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Guide for Mechanistic-Empirical Design

OF NEW AND REHABILITATED PAVEMENT STRUCTURES

FINAL REPORT

PART 2. DESIGN INPUTS

CHAPTER 4. TRAFFIC

NCHRP

Prepared for
National Cooperative Highway Research Program
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DISCLAIMER

PART 2—DESIGN INPUTS

CHAPTER 4
TRAFFIC

2.4.1 INTRODUCTION

Traffic data is one of the key data elements required for the structural design/analysis of pavement structures. It is required for estimating the loads that are applied to a pavement and the frequency with which those given loads are applied throughout the pavement's design life. For the Design Guide procedure, the traffic data required are the same regardless of pavement type (flexible or rigid) or design type (new or rehabilitated). The following lists typical traffic data required for design:

- Base year truck-traffic volume (the year used as the basis for design computations).
- Vehicle (truck) operational speed.
- Truck-traffic directional and lane distribution factors.
- Vehicle (truck) class distribution.
- Axle load distribution factors.
- Axle and wheel base configurations.
- Tire characteristics and inflation pressure.
- Truck lateral distribution factor.
- Truck growth factors.

Agencies typically collect three types of traffic data—weigh-in-motion (WIM), automatic vehicle classification (AVC), and vehicle counts. These data can be augmented by traffic estimates computed using traffic forecasting and trip generation models. WIM data are typically reported in a format similar to the FHWA W-4 Truck Weight Tables (i.e., data is presented as tabulations of the number of axles observed within a series of load groups, with each load group covering a specified load interval [1,000-, 2,000-, and 3,000-lb]). AVC data are reported as the number of vehicles by vehicle type counted over a period of time, while vehicle counts are reported as the number of vehicles counted over a period of time.

This chapter describes the traffic data (truck volumes and loadings characterized terms of the volume of heavy trucks applied over the pavements design life and axle load spectra for single, tandem, tridem, and quad axles) required for new and rehabilitated pavement design using the Design Guide. It also provides pavement designers with default traffic input data that may be used in traffic characterization when sufficient site-specific or regional/statewide traffic data are unavailable.

The equivalent single axle load (ESAL) approach used for traffic characterization in previous versions of the AASHTO Guide for Pavement Design is not needed for analysis presented in this Guide. The Design Guide software outputs on a monthly basis the cumulated number of heavy trucks in the design lane as an overall indicator of the magnitude of truck traffic loadings (FHWA class 4 and above) (*1*). The cumulated number of heavy trucks in the design lane can be considered as a general indicator of the level of truck traffic. For example, a pavement can be described as carrying 1 million heavy trucks or 100 million trucks over its design life.

More detailed guidance on determining the traffic inputs for pavement structural design is given in Appendix AA.

2.4.2 DESCRIPTION OF THE HIERARCHICAL APPROACH USED IN TRAFFIC CHARACTERIZATION

The full axle-load spectrum data for each axle type are needed for the Design Guide for both new pavement and rehabilitation design procedures. It is recognized, however, that some agencies may not have the resources that are needed to collect detailed traffic data over the years to accurately characterize future traffic for design. To facilitate the use of the Guide regardless of the level of detail of available traffic data, a hierarchical approach was adopted for developing the traffic inputs required for new and rehabilitated pavement design. The Design Guide defines three broad levels of traffic data input (Levels 1 through 3) based on the amount of traffic data available. These levels represent how well the pavement designer can estimate future truck traffic characteristics for the roadway being designed. The three levels can be defined simply as:

- Level 1 – There is a very good knowledge of past and future traffic characteristics.
- Level 2 – There is a modest knowledge of past and future traffic characteristics.
- Level 3 – There is a poor knowledge of past and future traffic characteristics.

Truck volumes and weights can vary considerably from road to road and even from location to location along a road. Thus, a very **good knowledge** of traffic loads can only be obtained where past traffic volume and weight data have been collected along or near the roadway segment to be designed. The data acquired through traffic monitoring is used to characterize future traffic characteristics, providing the designer with a high level of confidence in the accuracy of the truck traffic used in design.

Where only regional/statewide truck volume and weights data are available for the roadway in question, the design process assumes a **modest knowledge** of past and thus future traffic characteristics exists. In this case, the designer has the ability to predict with reasonable certainty the basic pattern of loads the trucks will carry. Where the designer must rely on default values computed from a national database and/or relatively little truck volume and weight information are available, the design process assumes a **poor knowledge** of past and thus future traffic characteristics.

2.4.2.1 Level 1 Inputs – A Very Good Knowledge of Traffic Characteristics

Level 1 requires the gathering and analysis of historical site-specific traffic volume and load data. The traffic data measured at or near a site must include counting and classifying the number of trucks traveling over the roadway, along with the breakdown by lane and direction, and measuring the axle loads for each truck class to determine the truck traffic for the first year after construction. Level 1 is considered the most accurate because it uses the actual axle weights and truck traffic volume distributions measured over or near the project site (e.g., the same segment of roadway without any intersecting roadways that would significantly change the loading pattern of the segment in question).

2.4.2.2 Level 2 Inputs – A Modest Knowledge of Traffic Characteristics

Level 2 requires the designer to collect enough truck volume information at a site to measure truck volumes accurately. This includes being able to account for any weekday/weekend volume variation, and any significant seasonal trends in truck loads (e.g., in areas affected by heavy, seasonal, agricultural hauls). Vehicle weights are taken from regional weight summaries maintained by each State (the "truck weight road groups" defined in FHWA's Traffic Monitoring Guide, 2001 Edition) that are used to differentiate routes with heavy (i.e., loaded trucks) weights, versus those with light (i.e., unloaded trucks) weights. The analyses of regional axle load spectra for each truck class are completed external to the traffic module.

2.4.2.3 Level 3 Inputs – A Poor Knowledge of Traffic Characteristics

Level 3 is used when the designer has little truck volume information for the roadway in question (for example, if all that is available is a value for Average Annual Daily Traffic [AADT] and a truck percentage). This level starts from AADT and percent trucks or from simple truck volume counts with no site-specific (or segment-specific) knowledge on the size of the loads those trucks are carrying. This lack of load knowledge means that a regional or statewide average load distribution (or other default load distribution table) must be used. An estimate of traffic inputs based on local experience is also considered Level 3.

2.4.2.4 Summary

For new alignments and roadways, pavement designers may not have access to past site-specific traffic data. For this condition, traffic inputs can be estimated using detailed traffic forecasting and trip generation models, and this is considered a Level 1 input. The important point is that the designer has a good understanding of the truck traffic loads and volumes, even though the truck loading patterns were estimated through traffic forecasting and trip generation models. Traffic forecasting and trip generation models can also be used to develop Level 2 and Level 3 input data. The application of traffic forecasting and trip generation models is beyond the scope and intent of the traffic module for the Design Guide. These types of studies need to be completed external to the traffic module in the Design Guide software.

For those roadways where there is a very good knowledge of both past and future truck volumes and weights, a high level of reliability is expected in the traffic-loading estimate and, thus, a much more reliable pavement design. Where the traffic loads (truck volumes and weights) are less well known, the traffic-loading estimates are less reliable, and consequently, the pavement design becomes less reliable. The use of Level 1 or 2 traffic inputs is preferable for the design of roadways that may eventually be a high-volume and very important route for transporting goods and the public. Regardless of the "level" of traffic data provided as input to the software, however, the traffic module software determines the total number of axle applications for each axle type and load group over the design or analysis period. The number of applications for each axle type and load increment is then used in pavement analysis, the computation of pavement responses, damage computation, and eventually for predicting load-related distresses for both new and rehabilitated rigid and flexible pavements.

Finally, for roadways with anticipated special future traffic characteristics, user-defined gear loads and axle configurations can be used to characterize future traffic. The user-defined axle loads and axle configurations are a subset wide array of load types and axle configurations that may be defined as part of the traffic characterization. This allows the designer to input a specific axle load and configuration so far as it falls within the range of loads and axles types provided. For example, this approach could be used for characterizing future traffic for parking lots or facilities used by heavy transport vehicles or to determine the effect on pavement performance of special vehicles in transporting very heavy loads.

2.4.3 DESCRIPTION OF DATA SOURCES AND DATA ELEMENTS USED IN TRAFFIC CHARACTERIZATION

Four main sources of traffic data are typically used for the traffic characterization in the Design Guide, as identified in table 2.4.1. Data from these sources are also used to identify the input data hierarchical level. Miscellaneous data elements used in traffic characterization but not necessarily obtained from the data sources listed in table 2.4.1 are presented in table 2.4.2. The sources of data are described in the following sections.

2.4.3.1 Traffic Load/Volume Data Sources

<u>WIM Data</u>

WIM data are a tabulation of the vehicle type and the number, spacing, and weight of axles for each vehicle weighed over a period of time. WIM data are used to determine the normalized axle load distribution or spectra for each axle type within each truck class. Analysis of the WIM data to determine the normalized axle load distributions is completed external to the Design Software, as described in Appendix AA. Classification of WIM data as Level 1 through 3 is based on the specific location at which data are collected (e.g., site-specific, regional/statewide, or national).

Table 2.4.1. Traffic data required for each of the three hierarchical input levels.

Data Sources		**Input Level**		
		1	**2**	**3**
Traffic load/volume data	WIM data – site/segment specific	X		
	WIM data – regional default summaries		X	
	WIM data –national default summaries			X
	AVC data – site/segment specific	X		
	AVC data – regional default summaries		X	
	AVC data – national default summaries			X
	Vehicle counts – site/segment specific[1]		X	X
	Traffic forecasting and trip generation models[2]	X	X	X

[1]Level depends on whether regional or national default values are used for the WIM or AVC information.
[2]Level depends on input data and model accuracy/reliability.

Table 2.4.2. Traffic data required for each of the three hierarchical input levels.

Data Elements/Variables		Input Level		
		1	**2**	**3**
Truck Traffic and Tire Factors	Truck directional distribution factor	Site specific WIM or AVC	Regional WIM or AVC	National WIM or AVC
	Truck lane distribution factor	Site specific WIM or AVC	Regional WIM or AVC	National WIM or AVC
	Number of axles by axle type per truck class	Site specific WIM or AVC	Regional WIM or AVC	National WIM or AVC
	Axle and tire spacing	Hierarchical levels not applicable for this input		
	Tire pressure or hot inflation pressure	Hierarchical levels not applicable for this input		
	Truck traffic growth function	Hierarchical levels not applicable for this input		
	Vehicle operational speed	Hierarchical levels not applicable for this input		
	Truck lateral distribution factor	Hierarchical levels not applicable for this input		
	Truck monthly distribution factors	Site specific WIM or AVC	Regional WIM or AVC	National WIM or AVC
	Truck hourly distribution factors	Site specific WIM or AVC	Regional WIM or AVC	National WIM or AVC
Truck traffic distribution and volume variables	AADT or AADTT for base year	Hierarchical levels not applicable for this input		
	Truck distribution/spectra by truck class for base year	Site specific WIM or AVC	Regional WIM or AVC	National WIM or AVC
	Axle load distribution/spectra by truck class and axle type	Site specific WIM or AVC	Regional WIM or AVC	National WIM or AVC
	Truck traffic classification group for pavement design	Hierarchical levels not applicable for this input		
	Percentage of trucks	Hierarchical levels not applicable for this input		

AVC Data

AVC data are a tabulation of the number and types of vehicles (FHWA Class 4 through 13) counted over a period of time. AVC data are used to determine the normalized truck class distribution. Analysis of the AVC data to determine the normalized truck class distribution is completed external to the Design Software, as described in Appendix AA. Classification of AVC data as Level 1 through 3 is based on the specific location at which data are collected (e.g., site-specific, regional/statewide, or national).

