Estimation of Truck Traffic Inputs for Mechanistic–Empirical Pavement Design in California

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This study developed default truck traffic inputs for mechanistic–empirical pavement design procedures for the California highway system based on California weigh-in-motion (WIM) data. Both cluster analysis and regression analysis were applied to develop the default axle load spectra. Regression analysis produced unsatisfactory results so it was not used. On the basis of cluster analysis of axle load spectra, the WIM sites were divided into several groups, and default truck traffic inputs were estimated for each group. A decision tree was developed to help designers select the appropriate default factors based on easily available information: geographic location and traffic volume and composition. These data can be obtained from the California Department of Transportation annual report of annual average daily truck traffic. Traffic inputs were developed for both the Caltrans Mechanistic–Empirical Pavement Design and NCHRP Mechanistic–Empirical Pavement Design Guide software.

The University of California Pavement Research Center and the California Department of Transportation (Caltrans) have been working together since 2000 to enable Caltrans to use mechanistic–empirical (ME) design procedures for pavement rehabilitation and reconstruction and new pavement designs. The work includes evaluation and calibration of the Mechanistic–Empirical Pavement Design Guide (MEPDG) software developed as part of the NCHRP 1-37A project and development of pavement analysis and design models for flexible pavement that are incorporated into the Caltrans Mechanistic–Empirical Pavement Design (CalME) software. Both software programs require more detailed data on truck traffic for pavement performance analysis than the older pavement design procedures used by Caltrans.

Truck traffic, a key input for the design and analysis of pavement structures, is the most important factor in pavement damage and deterioration. The mechanistic-based distress prediction models used in the MEPDG software require the input of specific data for each axle type and axle load group. MEPDG takes three levels of input data for the following types of traffic data, grouped into four categories:

- Traffic volume (base-year information)
  - Two-way annual average daily truck traffic (AADTT)
  - Percentage of trucks in design direction
  - Percentage of trucks in design lane
  - Vehicle (truck) operating speed
- Traffic-volume adjustment factors
  - Monthly adjustment
  - Vehicle-class distribution
  - Hourly truck distribution
  - Traffic growth factors
- Axle load distribution factors
  - Axle load distribution of each axle type (single, tandem, tridem, and quad) for each month and truck class
- General traffic inputs

To address the need for traffic data inputs for the MEPDG, NCHRP Project 1-39, Traffic Data Collection, Analysis, and Forecasting for Mechanistic Pavement Design, was conducted, and it included development of guidelines for forecasting traffic data to formulate load spectra. The guidelines included a proposed simple forecasting procedure: associate a project site with one or more sites that have known historical traffic data; analyze the data from these sites; and then, applying appropriate judgment, adjust the results based on a review of macroeconomic and site-specific factors. However, the project developed neither the procedure nor the criteria for associating a project site with others.

CalME is the software and accompanying documentation for the analysis and design of flexible pavements developed for Caltrans and specifically tailored to the materials, traffic, and climate conditions in California.

The CalME software also requires detailed truck traffic information, but the requirements are less demanding than those of MEPDG. CalME needs two types of truck traffic information: traffic volume and axle load spectra. Traffic volume includes three variables: number of axles per truck, number of axles per year per design lane, and growth rate of traffic volume. For the axle load spectra, the CalME models consider four axle groups: steering, single, tandem, and tridem. The average hourly load spectra of each axle group are needed for the entire year, in contrast to the monthly load spectra required by MEPDG. Analysis of historical Caltrans weigh-in-motion (WIM) data showed little seasonal variation in the state (*1*).

The CalME program for design of flexible pavements has three levels of analysis: an empirical method based on *R*-values and gravel factors, a classic ME approach based on equivalent single-

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axle load (ESAL) values, and an incremental-recursive method. The incremental-recursive method requires inputs of axle load spectra, whereas the first two levels require only the traditional Caltrans traffic index (ESALs in the design period).

Caltrans has been installing WIM stations and collecting truck traffic data on state highways in California since 1987. It has maintained a very detailed database of historical truck traffic information for more than 80 highway sites across the state. WIM data include axle load, axle spacing, and vehicle speed information for each truck, from which the complete traffic inputs for the ME design software can be derived. This information, however, is limited to the highway sections where WIM stations are installed. For many other highway sections where no, or limited, truck traffic data are collected, the traffic inputs for the ME design software must be estimated from other available sources.

OBJECTIVE

This paper analyzes the axle load spectra and truck traffic-volume data included in the California WIM database and develops the default truck traffic inputs for CalME and MEPDG for pavement sections where site-specific WIM traffic data are unavailable or incomplete.

METHODOLOGY AND DATA SOURCE

Extrapolation of truck traffic characteristics to other locations was explored in previous studies (*2–4*). The conventional approach is to categorize highway sections into groups and use traffic data from other sections within the same group. The determination of groups, however, is difficult because traffic streams on highways typically consist of vehicles with diverse origin–destination (O-D) areas and are affected by many factors in these O-D areas such as demographic and economic traits. Pioneering work on grouping conducted in the state of Washington found that it is not possible to form homogenous groups (*5*). The work of this study builds on that of previous investigations but focuses on the California highway network. Two approaches were explored to categorize traffic: regression analysis and cluster analysis.

Regression Analysis

Recently, regression analysis has been applied to examine the characteristics of axle load spectra among sites (*2*). Such a statistical model has the potential for quantitative prediction of traffic data for ME analysis and design. For functional responses (e.g., load spectrum), the analysis is performed in two steps: first, the load spectrum is fitted with some theoretical distribution functions, so that it is reduced to a few characteristic parameters; second, with the estimated parameters used as response variables, regression analysis is performed to determine the influence of other explanatory variables on these parameters.

Axle load spectra tend to appear with multiple concentrations of central tendency. For example, tandem axle load spectra typically have two peaks (bimodal distribution), representing empty and loaded trucks. Multimodal distribution of axle load can be modeled by the sum of several theoretical distributions. Mathematically, it can be expressed as follows:

$$f^* = \sum_i p_i f_i \tag{1}$$

where

f^* = axle load spectrum,
f_i = theoretical distribution of axle load,
p_i = scaling factor that gives weight to f_i in the sum, and
i = 1, 2, or larger integers.

Several theoretical distributions can be used in the formula, such as the normal distribution, the lognormal distribution, the beta distribution, and the gamma distribution. The fit between the sum of several theoretical distributions and observed load spectra has been shown to be excellent (*6*).

In this study, a gamma distribution and a normal distribution are combined to model the axle load spectra:

$$f(x) = p \cdot x^{k-1} \frac{e^{-x/\theta}}{\theta^k \Gamma(k)} + (1-p) \cdot \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{2}$$

where

$x^{k-1} \dfrac{e^{-x/\theta}}{\theta^k \Gamma(k)}$ = probability density function of a gamma distribution,
$\dfrac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$ = probability density function of a normal distribution,
k, θ, σ, and μ = parameters,
p = scaling factor between 0 and 1,
x = axle load within a given axle load type, and
$f(x)$ = relative frequency of axle load x for each axle load type: for example, steering single, single, tandem, and tridem.

