.011	0.001
19	UrbanInt&Expressways	0.068	0.328	0.067	0.005	0.061	0.441	0.009	0.014	0.007	0.001

STATE _CODE	ROAD_GROUP	***VCDF$_4$***	***VCDF$_5$***	***VCDF$_6$***	***VCDF$_7$***	***VCDF$_8$***	***VCDF$_9$***	***VCDF$_{10}$***	***VCDF$_{11}$***	***VCDF$_{12}$***	***VCDF$_{13}$***
20	UrbanInt&Expressways	0.040	0.270	0.153	0.010	0.103	0.377	0.008	0.026	0.005	0.008
21	UrbanInt&Expressways	0.056	0.313	0.118	0.152	0.102	0.233	0.011	0.012	0.002	0.001
24	UrbanInt&Expressways	0.106	0.427	0.070	0.026	0.056	0.298	0.005	0.006	0.004	0.001
25	UrbanInt&Expressways	0.061	0.215	0.101	0.029	0.099	0.416	0.028	0.010	0.008	0.033
26	UrbanInt&Expressways	0.018	0.173	0.055	0.009	0.045	0.562	0.068	0.010	0.006	0.055
27	UrbanInt&Expressways	0.048	0.186	0.072	0.014	0.092	0.523	0.047	0.015	0.002	0.002
28	UrbanInt&Expressways	0.013	0.271	0.047	0.001	0.098	0.526	0.007	0.025	0.011	0.002
29	UrbanInt&Expressways	0.022	0.163	0.068	0.007	0.043	0.660	0.008	0.015	0.012	0.002
31	UrbanInt&Expressways	0.021	0.153	0.177	0.018	0.113	0.444	0.047	0.007	0.003	0.017
32	UrbanInt&Expressways	0.067	0.328	0.055	0.006	0.052	0.413	0.012	0.023	0.011	0.035
33	UrbanInt&Expressways	0.071	0.420	0.088	0.023	0.089	0.243	0.062	0.003	0.001	0.001
34	UrbanInt&Expressways	0.016	0.296	0.096	0.048	0.066	0.461	0.010	0.006	0.000	0.000
35	UrbanInt&Expressways	0.034	0.621	0.022	0.000	0.094	0.205	0.009	0.013	0.000	0.001
36	UrbanInt&Expressways	0.101	0.254	0.078	0.014	0.105	0.348	0.042	0.019	0.021	0.018
37	UrbanInt&Expressways	0.040	0.152	0.066	0.009	0.112	0.566	0.014	0.024	0.007	0.012
38	UrbanInt&Expressways	0.038	0.149	0.063	0.007	0.144	0.502	0.051	0.008	0.008	0.031
39	UrbanInt&Expressways	0.030	0.159	0.084	0.027	0.052	0.595	0.017	0.021	0.009	0.005
40	UrbanInt&Expressways	0.029	0.474	0.076	0.006	0.104	0.280	0.009	0.009	0.004	0.009
42	UrbanInt&Expressways	0.016	0.120	0.053	0.015	0.065	0.639	0.010	0.041	0.023	0.017
44	UrbanInt&Expressways	0.031	0.551	0.074	0.012	0.053	0.249	0.008	0.005	0.002	0.015
48	UrbanInt&Expressways	0.040	0.272	0.121	0.003	0.099	0.432	0.009	0.015	0.005	0.004
49	UrbanInt&Expressways	0.014	0.313	0.020	0.000	0.128	0.377	0.006	0.009	0.033	0.100
51	UrbanInt&Expressways	0.125	0.136	0.096	0.020	0.051	0.537	0.010	0.016	0.008	0.000
53	UrbanInt&Expressways	0.042	0.350	0.062	0.020	0.082	0.252	0.137	0.010	0.012	0.034
54	UrbanInt&Expressways	0.057	0.140	0.047	0.010	0.031	0.661	0.007	0.032	0.015	0.001
55	UrbanInt&Expressways	0.063	0.244	0.082	0.056	0.123	0.404	0.015	0.008	0.003	0.001
56	UrbanInt&Expressways	0.013	0.050	0.020	0.002	0.033	0.716	0.048	0.018	0.028	0.071
1	Non-InterstateOrExpressway	0.024	0.296	0.065	0.010	0.101	0.471	0.018	0.010	0.004	0.001
2	Non-InterstateOrExpressway	0.043	0.679	0.102	0.001	0.051	0.058	0.035	0.000	0.000	0.031
4	Non-InterstateOrExpressway	0.016	0.457	0.083	0.007	0.151	0.252	0.005	0.016	0.004	0.009
5	Non-InterstateOrExpressway	0.053	0.406	0.050	0.008	0.118	0.340	0.012	0.008	0.001	0.005
6	Non-InterstateOrExpressway	0.012	0.396	0.041	0.002	0.037	0.450	0.002	0.049	0.010	0.001
8	Non-InterstateOrExpressway	0.050	0.206	0.111	0.011	0.084	0.472	0.032	0.010	0.007	0.018
9	Non-InterstateOrExpressway	0.031	0.674	0.136	0.062	0.038	0.055	0.004	0.001	0.000	0.000
10	Non-InterstateOrExpressway	0.099	0.460	0.085	0.021	0.075	0.247	0.006	0.003	0.001	0.001
12	Non-InterstateOrExpressway	0.026	0.403	0.072	0.013	0.227	0.245	0.009	0.003	0.002	0.001
13	Non-InterstateOrExpressway	0.087	0.481	0.079	0.002	0.086	0.250	0.010	0.002	0.001	0.001
15	Non-InterstateOrExpressway	0.074	0.747	0.082	0.002	0.020	0.070	0.004	0.000	0.000	0.000
16	Non-InterstateOrExpressway	0.039	0.529	0.051	0.019	0.109	0.137	0.079	0.002	0.002	0.035
17	Non-InterstateOrExpressway	0.054	0.306	0.117	0.005	0.103	0.351	0.011	0.009	0.007	0.038
18	Non-InterstateOrExpressway	0.030	0.301	0.113	0.036	0.082	0.412	0.011	0.011	0.003	0.001