Vehicle Counts

Vehicle counts are simply a counting of the total number of vehicles categorized by passenger vehicles (FHWA Class 1 through 3), buses (FHWA Class 4), and trucks (FHWA Class 5 through 13) over a period of time. Vehicle counts can be continuous, seasonal, or short duration. Continuous counts are taken 365 days a year and are the most consistent and accurate types of vehicle count data that can be used in traffic characterization. Seasonal counts are performed usually from 2 to 12 times a year, for periods of time ranging from 24 hours to 2 weeks, while short duration counts range from 6 hours to 7 days. Vehicle counts are needed for input Levels 2 and 3 when detailed truck traffic data are unavailable. Classification of vehicle count data as Levels 2 or 3 is based on the specific location at which data are collected (e.g., site-specific, regional/statewide, or national).

Traffic Forecasting and Trip Generation Models

Level 1 or Level 2 traffic inputs can be estimated using detailed traffic forecasting and trip generation models calibrated with site-specific or regional/statewide data. Traffic forecasting and trip generation models are particularly useful in urban areas and are based on information obtained from turning movement studies, origin and destination studies, license plate surveys, and so on. The use of nationally calibrated traffic forecasting and trip generation models is not recommended. The application of traffic forecasting and trip generation models is beyond the scope of the Design Guide.

2.4.4 ASSUMPTIONS

Two major assumptions are used in the traffic characterization module for the Design Guide software:

1. The normalized axle load distributions by axle type for each truck class remain constant from year to year unless there are political and/or economical changes that have an affect on the maximum axle or gross truck loads. The normalized truck traffic volume distributions, however, can change from year to year.
2. The normalized axle load distribution by axle type and truck class and normalized truck volume distribution do not change throughout the time of day or over the week (weekday versus weekend and night versus day) within a specific season.

2.4.5 INPUTS REQUIRED FOR TRAFFIC CHARACTERIZATION

Four basic types of traffic data are required for pavement structural design:

- Traffic volume—base year information.
- Traffic volume adjustment factors.
  - Monthly adjustment.
  - Vehicle class distribution.
  - Hourly truck distribution.
  - Traffic growth factors.
- Axle load distribution factors.
- General traffic inputs.
  - Number axles/trucks.
  - Axle configuration.
  - Wheel base.

Detailed description of the information required is presented in the remaining sections of this chapter. Guidance on determining these traffic inputs is presented in Appendix AA.

2.4.5.1 Traffic Volume – Base Year Information

The base year for the traffic inputs is defined as the first year that the roadway segment under design is opened to traffic. The following base year information is required:

- Two-way annual average daily truck traffic (AADTT).
- Number of lanes in the design direction.
- Percent trucks in design direction.
- Percent trucks in design lane.
- Vehicle (truck) operational speed.

<u>Two-Way Annual Average Daily Truck Traffic</u>

Two-way AADTT is the total volume of truck traffic (the total number of heavy vehicles [classes 4 to 13] in the traffic stream) passing a point or segment of a road facility to be designed in both directions during a 24-hour period. It is commonly obtained from traffic counts obtained from WIM, AVC, vehicle counts, and traffic forecasting and trip generation models during a given time period (whole days greater than 1 day and less than 1 year). AADTT is simply the total number of truck traffic of the given time period divided by the number of days in that time period. Base year AADTT is defined as follows:

- Level 1—AADTT estimated from site-specific WIM, AVC, vehicle count data or site calibrated traffic forecasting and trip generation models. It is recommended that the average of the three most recent years with adequate data be used as the base year AADTT. This average value may need to be adjusted to account for truck-traffic growth depending on the amount of time between the three historical years and the base year.

- Level 2— AADTT estimated from regional/statewide WIM, AVC, or vehicle count data or from regionally calibrated traffic forecasting and trip generation models. It is recommended that the average of the last three years prior to the base year be used as the base year AADTT.
- Level 3—AADTT is estimated from AADT obtained mostly from traffic counts and an estimate of the percentage of trucks expected in the traffic stream. The AADT and percentage of trucks (vehicle class 4-13) should be averaged over the three most recent years with data. Estimates based on local experience are also considered Level 3.

Note that for both Levels 2 and 3 the regional/statewide or national data must be from routes with similar characteristics (e.g., functional class, urban versus rural, adjacent land use, and so on). Also, for Level 3 inputs local agencies should determine the best way to estimate percent trucks in the traffic stream based on the information available. One method used is to assign known site-specific values obtained along roadways/routes located in the same geographical area with similar traffic characteristics (traffic volume and vehicle class distribution) or to assign known site-specific values to other roadways that are in the same functional class and are located in the same area type (rural, small urban, urbanized) with similar travel characteristics. Average regional/statewide values calculated by functional class only are not recommended.

Number of Lanes in the Design Direction

The number of lanes in the design direction is determined from design specifications and represents the total number of lanes in one direction.

Percent Trucks in Design Direction

Percent trucks in the design direction, or the directional distribution factor (DDF), is used to quantify any difference in the overall volume of trucks in two directions. It is usually assumed to be 50 percent when the AADT and AADTT are given in two directions; however, this is not always the case. In fact, using a different route for transporting goods to and from certain areas and facilities is common, and depends on the commodities being transported as well as other regional/local traffic patterns. The levels of input for percent trucks in design direction are described as follows:

- Level 1—a site-specific directional distribution factor determined from WIM, AVC, and vehicle count data.
- Level 2—a regional/statewide directional distribution factor determined from WIM, AVC, and vehicle count data. Estimates from trip generation models may also be used.
- Level 3—a national average value or an estimate based on local experience.

The Design Guide software provides a default value (Level 3) of 55 percent for Interstate type facilities computed using traffic data from the LTPP database (*1*, *2*). Figure 2.4.1 shows the mean directional distribution factors for selected vehicle classes (2, 3, 5, 8 and 9), total truck traffic, and all vehicles combined (obtained from LTPP data).

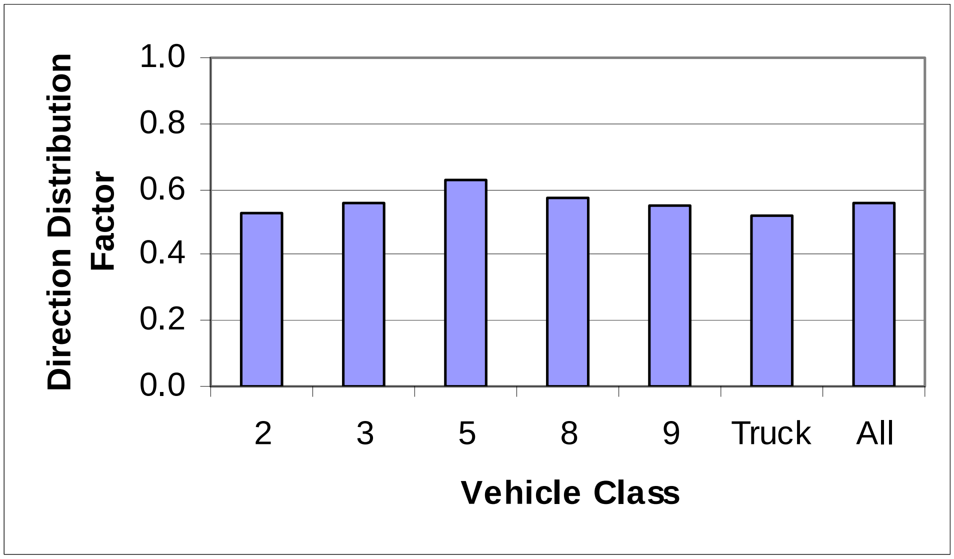

Figure 2.4.1. Directional distribution factors computed for different vehicle classes using LTPP data.

With the exception of vehicle class 5, the observed directional distribution factors lie in the range of 0.5 to 0.6. Those values computed using data from the LTPP traffic database are listed below (see also Appendix AA).

- Vehicle Class 4, Buses – 0.50, except for local or municipal bus routes. For local routes, the DDF for buses varies from 0.8 to 1.0.
- Vehicle Classes 5 – 7, Single Unit Trucks – 0.62. These types of trucks consistently have the greatest directional distribution factors.
- Vehicle Classes 8 – 10, Tractor-Trailer Trucks – 0.55.
- Vehicle Classes 11 – 13, Multi-Trailer Trucks – 0.50.

The default or Level 3 values for the DDF should represent the predominant type of truck using the roadway. If detailed site-specific or regional/statewide truck traffic data are unavailable, the truck DDF for the most common truck type (e.g., vehicle class 9) is suggested for use as the default value for all truck traffic.

<u>Percent Trucks in Design Lane</u>

Percent trucks in the design lane, or truck lane distribution factor (LDF), accounts for the distribution of truck traffic between the lanes in one direction. For two-lane, two-way highways (one lane in one direction), this factor is 1.0 because all truck traffic in any one direction must use the same lane. For multiple lanes in one direction, it depends on the AADTT and other geometric and site-specific conditions. The level of input for LDF is described as follows:

- Level 1—a site-specific lane distribution factor determined from WIM, AVC, or vehicle count data.

- Level 2—a regional/statewide lane distribution factor determined from WIM, AVC, or vehicle count data.
- Level 3—a national average value or an estimate obtained from traffic forecasting and trip generation models. An estimate based on local experience is also considered Level 3.

Figure 2.4.2 shows the mean lane distribution factors computed for the vehicle classes 2, 3, 5, 8, 9, all trucks, and all vehicles for 2- and 3-lanes/direction roads using data from the LTPP database. In general, the LDF for 2-lane/direction roads is 0.89 for truck class 9 and 0.78 for all trucks. For 3-lane/direction roads, the LDF is 0.59 for truck class 9 and 0.43 for all trucks. The default (Level 3) values recommended for use based on the LDF for the most common type of truck (vehicle class 9 trucks) is as follows:

- Single-lane roadways in one direction, LDF = 1.00.
- Two-lane roadways in one direction, LDF = 0.90.
- Three-lane roadways in one direction, LDF = 0.60.
- Four-lane roadways in one direction, LDF =0.45.

<u>Vehicle Operational Speed</u>

The vehicle operational speed of trucks or the average travel speed generally depends on many factors, including the roadway facility type (Interstate or otherwise), terrain, percentage of trucks in the traffic stream, and so on. A description of a detailed methodology used for determining operational speeds can be found in the Transportation Research Board (TRB) *Highway Capacity Manual* or AASHTO's *A Policy on Geometric Design of Highways and Streets* (often called the "Green Book") (*3, 4*). The Design Guide software uses 60 mph as the default operational speed value, but this speed can be modified to reflect local/site conditions.

2.4.5.2 Traffic Volume Adjustments

The following truck-traffic volume adjustment factors are required for traffic characterization, and each is described in the following sections:

- Monthly adjustment factors.
- Vehicle class distribution factors.
- Hourly truck distribution factors.
- Traffic growth factors.

<u>Monthly Adjustment Factors</u>

Truck traffic monthly adjustment factors simply represent the proportion of the annual truck traffic for a given truck class that occurs in a specific month. In other words, the monthly distribution factor for a specific month is equal to the monthly truck traffic for the given class for the month divided by the total truck traffic for that truck class for the entire year. Truck traffic monthly adjustment factors (MAF) depend on factors such as adjacent land use, the location of industries in the area, and roadway location (urban or rural). In reality, monthly differences in the truck traffic distribution could vary over the course of several years during the pavement life.