The four parameters and the scaling factor are estimated by minimizing the sum-of-the-squared errors between the actual and fitted load spectra coefficient (LSC). LSC, a statistical measure related to the concept of pavement damage, is defined as follows:

$$\text{LSC} = \sum_{i=1}^{l} \left(\frac{\left(\dfrac{\text{mid-load\_range}_i}{L} \right)}{80} \right)^m \times \frac{\text{load-range\_count}_i}{\text{total\_count}} \times L \tag{3}$$

where

l = number of load ranges,
mid-load_range$_i$ = average load for load range i,
load-range_count$_i$ = number of axles in load range i,
L = 1 for steering axle and single axle, 2 for tandem, and 3 for tridem, and
m = exponent (3.8).

The five estimated parameters (four distribution parameters and the scaling factor) are then used as the response variables in a multiple linear regression analysis to explore the relationship between these parameters and potential predictors, including highway characteristics and socioeconomic factors.

Cluster Analysis

Given the large number of WIM sites available, a hierarchical cluster analysis can be applied to group the multivariate response into informative clusters. This method makes no assumptions about the grouping criteria or influential factors. The highway characteristics within each cluster are then examined to extract the common traits. One advantage of cluster analysis is that it preserves the shape information of the multivariate response. The basic operations of the hierarchical clustering algorithm can be found in the literature (*7*).

Data Source

The WIM data collected during the period 1991–2003 from all 108 WIM stations installed before 2003 were obtained from the Caltrans Office of Truck Services and used in the analysis. The distribution of these WIM stations can be found in the literature (*7*).

RESULTS

Regression Analysis for Axle Load Spectra

The two-step regression analysis procedure was followed to investigate the relationship between explanatory variables and axle load spectra. The explanatory variables include a variety of factors that can affect the truck traffic flow on highways. In this study, two categories of factors are considered:

- Roadway characteristics
  - Number of lanes
  - Highway functional classification
  - Truck traffic volume and volume ratio of Class 5 and Class 9 trucks
  - Area types: urban and rural
- Socioeconomic factors
  - Population density and change in population density
  - Housing density and change in housing density
  - Land use

Highway functional classification consists of three levels: Interstate, U.S., and state highways. The Class 9 truck traffic volume in 2000 is used to represent the main truck flow at each WIM location. Area types have two levels: urban and rural. Changes in population and housing densities are the differences in the data between 1990 and 2000. Land use has two levels: agriculture–forest and other uses. Land use is considered because agricultural and logging activities typically generate truck traffic. All data for these explanatory variables were extracted from the California Spatial Information Library.

In addition to the two categories of factors, grouping based on the axle load spectra was incorporated into the regression analysis. A categorical variable, representing the three groups determined by preliminary cluster analysis of the tandem axle load spectra, was included as an explanatory variable (*7*).

Pearson's correlation matrix of these explanatory variables revealed that the number of lanes and area types, population density and housing density, and population density change and housing density change are highly correlated, so area type, housing density, and housing density change were removed from the analysis. In addition, the population density change over 10 years was normalized to the population density in the year 2000, so essentially a population density growth rate was used as an explanatory variable. Table 1 summarizes the estimation results for the five parameters. For the scaling factor (p), the multiple linear regression model fitted the data well. The scaling factor determines the relative heights of the two peaks in tandem axle load spectra: a larger scaling factor indicates a higher percentage of low-weight axles. The signs of the estimated coefficients for the explanatory variables suggest that a high volume of Class 9 trucks corresponds to a low percentage of low-weight axle loads, and highways in rural and inland areas have fewer low-weight axle loads.

The other four parameters determine the width and shape of the first peak (gamma function) curve and the width and position of the second peak (normal function) curve. The R^2-value is small for all

TABLE 1 Estimation Results from Regression Analysis of Tandem Axle Load Spectra

	p		k		Θ		μ		σ	
Parameter	Estimate	*P*-Value	Estimate	*P*-Value	Estimate	*P*-Value	Estimate	*P*-Value	Estimate	*P*-Value
(Intercept)	0.8054	<.001	1.6115	<.001	4.6530	.0009	0.8145	.0048	15.892	<.001
Ratio of Class 5 and Class 9 trucks	0.0085	.4274	0.0331	.6212	−0.0650	.8332	0.1829	.0062	−0.2213	.1088
Class 9 volume	−0.0018	.0213	−0.0054	.2547	0.0180	.4084	0.0055	.2278	−0.0285	.0042
Number of lanes	0.0056	.4839	0.0132	.7914	−0.0824	.7200	0.0404	.4026	−0.0997	.3281
U.S. highway or Interstate highway	0.0043	.7736	−0.0283	.7645	0.2620	.5490	0.0622	.4977	−0.0770	.6901
State highway or Interstate highway	0.0013	.9028	0.0841	.2227	−0.4507	.1579	0.0339	.6100	−0.0395	.7776
AADTT 2000	0.0000	.0164	0.0000	.7947	0.0000	.8596	0.0000	.6442	0.0001	.0775
Urban or rural	0.0081	.5553	0.0351	.6811	−0.3224	.4153	0.0300	.7172	−0.1727	.3242
PD2000[a]	0.0000	.0725	0.0001	.4885	0.0000	.9725	0.0001	.4831	−0.0002	.3505
NDPD[b]	0.0352	.3323	−0.0978	.6659	0.2357	.8216	−0.2411	.2739	0.0079	.9864
Land use[c]	0.0069	.5256	0.0618	.3651	−0.0930	.7671	−0.0246	.7086	0.0041	.9766
Cluster Group 3 or Cluster Group 1	−0.1043	<.001	0.0139	.8752	0.2664	.5140	−0.0491	.5658	0.3005	.0992
Cluster Group 2 or Cluster Group 1	−0.1418	<.001	0.0024	.9891	1.6364	.0433	−0.1958	.2434	0.6190	.0824
R^2	.866		.287		.421		.311		.198	
P-value for constant[d]	<.001		.046		<.001		.025		.309	

[a] Population density in 2000.
[b] Population density change from 1990 to 2000, normalized by PD2000.
[c] Agriculture–logging land-use reference to other land uses.
[d] *P*-value for the null hypothesis that the regression function is a constant term.

four parameters, indicating that the multiple linear regression model does not fit the data well.

Overall, the regression analysis does not capture the spatial variation characteristics of the tandem axle load spectra. The same conclusion was reached for the other axle groups.

Cluster Analysis of Axle Load Spectra

Both CalME and MEPDG require the load spectra of four axle groups, with slight differences. CalME needs the load spectra of steering, single, tandem, and tridem axles, whereas MEPDG requires the load spectra of single, tandem, tridem, and quadruple axles. Quadruple axles typically do not exist on California highways, so they are ignored in the analysis.