STATE _CODE	ROAD_GROUP	$VCDF_4$	$VCDF_5$	$VCDF_6$	$VCDF_7$	$VCDF_8$	$VCDF_9$	$VCDF_{10}$	$VCDF_{11}$	$VCDF_{12}$	$VCDF_{13}$
19	Non-InterstateOrExpressway	0.039	0.303	0.048	0.006	0.087	0.469	0.031	0.004	0.002	0.011
20	Non-InterstateOrExpressway	0.048	0.342	0.077	0.006	0.085	0.400	0.007	0.030	0.002	0.003
21	Non-InterstateOrExpressway	0.106	0.442	0.169	0.044	0.102	0.116	0.021	0.000	0.000	0.000
23	Non-InterstateOrExpressway	0.062	0.369	0.065	0.015	0.086	0.177	0.225	0.000	0.000	0.000
24	Non-InterstateOrExpressway	0.100	0.569	0.077	0.034	0.054	0.157	0.006	0.001	0.000	0.001
25	Non-InterstateOrExpressway	0.033	0.339	0.153	0.030	0.074	0.309	0.028	0.007	0.006	0.020
26	Non-InterstateOrExpressway	0.026	0.212	0.071	0.014	0.063	0.426	0.088	0.009	0.004	0.087
27	Non-InterstateOrExpressway	0.094	0.260	0.084	0.013	0.104	0.326	0.113	0.003	0.002	0.002
28	Non-InterstateOrExpressway	0.009	0.354	0.067	0.007	0.130	0.398	0.012	0.012	0.005	0.004
29	Non-InterstateOrExpressway	0.036	0.259	0.075	0.004	0.064	0.525	0.015	0.014	0.004	0.004
30	Non-InterstateOrExpressway	0.053	0.226	0.061	0.008	0.038	0.318	0.126	0.002	0.005	0.163
31	Non-InterstateOrExpressway	0.024	0.104	0.121	0.014	0.146	0.470	0.075	0.014	0.005	0.029
32	Non-InterstateOrExpressway	0.038	0.317	0.029	0.003	0.052	0.478	0.008	0.030	0.013	0.030
34	Non-InterstateOrExpressway	0.051	0.424	0.126	0.041	0.064	0.284	0.006	0.004	0.001	0.000
35	Non-InterstateOrExpressway	0.039	0.446	0.030	0.002	0.107	0.338	0.024	0.005	0.002	0.008
36	Non-InterstateOrExpressway	0.033	0.324	0.135	0.032	0.105	0.286	0.065	0.006	0.004	0.010
37	Non-InterstateOrExpressway	0.055	0.387	0.115	0.024	0.106	0.264	0.012	0.011	0.003	0.023
38	Non-InterstateOrExpressway	0.029	0.263	0.060	0.011	0.170	0.282	0.122	0.001	0.002	0.060
39	Non-InterstateOrExpressway	0.013	0.254	0.117	0.052	0.070	0.455	0.016	0.011	0.006	0.006
40	Non-InterstateOrExpressway	0.012	0.372	0.056	0.006	0.076	0.449	0.013	0.010	0.004	0.003
42	Non-InterstateOrExpressway	0.021	0.409	0.105	0.044	0.092	0.308	0.007	0.005	0.002	0.005
44	Non-InterstateOrExpressway	0.027	0.659	0.058	0.011	0.051	0.183	0.006	0.001	0.001	0.004
45	Non-InterstateOrExpressway	0.026	0.431	0.137	0.010	0.105	0.279	0.009	0.001	0.000	0.002
46	Non-InterstateOrExpressway	0.005	0.185	0.067	0.010	0.150	0.249	0.234	0.008	0.002	0.091
47	Non-InterstateOrExpressway	0.026	0.650	0.107	0.038	0.131	0.026	0.012	0.000	0.000	0.012
48	Non-InterstateOrExpressway	0.050	0.335	0.098	0.007	0.121	0.358	0.014	0.009	0.004	0.005
49	Non-InterstateOrExpressway	0.019	0.413	0.025	0.000	0.094	0.297	0.001	0.005	0.036	0.110
51	Non-InterstateOrExpressway	0.153	0.215	0.133	0.030	0.067	0.378	0.015	0.006	0.003	0.000
53	Non-InterstateOrExpressway	0.029	0.356	0.081	0.015	0.094	0.200	0.148	0.010	0.009	0.056
54	Non-InterstateOrExpressway	0.103	0.374	0.102	0.039	0.039	0.309	0.030	0.003	0.001	0.000
55	Non-InterstateOrExpressway	0.075	0.305	0.066	0.028	0.143	0.346	0.028	0.003	0.003	0.002
56	Non-InterstateOrExpressway	0.046	0.183	0.084	0.010	0.097	0.388	0.105	0.002	0.004	0.083