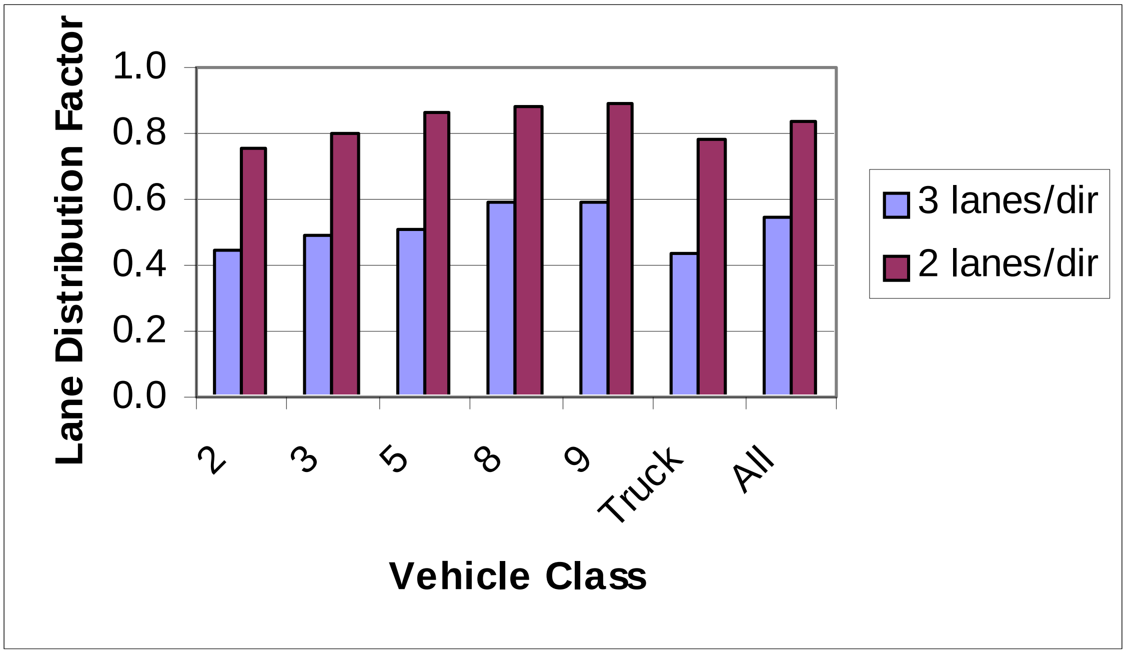

Figure 2.4.2. Lane distribution factors for four and six-lane roadways.

For this Design Guide, however, monthly distribution of truck traffic is assumed to be constant over the entire design period.

Figure 2.4.3 shows an example of the variation in monthly ADTT for LTPP test section 18-5022, while figure 2.4.4 shows the truck monthly distribution factors computed from ADTT for the same site (*2*). It must be noted that even though figure 2.4.3 shows a variation in the absolute ADTT values for weekday and weekend traffic (daily variation of traffic), the Design Guide assumes a uniform distribution of traffic for all days within a given month or year. The traffic data collection plan (discussed in section 2.4.6) should recognize the potential difference between the weekday and weekend truck traffic and consider that difference in determining the base year AADTT.

As noted, monthly variations in truck traffic volumes are site-specific as well as highly dependent on the local economy and climatic conditions. The following levels of input are specified:

- Level 1 – site- or segment-specific MAF for each vehicle class (classes 4 through 13) computed from WIM, AVC, or vehicle count data or trip generation models.
- Level 2 – regional/statewide MAF for each vehicle class (classes 4 through 13) computed from WIM, AVC, or vehicle count data or trip generation models.
- Level 3 –national MAF computed from WIM, AVC, or vehicle count data. The use of estimates based on local experience is also considered Level 3 data.

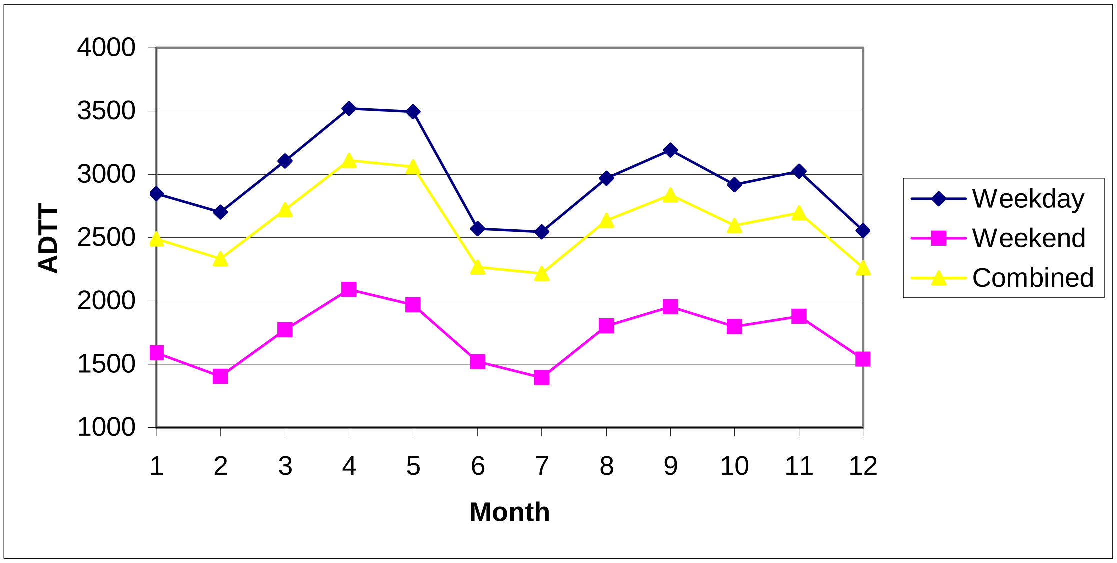

Figure 2.4.3. Average daily truck traffic for the weekdays, weekends, and weighted average by month for LTPP site 18-5022.

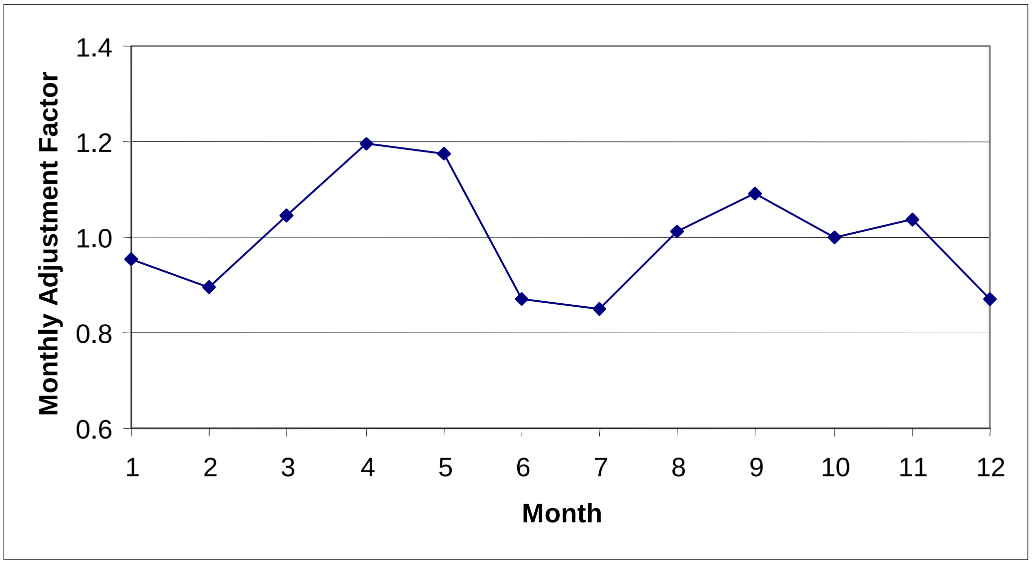

Figure 2.4.4. Truck monthly adjustment factors from the combined ADTT data presented in figure 2.4.3.

Regardless of the source of the data (WIM, AVC, vehicle count, and so on), each agency can develop these monthly adjustment factors for different types of highways as follows:

1. For the given traffic data (24-hours of continuous data collection), determine the total number of trucks (in a given class) for each 24-hour period. If data were not collected for the entire 24-hour period, the measured daily truck traffic should be adjusted to be representative of a 24-hour period.
2. Using representative daily data collected for the different months within a year, determine the average daily truck traffic for each month in the year.
3. Sum up the average daily truck traffic for each month for the entire year.
4. Calculate the monthly adjustment factors by dividing the average daily truck traffic for each month by summing the average daily truck traffic for each month for the entire year and multiplying it by 12 as given below:

$$MAF_i = \frac{AMDTT_i}{\sum_{i=1}^{12} AMDTT_i} * 12 \tag{2.4.1}$$

where

MAF_i = monthly adjustment factor for month i
$AMDTT_i$ = average monthly daily truck traffic for month i

The sum of the MAF of all months must equal 12.

Pavement designs can be sensitivity to MAF. If no information is available, it is recommended that designers assume an even or equal distribution (i.e., 1.0 for all months for all vehicle classes) as shown in table 2.4.3. The Design Software allows designers to directly input the MAF or import MAF from an already prepared file. The format of the input file must be compatible with the information presented in table 2.4.3.

Table 2.4.3. MAF default values for traffic characterization.

Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1	1	1	1	1	1	1	1	1	1
February	1	1	1	1	1	1	1	1	1	1
March	1	1	1	1	1	1	1	1	1	1
April	1	1	1	1	1	1	1	1	1	1
May	1	1	1	1	1	1	1	1	1	1
June	1	1	1	1	1	1	1	1	1	1
July	1	1	1	1	1	1	1	1	1	1
August	1	1	1	1	1	1	1	1	1	1
September	1	1	1	1	1	1	1	1	1	1
October	1	1	1	1	1	1	1	1	1	1
November	1	1	1	1	1	1	1	1	1	1
December	1	1	1	1	1	1	1	1	1	1

Note that the sum of all factors for a given vehicle/truck class for the year is 12.

Vehicle Class Distribution

Vehicle class distribution is computed from data obtained from vehicle classification counting programs such as AVC, WIM, and vehicle counts. Vehicle classification counting programs can be of short or continuous duration. Typically, the majority of data used to compute vehicle class distributions come from short duration counts such as WIM and AVC sites, urban traffic management centers, toll facilities, and other agencies that collect truck volume information. The key to a successful classification data collection program is not the source of the data, but the ability to routinely obtain it, verify its validity, summarize it into useable formats, report it in a manner that is useful to designers, and manage the process efficiently. Figure 2.4.5 shows the standard vehicle classes that have been used to summarize and vehicle classification data for FHWA and LTPP (*1*, *2*).