Tandem Axle Loads

Among the four axle groups considered, the tandem-axle group is the most important because it generally has the highest volume. Therefore, cluster analysis is first performed on the tandem axle load spectra to group the WIM sites. The grouping is then adjusted on the basis of the cluster analysis on the load spectra of other load groups. On the basis of the cluster analysis of the tandem axle load spectra, three groups were obtained. The second group was further split into two subgroups (Groups 2a and 2b) because of some significant variations in the low-load range.

The axle load spectra in each group, averaged to give the group-level default load spectra, are plotted in Figure 1. Trucks at WIM sites in Group 1 have more light axles than heavy axles, and trucks at other WIM sites have more heavy axles. Trucks at WIM sites in Group 3 have the highest percentage of heavy axles. Trucks at WIM sites in Groups 2a and 2b have similar percentages of heavy axles, but trucks at Group 2b WIM sites have higher percentages of intermediate load axles and lower percentages of light axles than trucks at Group 2a WIM sites.

A check of locations of the WIM sites reveals that most WIM sites in Group 1 are along the coast or near urban areas. These sites have more empty-truck axle loads and lighter loaded-truck axle loads. The sites in Groups 2a, 2b, and 3 are in inland and rural or mountain areas. These sites have more loaded-truck axle loads and heavier axle loads associated with them.

Further examination of the highway information reveals that truck traffic on I-5, US-99, and US-395 consists predominantly of heavy, long-haul trucks.

On the basis of highways and regions, California highways can be divided into the following four groups:

- All highways in the coastal regions and in urban areas are in Group 1.
- I-5 in Districts 3 (Sacramento County), 10, and 6; US-99 in Districts 3, 10, and 6; I-505; I-80 in Placer County (District 3); Highway 46 in District 5; and I-580 in District 10 are in Group 2a.
- I-5 in Tehama County (District 2), Glenn, Colusa, and Yolo Counties (District 3); Highway 58 in District 6; I-10 and I-15 in District 8; and US-395 are in Group 2b.
- I-5 and US-97 in Siskiyou and Shasta Counties (District 2) and Highway 58 and I-40 in District 8 are in Group 3.

Other highways in the inland and rural areas can be placed in Group 2 if no additional information is available.

For a given highway section, use of these physical locations alone to determine grouping may appear vague and sometimes erroneous. A better approach is to assign groups based on known traffic information. Fortunately, the Caltrans Traffic Data Branch compiles traffic counts for the entire California highway network in annual AADTT reports, which contain not only the annual average daily traffic (AADT) and AADTT but also counts of trucks with two, three, four, and five or more axles.

Four variables from the Caltrans annual AADTT report were examined for their usefulness in helping to classify the highway sections: AADT, AADTT, truck percentage, and (4–8)/(9–15) ratio. The truck percentage is the percentage of AADTT in AADT, and the (4–8)/(9–15) ratio corresponds to the ratio of Class 4 through Class 8 truck volume to Class 9 through Class 15 truck volume in the WIM data and is calculated as the number of trucks with two, three, and four axles divided by the number of trucks with five or more axles.

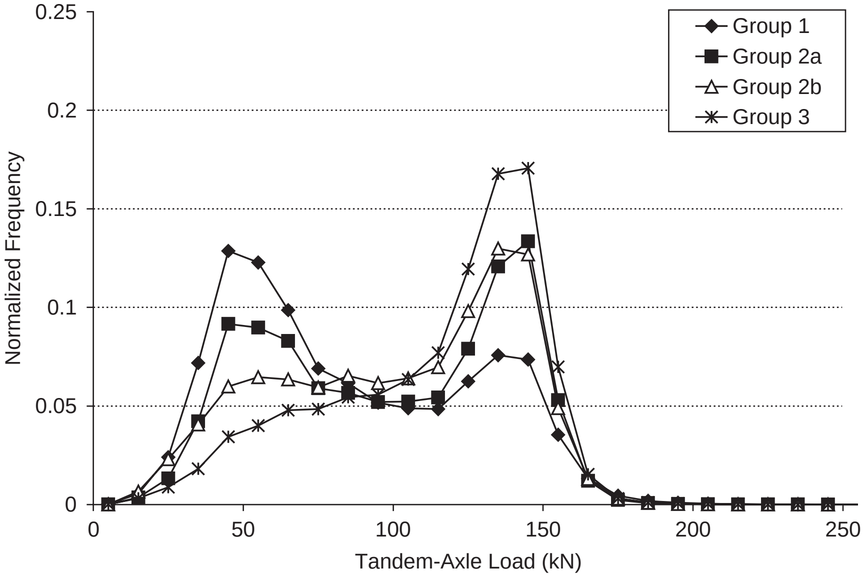
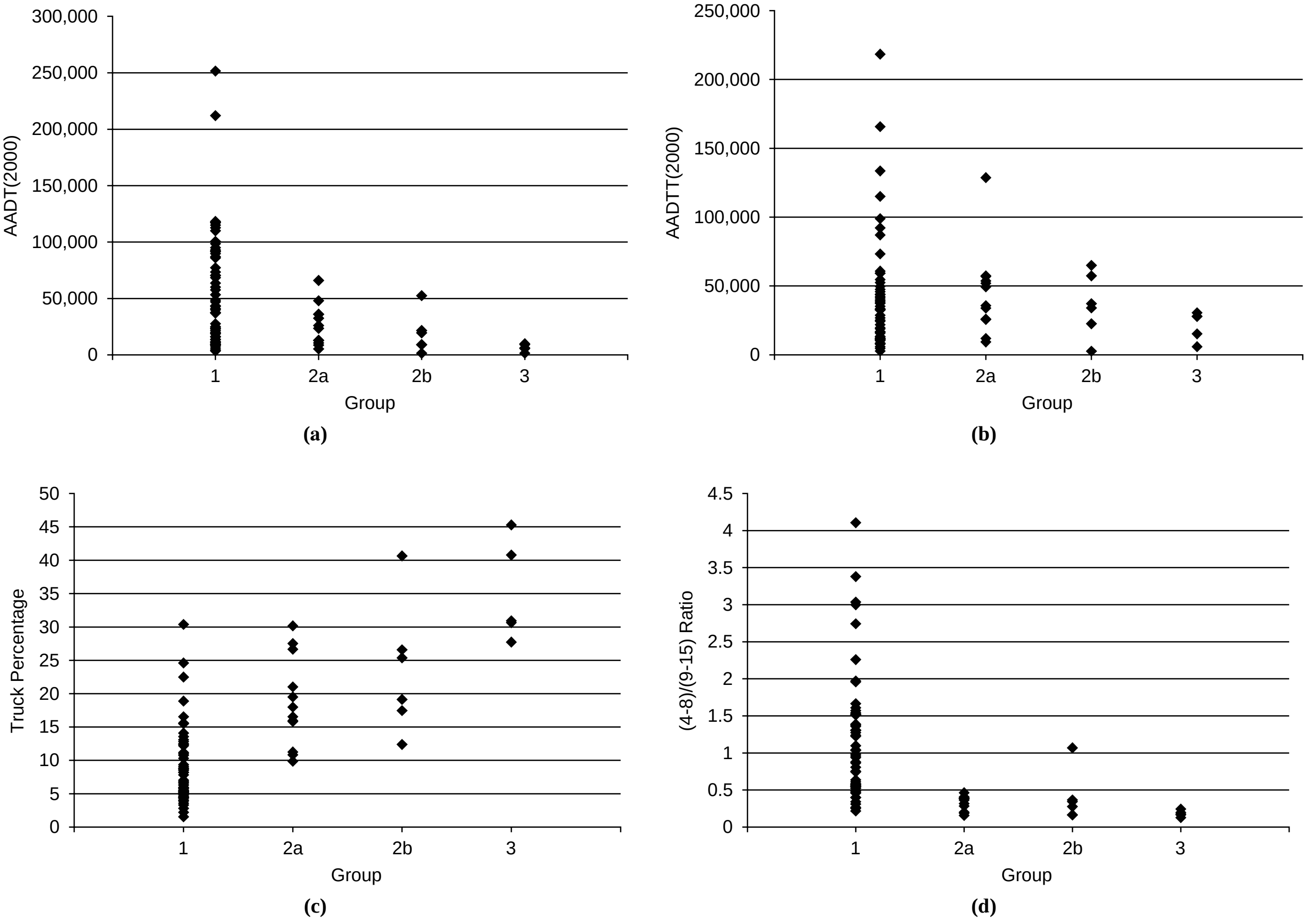