REFERENCES

1. American Association of State Highway and Transportation Officials. 2021. *Mechanistic–Empirical Pavement Design Guide: A Manual of Practice,* 3rd ed. 2021 Supplement. Washington, DC: American Association of State Highway and Transportation Officials.

2. Federal Highway Administration. 2016. *Traffic Monitoring Guide*. Report No. FHWA-PL-17-003. Washington, DC: Federal Highway Administration.

3. FHWA. 2021. "Highway Performance Monitoring System (HPMS)" (web page). https://www.fhwa.dot.gov/policyinformation/hpms.cfm, last accessed September 7, 2023.

4. Federal Highway Administration. 2016. *Highway Performance Monitoring System Field Manual.* Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/policyinformation/hpms/fieldmanual/, last accessed September 7, 2023.

5. FHWA. 2021. *Highway Performance Monitoring System Software Guide for Version 8.0*. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/policyinformation/hpms/softwareguide/hpms_software_guide.pdf, last accessed September 7, 2023.

6. General Services Administration. 2019. "Travel Monitoring Analysis System (TMAS)" (web page). https://catalog.data.gov/dataset/travel-monitoring-analysis-system-tmas-travel-monitoring-analysis-system, last accessed September 7, 2023.

7. FHWA. n.d. "LTPP InfoPave: Data" (web page). https://infopave.fhwa.dot.gov/Data/TableExport/, last accessed September 7, 2023.

8. Transportation Research Board. 2010. *HCM 2010 Highway Capacity Manual, Vol. 1: Concepts*. Washington, DC: Transportation Research Board.

Recommended Citation: Federal Highway Administration, *Estimating Design Lane Truck Volumes From HPMS Traffic Data for Long-Term Pavement Performance Analyses* (Washington, DC: 2023) https://doi.org/10.21949/1521435

HRDI-30/11-23(WEB)E