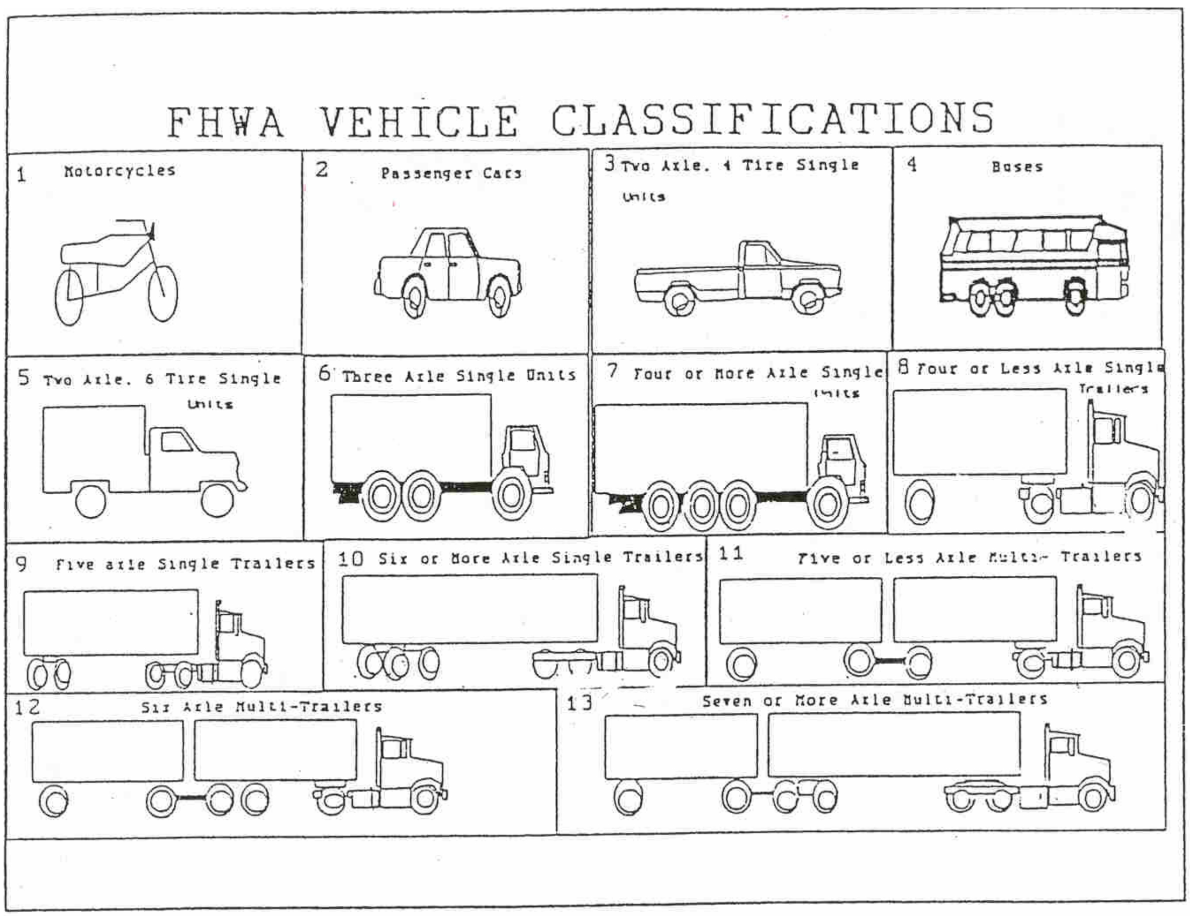

Figure 2.4.5. Illustrations and definitions of the vehicle classes used for collecting traffic data that are needed for design purposes (*1*).

Normalized vehicle class distribution represents the percentage of each truck class (classes 4 through 13) within the AADTT for the base year. The sum of the percent AADTT of all truck classes should equal 100. The inputs at different levels are as follows:

- Level 1 – data obtained from site or segment specific WIM, AVC, or vehicle counts.
- Level 2 – data obtained from regional/statewide WIM, AVC, or vehicle counts.
- Level 3 – data obtained from national WIM, AVC, or vehicle counts or local experience.

Default vehicle class distribution factors (Level 3) determined using LTPP traffic data are provided as part of the Design Guide software. The default vehicle class distribution factors are chosen based on the roadway function class and the best combination of Truck Traffic Classification (TTC) groups that describes the traffic stream expected on the given roadway. An example of the default vehicle class distribution factors for principal arterials (Interstate and Defense Routes) is shown in table 2.4.4. The default values were obtained by choosing a functional class and the combination of TTC groups (i.e., 1, 2, 3, 4, 5, 8, 11, and 13) that best characterized the traffic stream expected. A standardized set of TTC groups that best describes the traffic stream for the different functional classes are presented in table 2.4.5. Each TTC group represents a traffic stream with unique truck traffic characteristics (see table 2.4.4). For example, TTC 1 describes a traffic stream heavily populated with single-trailer trucks, while TTC 17 is populated with buses. Vehicle class distribution factors for a route populated with single-trailer trucks and buses would be computed using a combination of TTC 1 and 17.

Designers must choose the default set of vehicle class distribution for the TTC that most closely describes the design traffic stream for the roadway under design. This can be done with the information presented in tables 2.4.4 through 2.4.6. Details of how the TTC groups were developed using LTPP data are presented in Appendix AA. *For Level 1 and Level 2 inputs, it must be noted that the collection of site- or segment-specific or regional/statewide traffic data must begin years in advance of the start of design to ensure that an adequate amount of data is used in analysis.* This maybe impractical, so for many projects, an agency may elect to use a combination of site-specific and regional data to reduce the time required to collect the necessary data. The Design Software allows designers to directly input the vehicle classification distribution factors (Levels 1 through 3) or import from an already prepared file for Level 3.

<u>Truck Hourly Distribution Factors</u>

The hourly distribution factors (HDF) represent the percentage of the AADTT within each hour of the day. The inputs at different levels are as follows:

- Level 1 – a site- or segment-specific distribution determined from AVC, WIM, or vehicle count data.
- Level 2 – a regional/statewide distribution determined from AVC, WIM, or vehicle count data.
- Level 3 – the factors determined from a national data or local experience.

Table 2.4.4. Truck traffic classification (TTC) group description and corresponding vehicle (truck) class distribution default values (percentages) considered in the Design Guide Software.

TTC Group	TTC Description	Vehicle/Truck Class Distribution (percent)									
		4	5	6	7	8	9	10	11	12	13
1	Major single-trailer truck route (type I)	1.3	8.5	2.8	0.3	7.6	74.0	1.2	3.4	0.6	0.3
2	Major single-trailer truck route (Type II)	2.4	14.1	4.5	0.7	7.9	66.3	1.4	2.2	0.3	0.2
3	Major single- and multi- trailer truck route (Type I)	0.9	11.6	3.6	0.2	6.7	62.0	4.8	2.6	1.4	6.2
4	Major single-trailer truck route (Type III)	2.4	22.7	5.7	1.4	8.1	55.5	1.7	2.2	0.2	0.4
5	Major single- and multi- trailer truck route (Type II).	0.9	14.2	3.5	0.6	6.9	54.0	5.0	2.7	1.2	11.0
6	Intermediate light and single-trailer truck route (I)	2.8	31.0	7.3	0.8	9.3	44.8	2.3	1.0	0.4	0.3
7	Major mixed truck route (Type I)	1.0	23.8	4.2	0.5	10.2	42.2	5.8	2.6	1.3	8.4
8	Major multi-trailer truck route (Type I)	1.7	19.3	4.6	0.9	6.7	44.8	6.0	2.6	1.6	11.8
9	Intermediate light and single-trailer truck route (II)	3.3	34.0	11.7	1.6	9.9	36.2	1.0	1.8	0.2	0.3
10	Major mixed truck route (Type II)	0.8	30.8	6.9	0.1	7.8	37.5	3.7	1.2	4.5	6.7
11	Major multi-trailer truck route (Type II)	1.8	24.6	7.6	0.5	5.0	31.3	9.8	0.8	3.3	15.3
12	Intermediate light and single-trailer truck route (III)	3.9	40.8	11.7	1.5	12.2	25.0	2.7	0.6	0.3	1.3
13	Major mixed truck route (Type III)	0.8	33.6	6.2	0.1	7.9	26.0	10.5	1.4	3.2	10.3
14	Major light truck route (Type I)	2.9	56.9	10.4	3.7	9.2	15.3	0.6	0.3	0.4	0.3
15	Major light truck route (Type II)	1.8	56.5	8.5	1.8	6.2	14.1	5.4	0.0	0.0	5.7
16	Major light and multi-trailer truck route	1.3	48.4	10.8	1.9	6.7	13.4	4.3	0.5	0.1	12.6
17	Major bus route	36.2	14.6	13.4	0.5	14.6	17.8	0.5	0.8	0.1	1.5

Table 2.4.5. Suggested guidance for selecting appropriate TTC groups for different highway functional classifications.

Highway Functional Classification Descriptions	Applicable Truck Traffic Classification Group Number
Principal Arterials – Interstate and Defense Routes	1,2,3,4,5,8,11,13
Principal Arterials – Intrastate Routes, including Freeways and Expressways	1,2,3,4,6,7,8,9,10,11,12,14,16
Minor Arterials	4,6,8,9,10,11,12,15,16,17
Major Collectors	6,9,.12,14,15,17
Minor Collectors	9,12,14,17
Local Routes and Streets	9,12,14,17

Table 2.4.6. Definitions and descriptions for the TTC groups.

<table>
<tr><th rowspan="2">Buses in Traffic Stream</th><th colspan="2">Commodities being Transported by Type of Truck</th><th rowspan="2">TTC Group No.</th></tr>
<tr><th>Multi-Trailer</th><th>Single-Trailers and Single-Units</th></tr>
<tr><td rowspan="9">Low to none (<2%)</td><td rowspan="5">Relatively high amount of multi-trailer trucks (>10%)</td><td>Predominantly single-trailer trucks</td><td>5</td></tr>
<tr><td>High percentage of single-trailer trucks, but some single-unit trucks</td><td>8</td></tr>
<tr><td>Mixed truck traffic with a higher percentage of single-trailer trucks</td><td>11</td></tr>
<tr><td>Mixed truck traffic with about equal percentages of single-unit and single-trailer trucks</td><td>13</td></tr>
<tr><td>Predominantly single-unit trucks</td><td>16</td></tr>
<tr><td rowspan="4">Moderate amount of multi-trailer trucks (2-10%)</td><td>Predominantly single-trailer trucks</td><td>3</td></tr>
<tr><td>Mixed truck traffic with a higher percentage of single-trailer trucks</td><td>7</td></tr>
<tr><td>Mixed truck traffic with about equal percentages of single-unit and single-trailer trucks</td><td>10</td></tr>
<tr><td>Predominantly single-unit trucks</td><td>15</td></tr>
<tr><td rowspan="7">Low to moderate (>2%)</td><td rowspan="7">Low to none (<2%)</td><td>Predominantly single-trailer trucks</td><td>1</td></tr>
<tr><td>Predominantly single-trailer trucks, but with a low percentage of single-unit trucks</td><td>2</td></tr>
<tr><td>Predominantly single-trailer trucks with a low to moderate amount of single-unit trucks</td><td>4</td></tr>
<tr><td>Mixed truck traffic with a higher percentage of single-trailer trucks</td><td>6</td></tr>
<tr><td>Mixed truck traffic with about equal percentages of single-unit and single-trailer trucks</td><td>9</td></tr>
<tr><td>Mixed truck traffic with a higher percentage of single-unit trucks</td><td>12</td></tr>
<tr><td>Predominantly single-unit trucks</td><td>14</td></tr>
<tr><td>Major bus route (>25%)</td><td>Low to none (<2%)</td><td>Mixed truck traffic with about equal single-unit and single-trailer trucks</td><td>17</td></tr>
</table>

For Level 1 through 3 inputs, HDF may be computed using truck traffic data measured continuously over a 24-hour period of time. The hourly data are used to determine the percentage of total trucks within each hour as follows:

1. Determine the total number of trucks counted within each hour of traffic data in the sample.
2. Average the number of trucks for each of the 24 hours of the day in the sample. For example, if the data include truck counts for the first hour of the day for 6 days, then total those 6 counts and divide by 6.
3. Total the 24 hourly averages from step 3.
4. Divide each of the 24 hourly averages from step 2 by the total from step 3 and multiply by 100.