FIGURE 1 Tandem axle load spectra averaged by group.



(a) (b)

(c) (d)

FIGURE 2 Distribution of site characteristics in each group based on tandem axle load spectra.

Figure 2 shows the distributions of AADT, AADTT, truck percentage, and (4–8)/(9–15) ratio in each group. The following observations can be made from these plots:

1. Highways with AADT of more than 70,000, or with less than 10% trucks, or with a (4–8)/(9–15) ratio greater than 1 (higher volume of two-, three-, and four-axle trucks than of trucks with five or more axles) are in Group 1.
2. The (4–8)/(9–15) ratio for highways in Groups 2a, 2b, and 3 is typically less than 0.5.
3. Highways in Group 3 have at least 25% trucks in the traffic stream.
4. Traffic on highways in Group 1 has broad distributions in terms of AADT, AADTT, truck percentage, and (4–8)/(9–15) ratio.

On the basis of the preceding observations, a decision tree can be developed to determine to which group a highway section should belong.

Steering Axle, Single Axle, and Tridem Axle Loads

Cluster analysis of the steering axle load spectra divides the WIM sites into two major groups. Comparison of the groups based on tandem-axle load and the groups based on steering-axle load reveals that all the WIM sites in Group 1 of steering-axle load are part of the WIM sites in Group 1 of tandem-axle load. These WIM sites are mainly on highways in densely populated areas, including the Bay Area, Los Angeles, San Diego, and a few other California cities.

The WIM sites in Group 1 based on tandem axle load spectra can be further divided into two subgroups (Groups 1a and 1b) based on the steering axle load spectra. The relationship between the truck percentage and the (4–8)/(9–15) ratio is used as the criterion for division, as shown in Figure 3. WIM sites with a truck percentage less than 10 and a (4–8)/(9–15) ratio greater than 1.2 are placed in Group 1a; otherwise, they are placed in Group 1b.

Cluster analysis of the single axle load spectra also divides the WIM sites into two major groups. The WIM sites in the first group are all in Group 1 based on the tandem axle load, and most WIM sites in the second group are in Group 2 or 3 based on the tandem-axle load.

Cluster analysis of the tridem axle load spectra divides the WIM sites into two major groups. A location check reveals that the WIM sites in the second group are mainly on I-5, US-97, and I-505.

Grouping of WIM Sites Based on Axle Load Spectra

Because regression analysis has produced poor results for fitting axle load spectra, the rest of the study focuses on use of the grouping technique to develop default truck traffic inputs.

Using the load spectra characteristics of steering axles and tridem axles, the grouping based on the tandem axle load spectra was further divided into eight subgroups (Level 3 groups), as shown in

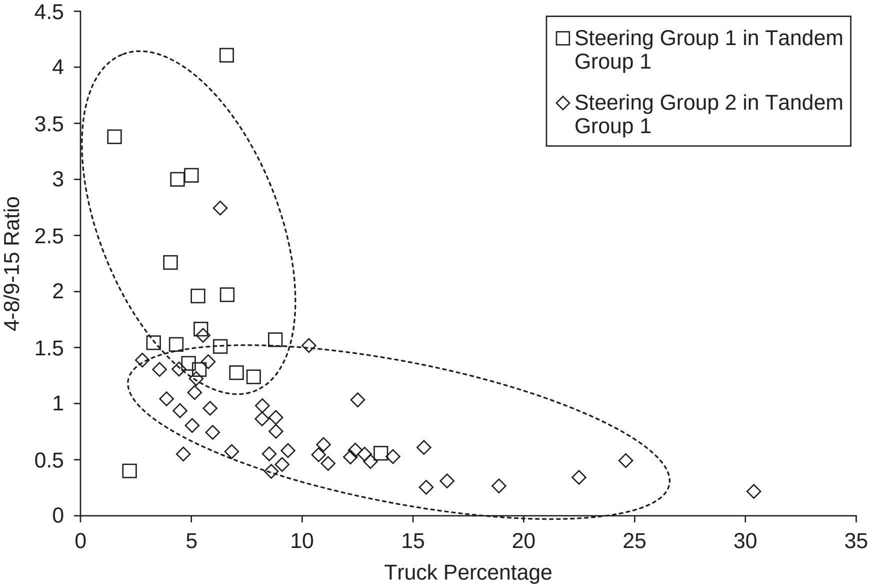


FIGURE 3 Relationship between truck percentage and (4–8)/(9–15) ratio for Group 1 WIM sites (based on tandem axle load spectra).

Table 2. If only the tandem axle load spectrum is to be considered for grouping, the WIM sites can be divided into Level 1 or 2 groups.

A decision tree was developed to help determine in which group a highway section should be placed, as shown in Figure 4. The averaged traffic inputs from all WIM sites in each group were used as the traffic characteristics of the regions covered by the group. For CalME, the number of axles per truck and the hourly axle load spectra are averaged for each group. Other traffic inputs, including the number of axles per lane per year and the growth rate of truck traffic, should be developed for each highway section from the Caltrans annual AADTT report.

The number of axles per lane per year can be calculated based on the following equation:

$$N_{\text{axleLY}} = \text{AADTT} \cdot \text{Axle\_per\_Truck} \cdot f_d \cdot f_l \cdot 365 \qquad (4)$$

where

N_{axleLY} = number of axles per lane per year,
AADTT = annual average daily truck traffic (two-way),
Axle_per_Truck = number of axles per truck,
f_d = directional distribution factor of truck traffic (default value = 0.52), and
f_l = lane distribution factor of truck traffic.