The sum of the percent of daily truck traffic per time increment must add up to 100 percent.

Default HDF are provided in the Design Guide software computed from the LTPP traffic database and it is recommended as Level 3. Table 2.4.7 presents a summary of the default HDF values presented in the Design Guide software.

Table 2.4.7. Hourly truck traffic distribution default values based on LTPP traffic data.

Time Period	**Distribution, percent**	**Time Period**	**Distribution, percent**
12:00 a.m. - 1:00 a.m.	2.3	12:00 p.m. - 1:00 p.m.	5.9
1:00 a.m. - 2:00 a.m.	2.3	1:00 p.m. - 2:00 p.m.	5.9
2:00 a.m. - 3:00 a.m.	2.3	2:00 p.m. - 3:00 p.m.	5.9
3:00 a.m. - 4:00 a.m.	2.3	3:00 p.m. - 4:00 p.m.	5.9
4:00 a.m. - 5:00 a.m.	2.3	4:00 p.m. - 5:00 p.m.	4.6
5:00 a.m. - 6:00 a.m.	2.3	5:00 p.m. - 6:00 p.m.	4.6
6:00 a.m. - 7:00 a.m.	5.0	6:00 p.m. - 7:00 p.m.	4.6
7:00 a.m. - 8:00 a.m.	5.0	7:00 p.m. - 8:00 p.m.	4.6
8:00 a.m. - 9:00 a.m.	5.0	8:00 p.m. - 9:00 p.m.	3.1
9:00 a.m. - 10:00 a.m.	5.0	9:00 p.m. - 10:00 p.m.	3.1
10:00 a.m. – 11:00 a.m.	5.9	10:00 p.m. - 11:00 p.m.	3.1
11:00 a.m. – 12:00 p.m.	5.9	11:00 p.m. - 12:00 a.m.	3.1

<u>Traffic Growth Factors</u>

Traffic growth factors at a particular site or segment are best estimated when a continuous traffic count data is available (assuming that the data is reliable and that the differences found from year to year can be attributed to growth), since it is well known that traffic volumes at a single site can be affected by a variety of extraneous factors, and thus growth factors computed from limited data collected from a limited number of locations can be biased. A less reliable estimate of growth factors can also be computed from data obtained from short duration counts, since the individual estimates of AADTT from such counts are not nearly as accurate as those available from continuous traffic counts.

both continuous and short duration counts, if data from the same count locations collected over several years are used to compute growth factors, errors at any one given location due to the inaccuracy of the AADTT estimate tend to self-correct. That is, if this year's AADTT count is too high, making this year's growth estimate too high, next year's "correct" AADT value will cause a much lower growth estimate to be computed, resulting in a more reliable growth estimate over the years.

It must be emphasized no single procedure is best in all cases for estimating traffic growth factors, and it is recommended that instead of concentrating on a specific procedure (e.g., short duration versus continuous counts or site specific versus regional) a better approach is to use all the tools and data available to examine traffic growth from several perspectives for a given site. Rather than develop a single estimate, the different data sources may be used to develop a number of growth factors from which appropriate growth factor estimate can be derived.

The Design Guide software allows users to use three different traffic growth functions to compute the growth or decay in truck traffic over time (forecasting truck traffic). The three functions provided to estimate future truck traffic volumes are presented in table 2.4.8.

Table 2.4.8. Function used in computing/forecasting truck traffic over time.

Function Description	Model
No growth	$AADTT_X = 1.0 * AADTT_{BY}$
Linear growth	$AADTT_X = GR * AGE + AADTT_{BY}$
Compound growth	$AADTT_X = ADTT_{BY} * (GR)^{AGE}$

where $AADTT_X$ is the annual average daily truck traffic at age X, GR is the traffic growth rate and $AADTT_{BY}$ is the base year annual average daily truck traffic.

The Design Guide software allows users to input both a growth rate and the growth function. A common growth function may be chosen for all truck classes, or different functions may be chosen for the different truck classes. Based on the function chosen, the opening date of the roadway to traffic (excluding construction traffic) and the pavement design life, AADTT is forecast for the entire design life of the pavement.

2.4.5.3 Axle Load Distribution Factors

The axle load distribution factors simply represent the percentage of the total axle applications within each load interval for a specific axle type (single, tandem, tridem, and quad) and vehicle class (classes 4 through 13). A definition of load intervals for each axle type is provided below:

- Single axles – 3,000 lb to 40,000 lb at 1,000-lb intervals.
- Tandem axles – 6,000 lb to 80,000 lb at 2,000-lb intervals.
- Tridem and quad axles – 12,000 lb to 102,000 lb at 3,000-lb intervals.

The normalized axle load distribution or spectra can only be determined from WIM data. Therefore, the level of input depends on the data source (site, regional, or national). For this design procedure, load spectra are normalized on an annual basis because no systematic or significant year-to-year or month-to-month differences were found in the analysis of the LTPP WIM data (*5*).

Figures 2.4.6 and 2.4.7 show the single and tandem axle load spectra for truck class 9 from two LTPP test sections with multiple years of data, respectively. Figure 2.4.8 shows the average normalized tandem axle load distribution for each month for truck class 9. As shown in figure 2.4.8, the normalized tandem axle load spectrum was found to be month/season independent. Figure 2.4.9 shows an example of the annual average (5 years of data) normalized tandem axle load spectra for vehicle classes 8, 9, and 10. The normalized tandem axle load spectra for vehicle classes 9 and 10 are approximately the same, whereas the one for vehicle class 8 is significantly different. Figure 2.4.10 shows an example of the annual normalized tandem axle load distribution for vehicle class 7, 8, and 9 for all years of available data combined. The tandem axle load spectra for these three types of trucks are different. Based on the results obtained from analyzing the LTPP traffic data the following input levels for axle load distribution factors were defined:

- Level 1 – the distribution factors determined based on an analysis of site- or segment-specific WIM data.
- Level 2 – the distribution factors determined based on an analysis of regional/statewide WIM data.
- Level 3 – the default distribution factors computed from a national database such as LTPP.

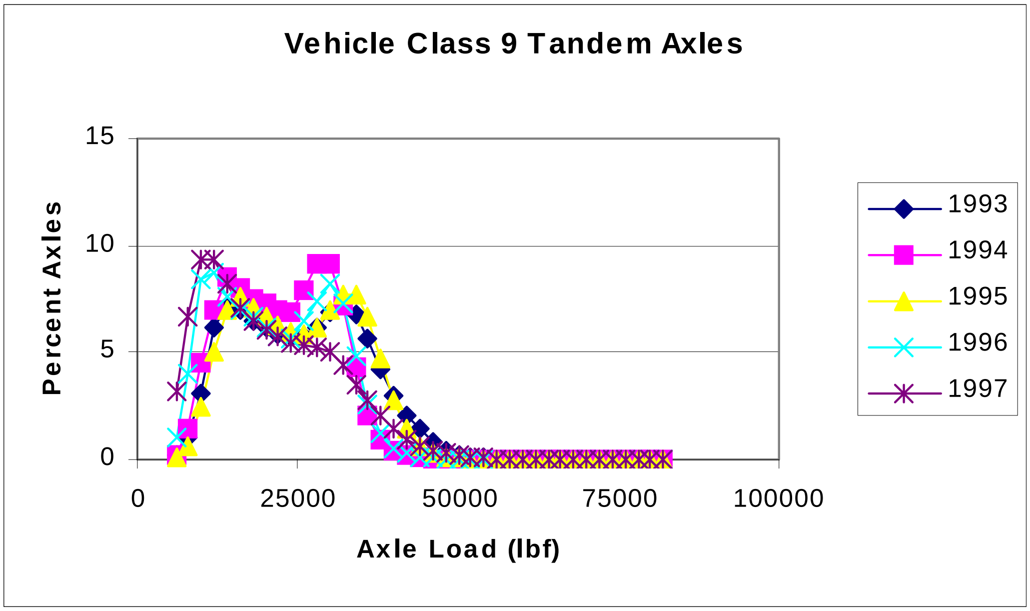

Figure 2.4.6. Average normalized single axle load spectra for truck class 9 for 5 years of WIM data.

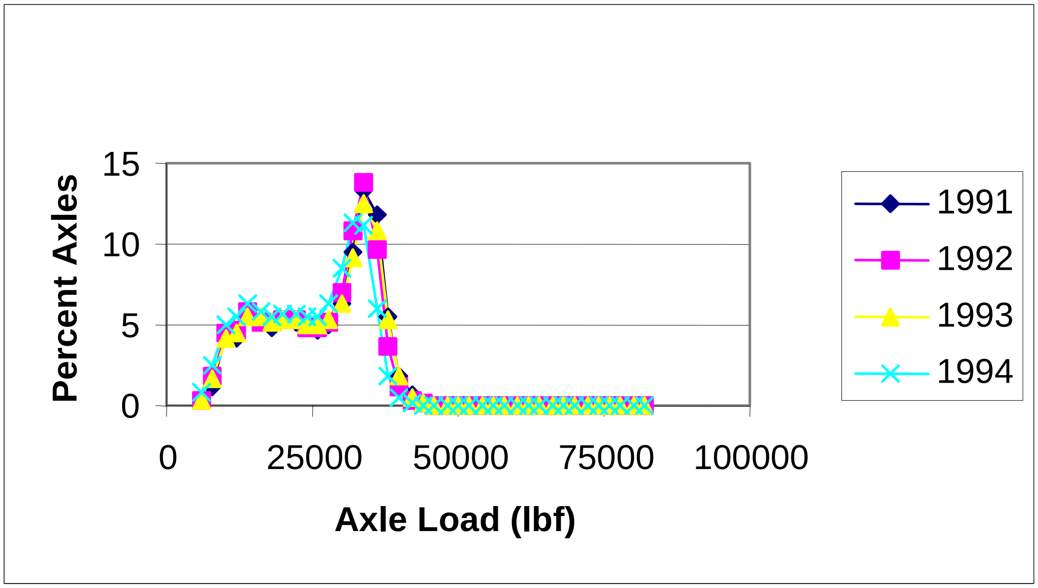

Figure 2.4.7. Average normalized tandem axle load distribution for truck class 9 for 4 years of WIM data.