Analysis of Traffic Volume in Each Group

MEPDG requires more traffic inputs than CalME, particularly for traffic volume, needing both base year information and adjustment factors, as indicated in the introduction. Development of the default values for each entry in the list is discussed here.

AADTT and Number of Lanes

Two-way AADTT can be estimated from the historical AADTT data compiled in the Caltrans annual reports, and the number of lanes in the design direction can be found in the design documents. Therefore, these two inputs are not discussed here.

TABLE 2 WIM Site Grouping Based on All Axle Load Spectra

Level 1 Groups	Level 2 Groups	Level 3 Groups	WIM Sites
1	1	1a	011, 020, 040, 097, 057/058, 077/078, 079/080, 006, 022, 023, 026, 035, 036, 044, 045, 046, 065, 067, 068, 074, 081, 094, 003/004, 008/009, 012/013, 015/016, 017/018, 037/038, 041/042, 047/048, 051/052, 055/056, 059/060, 061/062, 082/083, 084/085, 095/096, 102, 103/104, 106, 848, 854, 856
		1b	014, 024, 031/032, 033/034, 039, 049, 063, 064, 076, 087/088, 089/090, 091/092, 093, 098, 099, 100/101, 107, 111/112
2	2a	2aa	001, 007, 027, 029, 050, 073, 105
		2ab	010, 043, 072, 075,113, 804, 828
	2b	2ba	108, 812, 846
		2bb	005, 021, 066, 069/070, 110, 814
3	3	3a	002, 028, 030
		3b	025, 071

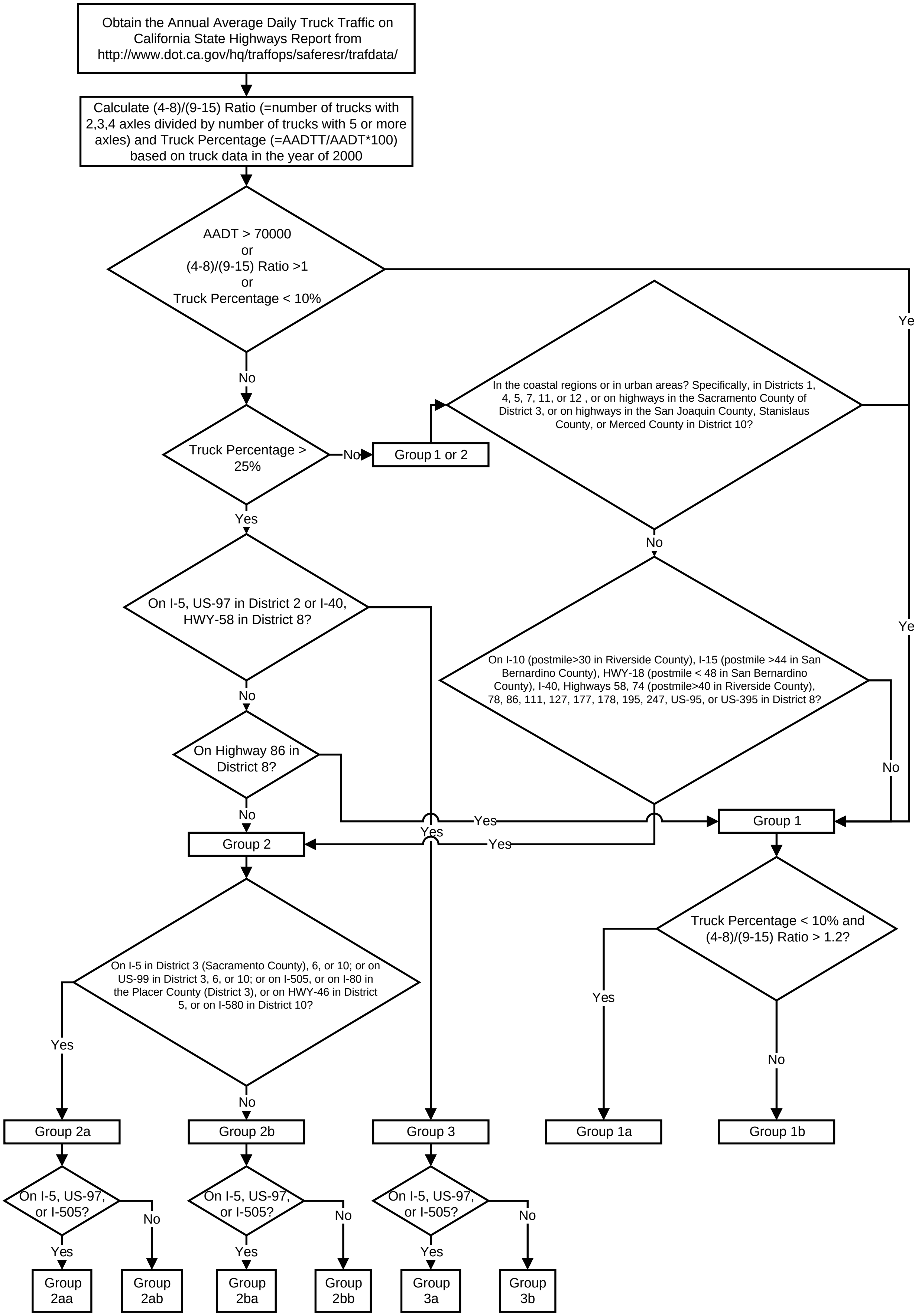


FIGURE 4 Flowchart for grouping highways based on axle load spectra.

Direction and Lane Distribution

Analysis of the WIM data revealed that truck volume is quite similar in the two opposite travel directions at all WIM sites, and AADTT is almost identical in the two travel directions for most WIM sites. The directional distribution factor, which is defined as the ratio of truck volume in the most heavily traveled direction to the truck volume in both directions, ranges between 0.50 and 0.56. The average directional distribution factors for each subgroup are very close to each other. A default value of 0.520 is recommended for the statewide average.

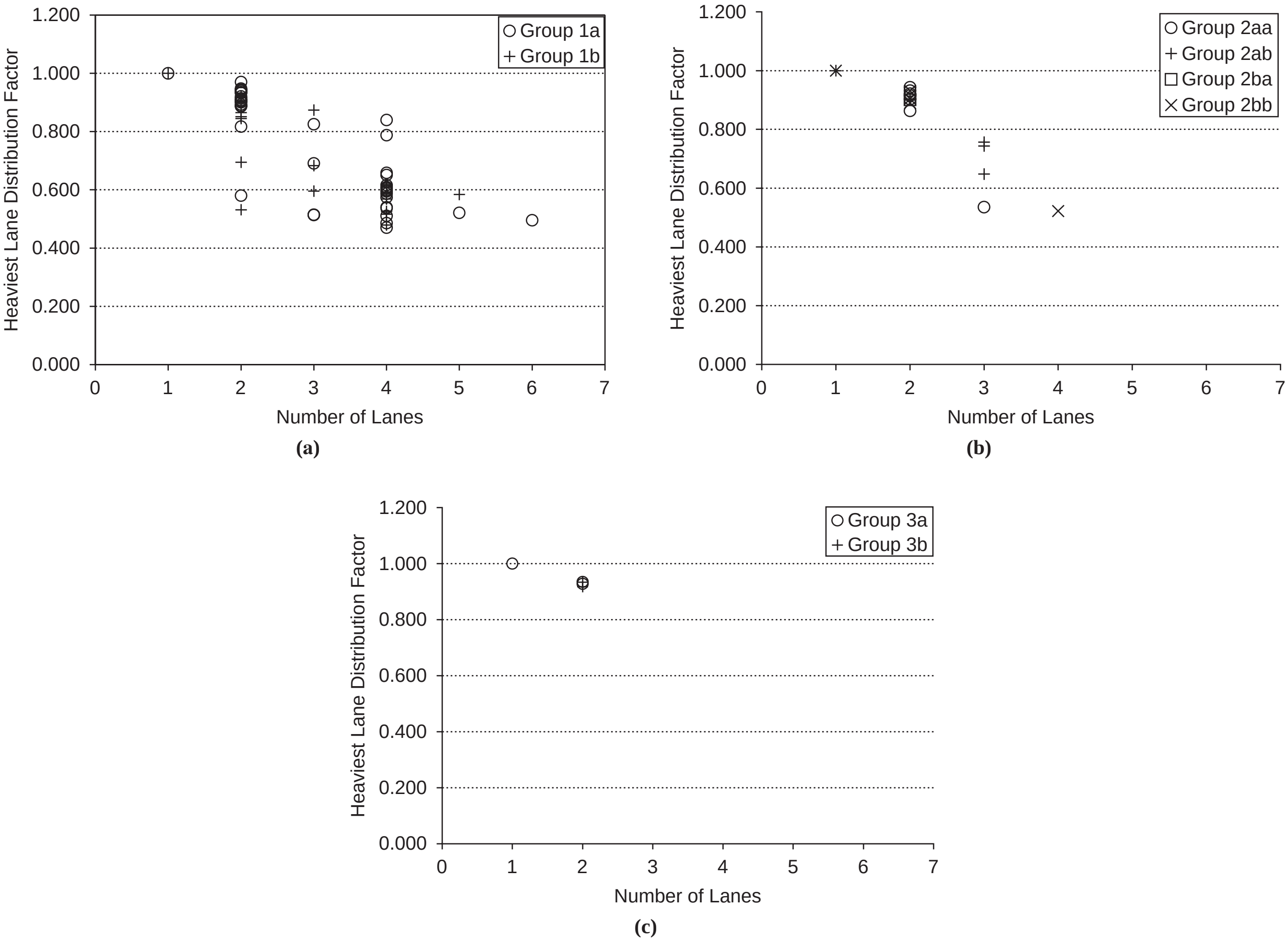
Knowledge of traffic distribution by lane is important in determining the expected volume of traffic traveling in the design (heaviest volume) lane. The heaviest lane distribution factor (HLDF), which is defined as the ratio of the truck volume in the heaviest lane to the truck volume in all lanes in one travel direction, varies between 0.53 and 0.97, with a mean value of 0.89, for highways with two lanes in one direction; between 0.51 and 0.87, with a mean value of 0.67, for highways with three lanes in one direction; and between 0.47 and 0.84, with a mean value of 0.59, for highways with four lanes in one direction.

The HLDFs in each subgroup are presented in Figure 5, which shows that the HLDF on highways with two, three, or four lanes in one direction has a wider range of variation for highways in Group 1 than for highways in Groups 2 and 3. For highways in Group 1, there is no significant difference in HLDF in the two subgroups (Groups 1a and 1b).

Truck Operating Speed

The speed of each truck class has a narrow distribution band, mainly between 80 and 112 km/h (48 and 67 mph), except for Class 4 and Class 5, in which the speed falls between 80 and 120 km/h (48 and 72 mph). All distributions are bimodal, indicating that the truck traffic streams consist of both aggressive and conservative drivers.

The means and variances of the speed distributions were calculated for each WIM site. The spatial distribution of the time-averaged speed, calculated by kernel density estimation, revealed that the spatial distributions of time-averaged truck speeds are in the same bands as the temporal speed distributions, and Class 5 and Class 6 trucks tend to move faster than other trucks. However, the bimodal phenomenon is not observed, indicating that there are no specific areas where trucks generally move slower or faster. Therefore, statewide averages of truck operating speeds can be used as default inputs.



(a)

(b)

(c)

FIGURE 5 Lane distribution factors for lanes with heaviest truck traffic volume versus number of lanes in each group.

Hourly and Monthly Truck Distribution

Figure 6 shows the hourly distribution factors for truck volume in each Level 2 group as defined in Table 2. The hourly distribution factor is defined as the percentage of truck volume in a specific hour in the 1-day truck volume.

In Group 1, the hourly distribution factor curve is almost symmetric around 12 p.m. The maximum hourly traffic occurs at 12 p.m. and is significantly higher than the minimum hourly traffic, which occurs at 2 a.m. Most WIM sites in this group are in urban areas, where short-distance transportation activities account for a large part of the traffic.