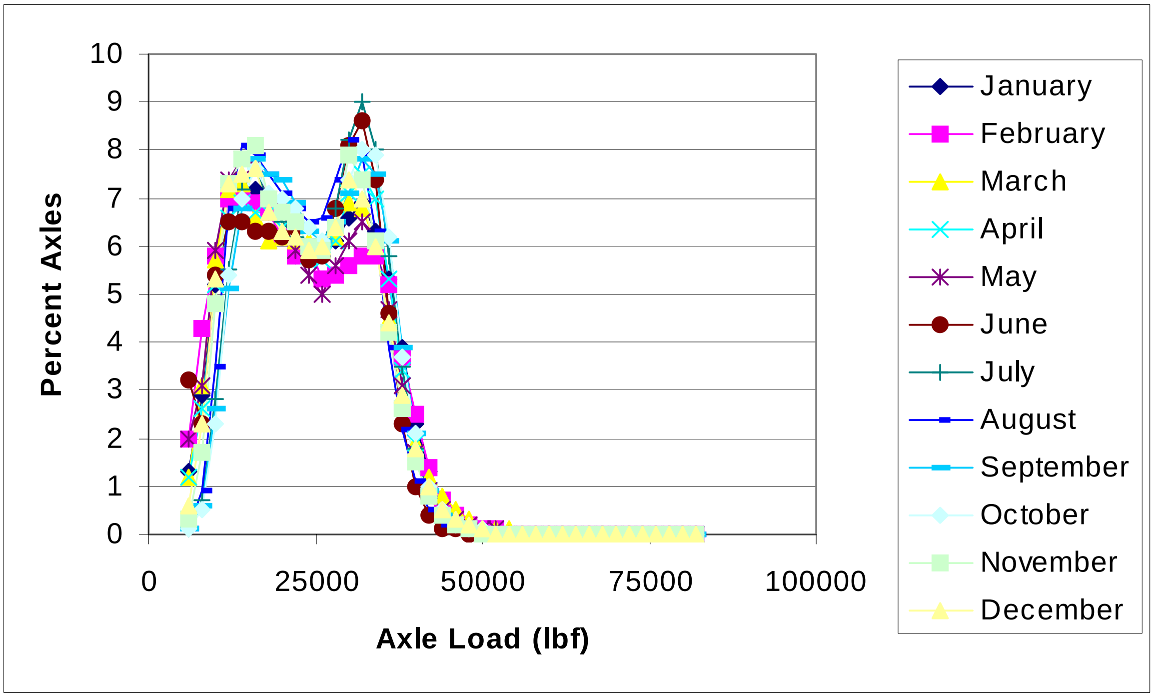

Figure 2.4.8. Monthly differences in the average normalized tandem axle load spectra for truck class 9 (LTPP test section 185022).

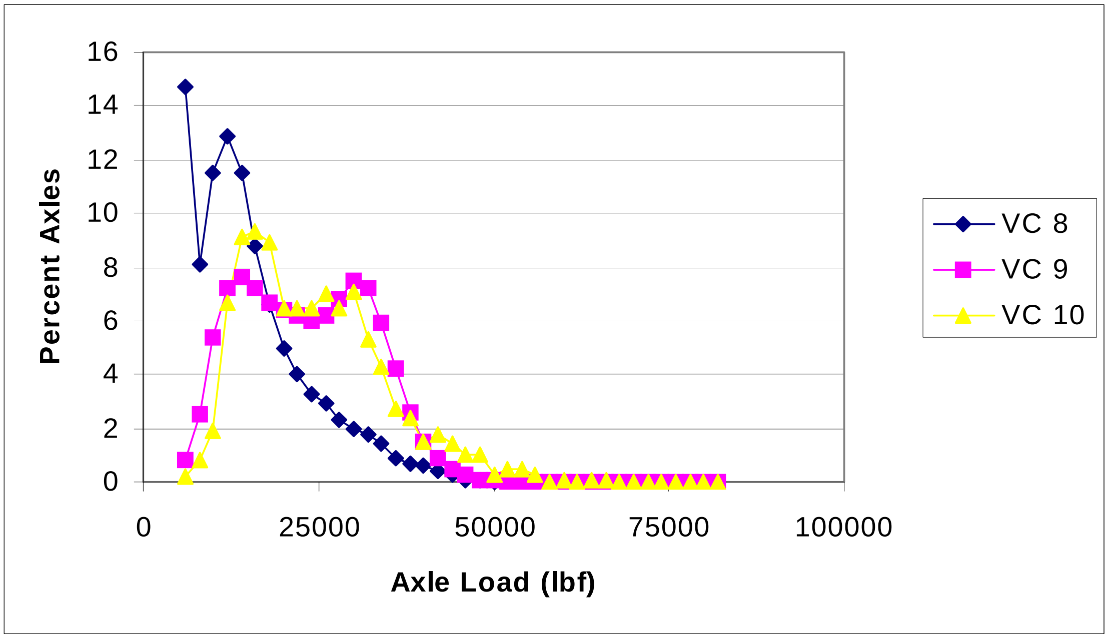

Figure 2.4.9. Average normalized tandem axle load spectra for truck classes 8, 9, and 10 (LTPP test section 185022).

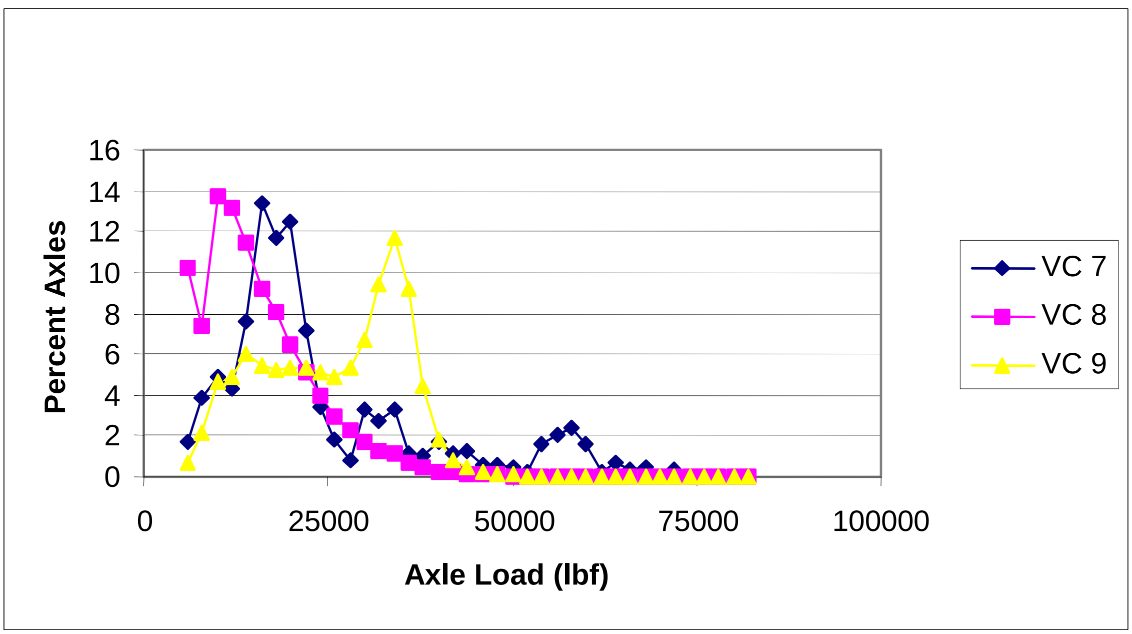

Figure 2.4.10. Average annual tandem axle load distribution for truck class 7, 8, and 9 for all available years of "good" data (LTPP test section 421627).

The Design Guide software allows user to input the following for level 1 through 3 inputs:

- Axle load distribution for each axle type (single, tandem, tridem, and quad) for the following load intervals:
    - Single axles – 3,000 lb to 40,000 lb at 1,000-lb intervals.
    - Tandem axles – 6,000 lb to 80,000 lb at 2,000-lb intervals.
    - Tridem and Quad axles – 12,000 lb to 102,000 lb at 3,000-lb intervals.
- For each axle type, load distribution is required for each month (January through December) and truck class (vehicle class 4 through 13).

For Level 1 inputs, the axle load distribution factors can be imported from already prepared text files, while for Level 3 inputs default values prepared using data from the LTPP database is provided. As an example, tables 2.4.9 and 2.4.10 list the axle load distribution default values for single and tandem axles for each truck class in all TTC groups. The following guide is recommended for computing axle load distribution factors using WIM data:

1. Assemble WIM data (total the number of axles measured within each axle load range by axle type within each truck class) and calculate the percentage of the total number of axle applications within each load range for each axle type and truck class for each year of data. In other words, normalize the number of axle load applications within each truck class and axle type.
2. Calculate the annual mean and variance for each axle load range for each axle type within each truck class. Both the mean and variance are important for determining if there are significant differences between years.
3. Compare the annual normalized axle load spectra or distributions for the truck class that has the greatest number of truck applications at the site. If the annual normalized values are not significantly different from year to year, all of the years can be combined to result in a site normalized load distribution for each truck class and axle type. If statistical differences (defined based on local experience) are found, the years should be considered separately, and the designer has the following options:
    a. Decide which axle load distribution should be used as the base year. It is suggested that one axle load distribution for each axle type and truck class be used and that distribution be kept constant throughout the analysis period.
    b. Decide whether to combine all years, selected years or use only one year of data to determine the base annual axle load distribution for each axle type and truck class.
    c. Determine how the normalized load distributions change with time and then predict the load distribution values for future years. The load distribution values for future years can then be used to compute an effective load distribution value to design.

In summary, the axle load spectra for each axle type for the different truck classes may be significantly different and should be considered separately in the analysis. Appendix AA provides greater detail on how default Level 3 axle load spectra values were computed using LTPP data.

Table 2.4.9. Single-axle load distribution default values (percentages) for each vehicle/truck class.

Mean Axle Load, lbs.	Vehicle/Truck Class									
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
3000	1.80	10.03	2.47	2.14	11.62	1.74	3.64	3.55	6.68	8.88
4000	0.96	13.19	1.78	0.55	5.36	1.37	1.24	2.91	2.29	2.67
5000	2.91	16.40	3.45	2.42	7.82	2.84	2.36	5.19	4.87	3.81
6000	3.99	10.69	3.95	2.70	6.98	3.53	3.38	5.27	5.86	5.23
7000	6.80	9.21	6.70	3.21	7.98	4.93	5.18	6.32	5.97	6.03
8000	11.45	8.26	8.44	5.81	9.69	8.43	8.34	6.97	8.85	8.10
9000	11.28	7.11	11.93	5.26	9.98	13.66	13.84	8.07	9.57	8.35
10000	11.04	5.84	13.55	7.38	8.49	17.66	17.33	9.70	9.95	10.69
11000	9.86	4.53	12.12	6.85	6.46	16.69	16.19	8.54	8.59	10.69
12000	8.53	3.46	9.47	7.41	5.18	11.63	10.30	7.28	7.09	11.11
13000	7.32	2.56	6.81	8.99	4.00	6.09	6.52	7.16	5.86	7.34
14000	5.55	1.92	5.05	8.15	3.38	3.52	3.94	5.65	6.58	3.78
15000	4.23	1.54	2.74	7.77	2.73	1.91	2.33	4.77	4.55	3.10
16000	3.11	1.19	2.66	6.84	2.19	1.55	1.57	4.35	3.63	2.58
17000	2.54	0.90	1.92	5.67	1.83	1.10	1.07	3.56	2.56	1.52
18000	1.98	0.68	1.43	4.63	1.53	0.88	0.71	3.02	2.00	1.32
19000	1.53	0.52	1.07	3.50	1.16	0.73	0.53	2.06	1.54	1.00
20000	1.19	0.40	0.82	2.64	0.97	0.53	0.32	1.63	0.98	0.83
21000	1.16	0.31	0.64	1.90	0.61	0.38	0.29	1.27	0.71	0.64
22000	0.66	0.31	0.49	1.31	0.55	0.25	0.19	0.76	0.51	0.38
23000	0.56	0.18	0.38	0.97	0.36	0.17	0.15	0.59	0.29	0.52
24000	0.37	0.14	0.26	0.67	0.26	0.13	0.17	0.41	0.27	0.22
25000	0.31	0.15	0.24	0.43	0.19	0.08	0.09	0.25	0.19	0.13
26000	0.18	0.12	0.13	1.18	0.16	0.06	0.05	0.14	0.15	0.26
27000	0.18	0.08	0.13	0.26	0.11	0.04	0.03	0.21	0.12	0.28
28000	0.14	0.05	0.08	0.17	0.08	0.03	0.02	0.07	0.08	0.12
29000	0.08	0.05	0.08	0.17	0.05	0.02	0.03	0.09	0.09	0.13
30000	0.05	0.02	0.05	0.08	0.04	0.01	0.02	0.06	0.02	0.05
31000	0.04	0.02	0.03	0.72	0.04	0.01	0.03	0.03	0.03	0.05
32000	0.04	0.02	0.03	0.06	0.12	0.01	0.01	0.04	0.01	0.08
33000	0.04	0.02	0.03	0.03	0.01	0.01	0.02	0.01	0.01	0.06
34000	0.03	0.02	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.02
35000	0.02	0.02	0.01	0.02	0.02	0.00	0.01	0.01	0.01	0.01
36000	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
37000	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01
38000	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.02	0.01	0.01
39000	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01
40000	0.01	0.00	0.01	0.01	0.00	0.00	0.04	0.02	0.00	0.00
41000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2.4.10. Tandem-axle load distribution default values (percentages) for each vehicle/truck class.