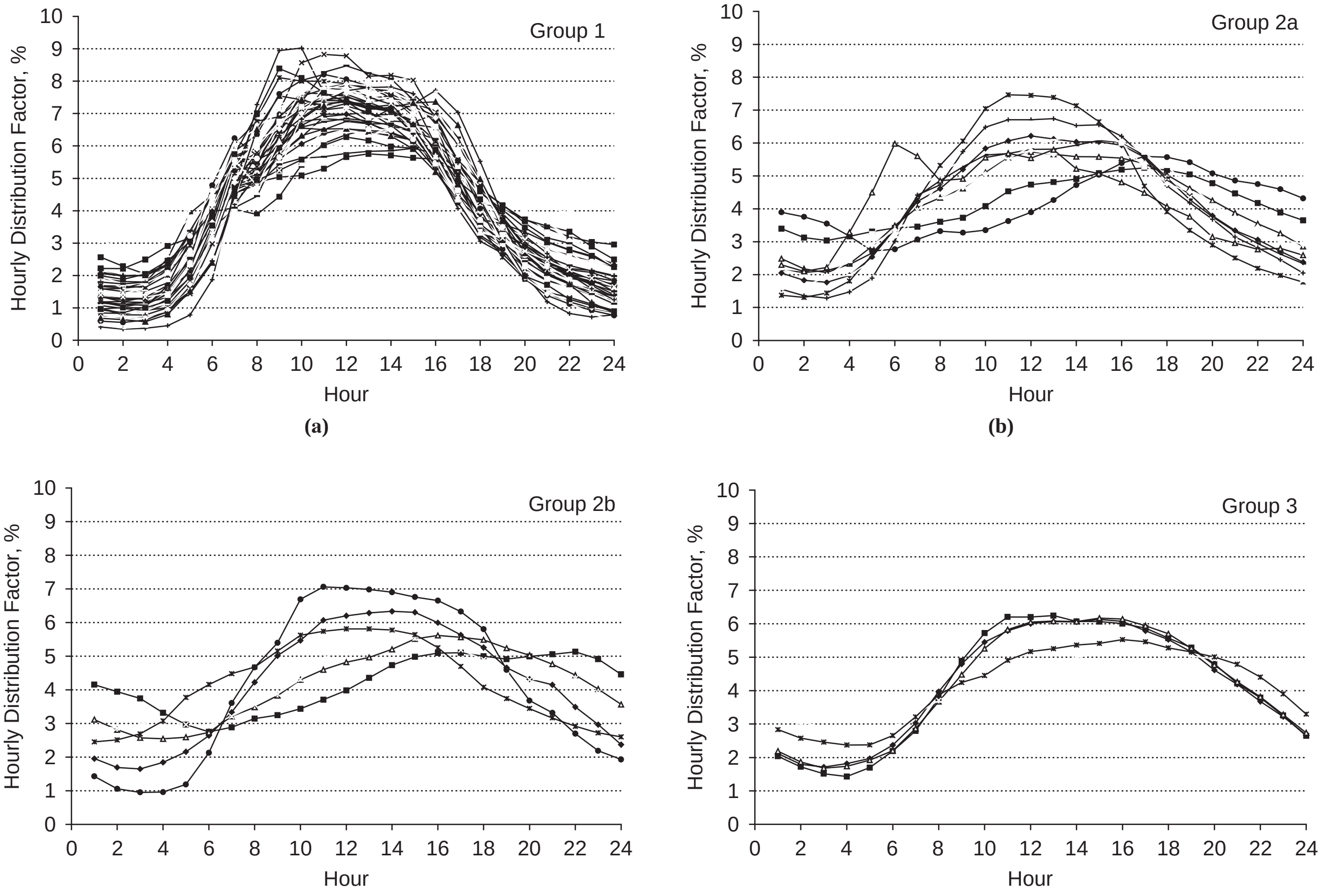
In Groups 2b and 3, the hourly distribution factor curve reaches its peak at around 5 p.m. and its minimum at around 5 a.m. As discussed in the previous section, most WIM sites in these groups are in rural areas or along major long arterials across the state and connect with other states. These routes are dominated by long-haul traffic, which is not heavily affected by the periodicity of urban activities. In Group 2a, the average hourly distribution factor curve is flatter than that of Group 1 but sharper than the curves of Groups 2b and 3. The average hourly distribution factor in each group can be used as the default inputs for ME pavement design.

The seasonal variation of truck traffic is characterized by a monthly distribution factor, which is defined as the ratio of monthly truck volume and average monthly truck volume. Figure 7 shows the monthly distribution factors in each group.

There is an obvious seasonal variation pattern in truck volume. For most WIM sites, the truck volume reaches the highest level in August and the lowest level in January. The average monthly distribution factor is about 1.1 in August and 0.9 in January. The exceptions to this pattern are at WIM sites 023 and 040, where the monthly distribution factors have a pattern opposite the pattern elsewhere: the factors are significantly higher (1.3) in February and significantly lower (0.7) in August. These two sites are on major highways connecting California and Mexico. Except for these two sites, there is no significant difference in monthly distribution factors among the three groups.

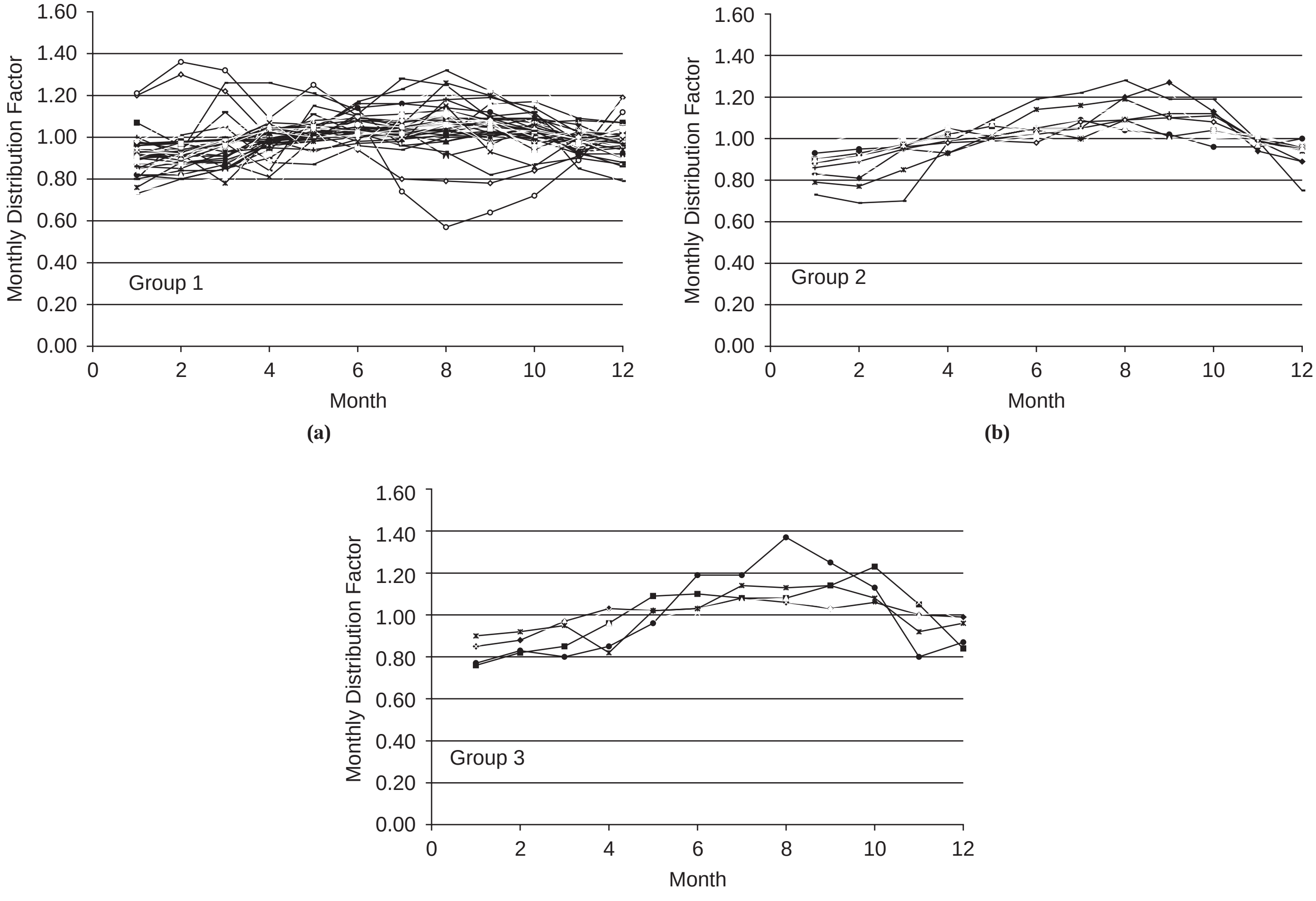
Vehicle Class Distribution

All the truck records in the data set were combined to gain an overall picture of the truck traffic composition in California. Figure 8 shows the percentages of each truck class at each WIM site in different groups. Truck Classes 5 (two axles, six tires, single unit),



(a) (b) (c) (d)

FIGURE 6 Hourly distribution factors in each group.



(a)

(b)

(c)

FIGURE 7 Monthly distribution factors in each group.

6 (three axles, single unit), 8 (four or fewer axles, single trailer), 9 (five axles, single trailer), and 11 (five or fewer axles, multitrailer) account for an average of 90% of all truck traffic at most sites.

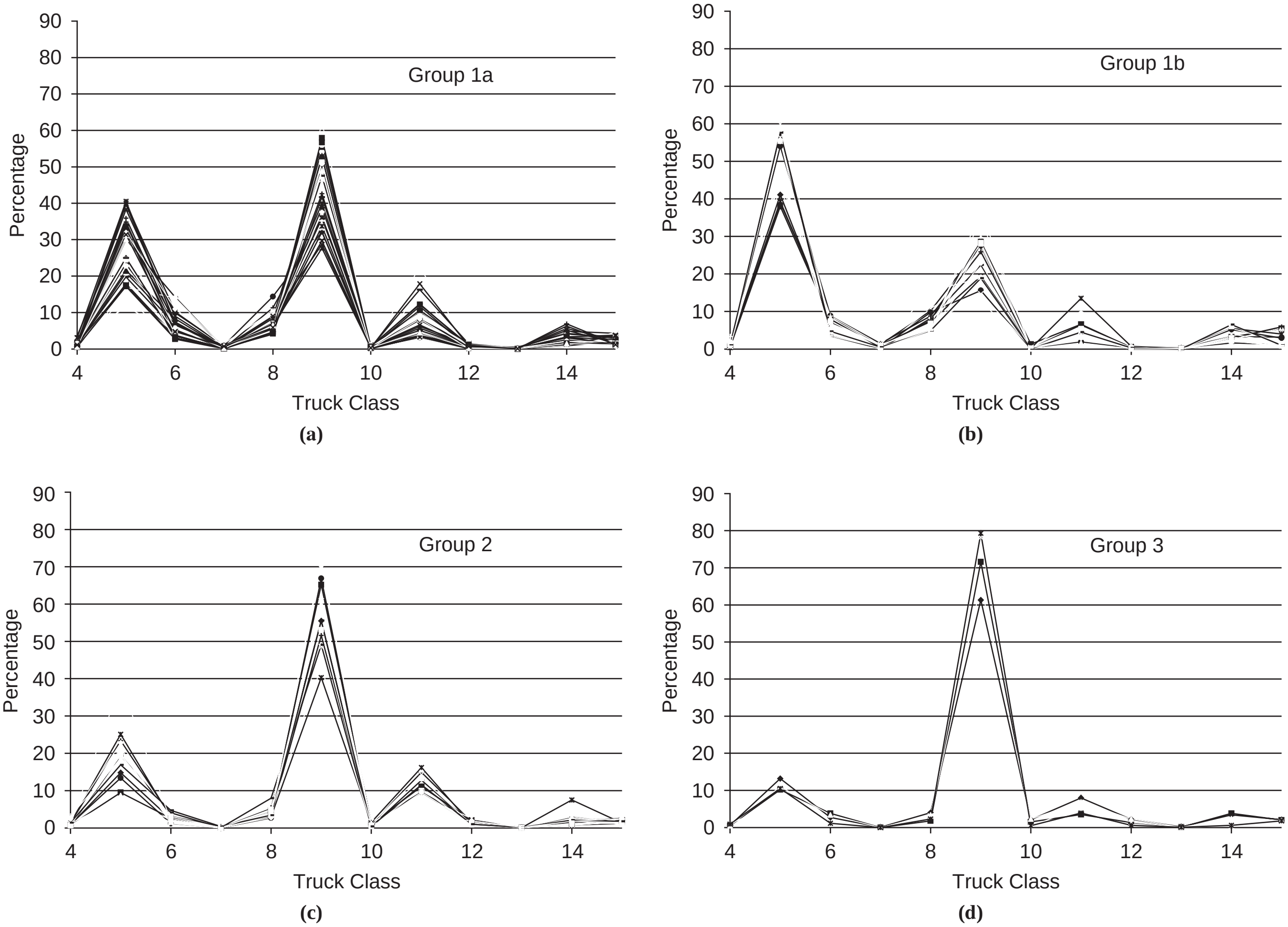
In Figure 8, most WIM sites in Group 1a are in coastal urban areas, where both local hauls and long hauls (for port freight transportation) are frequent. Most WIM sites in Group 1b are on highways in urban areas without direct connections to ports, where local hauls are predominant. WIM sites in Group 2 are mainly distributed in inland areas. Most WIM sites in Group 3 are on I-5, Highway 58, I-40, and I-15. Long hauls are predominant on these roads. The grouping based on axle load spectra is consistent with the grouping based on truck-class composition. The average vehicle distribution factors can be used as default inputs for each group.

Traffic Growth Factor

The truck traffic growth factor can be estimated from the historical AADTT data compiled in Caltrans annual AADTT reports. Analysis of the truck traffic growth trend based on the WIM data found that the annual growth of AADTT estimated from a simple linear regression model differs from site to site, mostly in a range of 20 to 400 trucks per year, with growth at a few sites being negative or 0. Forecasting of growth factors based on regression analysis did not yield good results, so without further information, statewide averages are recommended as the default inputs for the MEPDG and CalME software (*8*).

SUMMARY

This paper presents the results of analysis of the axle load spectra and volume of truck traffic in California based on WIM data collected on California highways and develops a procedure to estimate truck traffic inputs for the CalME and the MEPDG software for highways where site-specific traffic data are unavailable or incomplete. Both cluster analysis and regression analysis were applied, but regression analysis was not adopted because of its poor results. On the basis of cluster analysis of the axle load spectra, the WIM sites were divided into eight groups, and default truck traffic inputs were developed for each group. A decision tree was developed to determine in which group a highway section is categorized. The inputs for the decision tree are the geographic location of the highway section (district, county, highway number, and postmile) and the traffic volume and composition, obtainable from the Caltrans annual report of AADTT.



(a) (b) (c) (d)

FIGURE 8 Vehicle class distribution in each group.

Default traffic inputs for each group were developed for both CalME and MEPDG. These inputs, along with the traffic inputs for each WIM site, are stored in a Microsoft Access database, from which information can be easily retrieved.

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