Mean Axle Load, lbs.	**Vehicle/Truck Class**									
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
6000	5.88	7.06	5.28	13.74	18.95	2.78	2.45	7.93	5.23	6.41
8000	1.44	35.42	8.42	6.71	8.05	3.92	2.19	3.15	1.75	3.85
10000	1.94	13.23	10.81	6.49	11.15	6.51	3.65	5.21	3.35	5.58
12000	2.73	6.32	8.99	3.46	11.92	7.61	5.40	8.24	5.89	5.66
14000	3.63	4.33	7.71	7.06	10.51	7.74	6.90	8.88	8.72	5.73
16000	4.96	5.09	7.50	4.83	8.25	7.00	7.51	8.45	8.37	5.53
18000	7.95	5.05	6.76	4.97	6.77	5.82	6.99	7.08	9.76	4.90
20000	11.58	4.39	6.06	4.58	5.32	5.59	6.61	5.49	10.85	4.54
22000	14.20	2.31	5.71	4.26	4.13	5.16	6.26	5.14	10.78	6.45
24000	13.14	2.28	5.17	3.85	3.12	5.05	5.95	5.99	7.24	4.77
26000	10.75	1.53	4.52	3.44	2.34	5.28	6.16	5.73	6.14	4.34
28000	7.47	1.96	3.96	6.06	1.82	5.53	6.54	4.37	4.93	5.63
30000	5.08	1.89	3.21	3.68	1.58	6.13	6.24	6.57	3.93	7.24
32000	3.12	2.19	3.91	2.98	1.20	6.34	5.92	4.61	3.09	4.69
34000	1.87	1.74	2.12	2.89	1.05	5.67	4.99	4.48	2.74	4.51
36000	1.30	1.78	1.74	2.54	0.94	4.46	3.63	2.91	1.73	3.93
38000	0.76	1.67	1.44	2.66	0.56	3.16	2.79	1.83	1.32	4.20
40000	0.53	0.38	1.26	2.50	0.64	2.13	2.24	1.12	1.07	3.22
42000	0.52	0.36	1.01	1.57	0.28	1.41	1.69	0.84	0.58	2.28
44000	0.30	0.19	0.83	1.53	0.28	0.91	1.26	0.68	0.51	1.77
46000	0.21	0.13	0.71	2.13	0.41	0.59	1.54	0.32	0.43	1.23
48000	0.18	0.13	0.63	1.89	0.20	0.39	0.73	0.21	0.22	0.85
50000	0.11	0.14	0.49	1.17	0.14	0.26	0.57	0.21	0.22	0.64
52000	0.06	0.20	0.39	1.07	0.11	0.17	0.40	0.07	0.23	0.39
54000	0.04	0.06	0.32	0.87	0.06	0.11	0.38	0.13	0.20	0.60
56000	0.08	0.06	0.26	0.81	0.05	0.08	0.25	0.15	0.12	0.26
58000	0.01	0.02	0.19	0.47	0.03	0.05	0.16	0.09	0.07	0.18
60000	0.02	0.02	0.17	0.49	0.02	0.03	0.15	0.03	0.19	0.08
62000	0.10	0.01	0.13	0.38	0.06	0.02	0.09	0.06	0.09	0.14
64000	0.01	0.01	0.08	0.24	0.02	0.02	0.08	0.01	0.04	0.07
66000	0.02	0.01	0.06	0.15	0.02	0.02	0.06	0.01	0.02	0.08
68000	0.01	0.00	0.07	0.16	0.00	0.02	0.05	0.01	0.04	0.03
70000	0.01	0.02	0.04	0.06	0.00	0.01	0.11	0.00	0.12	0.01
72000	0.00	0.01	0.04	0.13	0.00	0.01	0.04	0.00	0.01	0.04
74000	0.00	0.00	0.02	0.06	0.00	0.01	0.01	0.00	0.01	0.02
76000	0.00	0.00	0.01	0.06	0.00	0.00	0.01	0.00	0.01	0.04
78000	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.02
80000	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.08
82000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.4.5.4 General Traffic Inputs

Most of the inputs under this category define the axle load configuration and loading details used for calculating pavement responses. The exceptions are "Number of Axles by Axle Type per Truck Class" and "Wheelbase" inputs, which are used in the traffic volume calculations.

<u>Mean Wheel Location</u>

Distance from the outer edge of the wheel to the pavement marking. The inputs at different levels are as follows:

- Level 1 – the value determined through direct measurements on site-specific segments (not applicable to new alignments).
- Level 2 – a regional/statewide average value determined from measurements on roadways with similar traffic characteristics and site conditions (e.g., functional class, pavement type, level of service and so on).
- Level 3 – national average value or estimates based on local experience.

A default (Level 3) mean wheel location of 18 inches is provided in the Design Guide software. This is recommended if more accurate information is not available.

<u>Traffic Wander Standard Deviation</u>

This is the standard deviation of the lateral traffic wander. The wander is used to determine the number of axle load applications over a point for predicting distress and performance. The different levels for traffic wander are:

- Level 1 – the value determined through direct measurements on site-specific segments (not applicable to new alignments).
- Level 2 – a regional/statewide average value determined from measurements on roadways with similar traffic characteristics and site conditions (e.g., functional class, pavement type, level of service and so on).
- Level 3 – national average value or estimates based on local experience.

A default (Level 3) mean truck traffic wander standard deviation of 10 inches is provided in the Design Guide software. This is recommended if more accurate information is not available.

<u>Design Lane Width</u>

This parameter refers to the actual traffic lane width, as defined by the distance between the lane markings on either side of the design lane. It is a design factor and may or may not equal the slab width. The default value for standard-width lanes is 12 ft.

Number of Axle Types per Truck Class

This input represents the average number of axles for each truck class (class 4 to 13) for each axle type (single, tandem, tridem, and quad). The inputs at different levels are as follows:

- Level 1 – the values determined through direct analysis of site-specific traffic data (AVC, WIM, or traffic counts).
- Level 2 – the values determined through direct analysis of regional/statewide traffic data (AVC, WIM, or traffic counts).
- Level 3 – the default values based on analysis of national databases such as the LTPP databases.

Default (Level 3) estimates of the number of axle types per truck class provided in the Design Guide software and estimated using LTPP data are presented table 2.4.11.

Table 2.4.11. Suggested default values for the average number of single, tandem, and tridem axles per truck class.

Truck Classification	Number of Single Axles per Truck	Number of Tandem Axles per Truck	Number of Tridem Axles per Truck	Number of Quad Axles per Truck
4	1.62	0.39	0.00	0.00
5	2.00	0.00	0.00	0.00
6	1.02	0.99	0.00	0.00
7	1.00	0.26	0.83	0.00
8	2.38	0.67	0.00	0.00
9	1.13	1.93	0.00	0.00
10	1.19	1.09	0.89	0.00
11	4.29	0.26	0.06	0.00
12	3.52	1.14	0.06	0.00
13	2.15	2.13	0.35	0.00

Note: The number of quad axles per truck class is 0.00, because there were too few counted in the LTPP traffic database.

Axle Configuration

A series of data elements are needed to describe the configurations of the typical tire and axle loads that would be applied to the roadway because computed pavement responses are generally sensitive to both wheel locations and the interaction between the various wheels on a given axle. These data elements can be obtained directly from manufacturers databases or measured directly in the field. Typical values are provided for each of the following elements; however, site-specific values may be used, if available.

- Average axle-width – the distance between two outside edges of an axle. For typical trucks, 8.5 ft may be assumed for axle width.
- Dual tire spacing – the distance between centers of a dual tire. Typical dual tire spacing for trucks is 12 in.
- Axle spacing – the distance between the two consecutive axles of a tandem, tridem, or quad. The average axle spacing is 51.6 inches for tandem and 49.2 inches for tridem and quad axles.

For analysis of jointed plain concrete pavement (JPCP), the spacing between the steering and drive axles is used to determine the critical location of the axles on the portland cement concrete (PCC) slab and hence must be provided. Default Level 3 values for spacing between the first and second axles of trucks have been developed using the LTPP WIM data. A review of the individual truck record data suggests a normal, skewed, or bimodal distribution between the first and second axles, and is dependent on the truck class. Table 2.4.12 lists the mean, median and peak spacing and type of distribution between the first (steering) and second (drive) axles. The spacing between the axles for the predominant truck class should be used.

Table 2.4.12. Spacing between the steering and drive axles and type of distribution between the axles that were found from an analysis of the LTPP WIM database.

Truck Class	Spacing Between the Axles			
	Type of Distribution	**Average Spacing, ft.**	**Median Spacing, ft.**	**Peaks of occurrence, ft.**
4	Bimodal	29.9	29.9	26.9 and 30.5
5	Skewed to higher spacing	19.7	18.7	16.1
6	Normal	20.7	21.0	21.7
7	Normal	15.7	15.1	14.8
8	Normal	13.8	16.1	16.1
9	Bimodal	19.4	20.0	15.1 and 22.0
10	Skewed to lower spacing	20.3	21.0	23.3
11	Skewed to higher spacing	17.7	16.4	16.7
12	Bimodal	18.0	17.1	15.1 and 21.7
13	Bimodal	17.7	16.4	15.7 and 23.0

Wheelbase

A series of data elements are needed to describe the details of the vehicles wheelbase for use in computing pavement responses. These data elements can be obtained directly from manufacturer's databases or measured directly in the field. Typical values are provided for each of the following elements; however, site-specific values may be used, if available.

Average axle spacing (ft) – short, medium, or long. The recommended values are 12, 15, and 18 ft for short, medium, and long axle spacing, respectively.
Percent of trucks in class 8 through 13 with the short, medium, and long axle spacing – use even distribution (e.g., 33, 33, and 34 percent for short, medium, and long axles, respectively), unless more accurate information is available.

Note that axle spacing distribution is applicable to only truck tractors (Class 8 and above). If other vehicles in the traffic stream also have the axle spacing in the range of the short, medium, and long axles defined above, the frequency of those vehicles should be added to the axle-spacing distribution of truck tractors. For example, if 10 percent of truck traffic is from multiple trailers (Class 11 and above) that have the trailer-to-trailer axle spacing in the "short" range, 10 percent should be added to the percent trucks for "short" axles. Thus, the sum of percent trucks in the short, medium, and long categories can be greater than 100.

Tire Dimensions and Inflation Pressures

Tire dimensions and inflation pressures are important inputs in the performance prediction models. An effort was undertaken to verify tire pressures used in the trucking industry based on information collected from the Tire and Rim Association (TRA), Rubber Manufacturers' Association (RMA), American Trucking Association (ATA), and Truck Trailer Manufacturers' Association (TTMA). Table 2.4.13 shows the section widths for new tires and overall widths for maximum grown tires as well as minimum dual spacing from the 1999 TRA yearbook. Maximum grown tires are tires that have reached their maximum possible increase in dimensions due to wear. These widths are used to determine the minimum dual spacing (spacing between tires in dual applications).

Table 2.4.13. Tire widths and minimum dual spacing from TRA yearbook.

RMA Size	Ply Rating	Minimum Dual Spacing, in.	Tire Width, in.	
			Section (New)	Overall (Max. Grown)
295/75R22.5	14	13.5	11.7	12.5
11R22.5	14	12.5	11.0	12.0
11R24.5	14	12.5	11.0	12.0
285/75R24.5	14	12.5	11.1	11.7
11R22.5	16	12.5	11.0	12.0
11R24.5	16	12.5	11.0	12.0
225/70R19.5	12	10.0	8.9	9.5
255/70R22.5	16	11.5	10.0	10.5

Table 2.4.14 shows the maximum allowable loads and cold inflation pressures for different tires. Hot inflation pressures should be used in the Design Guide Software. The hot inflation pressure is typically about 10 to 15 percent greater than the cold inflation pressure. A default hot inflation pressure of 120 psi is used in the Design Guide Software.

Table 2.4.14. Maximum loads and cold inflation pressures for different tires.

RMA Size	Ply Rating	Tire Inflation Pressure, psi		Maximum Tire Load, lbs.	
		Single-Usage	Dual-Usage	Single-Usage	Dual-Usage
295/75R22.5	14	110	110	6,200	5,700
11R22.5	14	104	104	6,200	5,900
11R24.5	14	104	104	6,600	6,000
285/75R24.5	14	110	110	6,200	5,700
11R22.5	16	120	120	6,600	6,000
11R24.5	16	120	120	7,200	6,600
225/70R19.5	12	96	96	3,600	3,400
255/70R22.5	16	120	120	5,500	5,100

2.4.6 INPUT PROCESSING

The traffic inputs described in the preceding sections of this chapter are processed in the Design Guide software/procedure for use in computing pavement responses due to applied wheel loads. The outputs are the number of axle loadings applied incrementally (hourly or monthly) at a specific location over the entire design period. The end result is to produce the following for each wheel load category and wheel location for on an hourly or monthly basis (depending on the analysis type):

- Number of single axles.
- Number of tandem axles.
- Number of tridem axles.
- Number of quad axles.
- Number of truck tractors (Class 8 and above for computing JPCP top-down cracking).

This section presents and discusses the 8 major steps that performed by the Design Guide software for developing the "processed inputs" needed for analysis. The steps are as follows:

1. Determine increments (hourly or monthly).
2. Determine the AADTT value for the base year.
3. Determine the normalized truck traffic class distribution for the base year.
4. Determine the number of axles by axle type for each truck class.
5. Determine the normalized axle load spectra for each axle type and truck class.
6. Decide on the truck traffic forecast or reverse forecast function, and revise the incremental truck traffic for each successive year in the design/analysis period.
7. Multiply the normalized axle load spectra and normalized truck class spectra to the incremental truck traffic to determine the total number of axle applications within each axle load group for each axle type for each hour of each month of each year in the design/analysis period.
8. Specify details of the axle and tire loads.

2.4.6.1 Step 1: Subdivide the Year into Traffic Seasons – Hours of the Day or Months of the Year with Similar Traffic Features

The traffic data for a design segment should be divided into different traffic increments for data collection purposes. An increment can be defined in various ways, but the length of each increment in the Design Guide software has been preset to 1 hour or month for simplicity and computation efficiency between the different modules in the software

2.4.6.2 Step 2: Determine AADTT for the Base Year

This step has been described in detail in the preceding sections of this chapter.

2.4.6.3 Step 3: Determine the Normalized Truck Traffic Distribution

The third step of the procedure is to determine the normalized distribution of the number of trucks by vehicle class and to determine if the percentages of the total number of trucks within each vehicle class are changing with time.

2.4.6.4 Step 4: Determine the Number of Axles by Each Axle Type and Truck Class

The number of axles by each axle type and truck class can be determined from an analysis of the WIM data as described in the preceding sections of this chapter by computing the total number of each axle type weighed (single, tandem, tridem, quad axles) for a specific truck class and dividing it by the total number of trucks weighed within that truck class to determine the average number of axles of each axle type for each truck class. The average number of axles per truck class is typically independent of site-specific conditions.

2.4.6.5 Step 5: Determine the Normalized Axle Load Spectra for Each Axle Type

The fifth major step of the process is to determine the normalized axle load distribution or spectra from the site-specific, regional/statewide, or national WIM data. The load spectra are normalized on an annual basis because no systematic or significant year-to-year or month-to-month differences were found in the analysis of the LTPP WIM data.

2.4.6.6 Step 6: Establish Traffic Growth/Decay Rates

The traffic inputs for the base year for pavement design and evaluation are estimated from historical and existing traffic levels. The base year input values are modified to account for future growth that reflects changes in the local conditions affecting the transport of goods and materials. While it may be possible to measure current traffic levels and axle loads along a roadway, the characteristics of the traffic stream change over time and some of these changes can be substantial and highly variable. Thus, estimating historical traffic and projecting future traffic levels are difficult and risky. The longer period of time the projections are made, the greater the potential error.

2.4.6.7 Step 7: Predict Total Traffic – Future and Historical

The normalized axle load distribution and the normalized traffic distribution are combined with the total number of vehicles that are predicted with time. These normalized relationships are used to determine the number of axle loads within each load group for each axle type. The following steps summarize the prediction of the future or historical total number of single, tandem and tridem axles within each load group.

1. The average annual number of trucks per day is obtained for year l based on the selected growth function, $AADTT_l$. This value is multiplied by the truck factors discussed in step 4 and by the number of days within month j to obtain the total number of trucks within time increment i of month j of year l, $TT_{l,j,i}$.

a. $TT_{l,j,i} = (AADTT_l)(MDF_j)(HDF_i)(DDF)(LDF)(\text{No. of Days}_j)$ (2.4.2)

2. The total number of trucks within each time increment of a particular year and month is multiplied by the normalized truck class distribution percentage for a particular truck class k (NTP_k) to obtain the total number of trucks for each truck class, $T_{l,j,I,k}$.

b. $T_{l,j,I,k} = (TT_{l,j,I})(NTP_k)$ (2.4.3)

3. The average number of axles by axle type (single, tandem and tridem) for each truck class (which is independent of time), $NAT_{k,a}$, is multiplied by the total number of trucks within each truck class to obtain the total number of axles for each axle type, a (single, tandem, tridem, and quad) for that truck class, $NA_{l,j,I,k,a}$.

c. $NA_{l,j,I,k,a} = (T_{l,j,I,k})(NAT_{k,a})$ (2.4.4)

b. The total number axles for each axle type for a specific truck class are multiplied by the normalized axle load distribution percentage of a specific load group to obtain the number of axles (by axle type) within each load group for a specific axle type under a specific truck class, $AL_{l,j,I,k,a,w}$.

d. $AL_{l,j,I,k,a,w} = (NWP_{a,w})(NA_{l,j,I,k,a})$ (2.4.5)

The axle applications for each axle type are then summed for all truck classifications within each time increment to obtain the total number of axle applications within each load group by axle type for that time increment. These number of axle applications by axle type and load group for each time increment by year are then used within the incremental damage module to predict the load related distresses with time.

It should be noted that the percentage of the total traffic population in the light axle load groups are not important regarding pavement design and prediction of load related distresses. Therefore, the normalized approach focuses more on the heavier load groups for which a sufficient number of axles were recorded in the WIM data.

2.4.6.8 Step 8: Determine the Axle and Tire Loading Details

Recommendations were presented in preceding sections of this chapter.

2.4.7 TRAFFIC SAMPLING PLAN FOR SITE SPECIFIC AVC AND WIM DATA

This section provides an overview of the sampling plan requirements to estimate the truck traffic characteristics from the AVC and WIM data measured for a specific design segment of a roadway. For the cases when the traffic inputs are determined from regional/statewide or national data the historical AVC and/or WIM traffic data measured on roadways with similar traffic characteristics should be combined and used to compute the require traffic inputs for design.

2.4.7.1 Sample Location—Location of Traffic Measurement Equipment

In most cases, the normalized axle load distribution or spectra for a project can be assumed to be constant for a specific truck class and axle type. However, the truck traffic spectra can change along a segment of highway, especially through urban areas. As such, one WIM location per project should be sufficient, but multiple locations of the AVC equipment may be needed to estimate truck volumes and distributions accurately along a project. The decision on the number of AVC sampling locations within the project limits should be based on experience and the locations of industries and intersecting highways along the project that have an effect on the truck volume and distribution.

2.4.7.2 Sample Size and Frequency

Traffic data should be collected in accordance with the procedures and equipment (that has been properly calibrated) specified by LTPP. Tables 2.4.15 through 2.4.17 can be used as guidance for initially selecting the number of days required to collect an adequate amount of data from the traffic population for a specific site. The number of days for sampling the traffic was based on analyses of LTPP traffic data using the predominant truck type and load for the site and is dependent on the level of confidence and expected error considered acceptable to the designer. The sample size (minimum number of days) was not based on measuring the heaviest loads (or overloaded trucks) or on a truck class with very few operations within the traffic stream.

Table 2.4.15. Minimum sample size (number of days per year) to estimate the normalized axle load distribution – WIM data.

Expected Error (± percent)	Level of Confidence or Significance, percent				
	80	**90**	**95**	**97.5**	**99**
20	1	1	1	1	1
10	1	1	2	2	3
5	2	3	5	7	10
2	8	19	30	43	61
1	32	74	122	172	242

Table 2.4.16. Minimum sample size (number of days per season) to estimate the normalized truck traffic distribution – AVC data.

Expected Error (± percent)	Level of Confidence or Significance, percent				
	80	**90**	**95**	**97.5**	**99**
20	1	1	1	2	2
10	1	2	3	5	6
5	3	8	12	17	24
2	20	45	74	105	148
1	78	180	295	—***	—***

***Continuous sampling is required for these conditions.

Note: If the difference between weekday and weekend truck volumes is required, the number of days per season must be measured on both the weekdays and weekends.

Table 2.4.17. Minimum sample size (number of days per year) to estimate the total vehicles per day and year – AVC or vehicle count data.

Expected Error (± percent)	**Level of Confidence or Significance, percent**				
	80	**90**	**95**	**97.5**	**99**
20	3	7	12	16	23
10	12	27	45	64	90
5	47	109	179	254	—***
2	292	—***	—***	—***	—***
1	—***	—***	—***	—***	—***

***Continuous sampling is required for these conditions.

<u>WIM Data</u>

The normalized axle load distribution has been found to be constant over time and season. Thus, the suggested lot size for collecting the WIM data is one year, unless previous experience or studies indicate significant changes in the axle load distribution with time. Table 2.4.15 can be used as a guide for selecting the continuous number of WIM days per year that are needed for a specific confidence interval and expected error.

<u>AVC Data</u>

Minimum Number of Years Included in Traffic Volume Sample.

A minimum of 3 years should be included in the traffic sample, if possible, to reduce any bias of the sample caused by an anomaly that may appear in any one year of the traffic data. Where an agency has extensive regional data for similar highways, this minimum value can be reduced to 1 year.

Seasonal Samples

The sampling plan should be consistent with the time frame used for the damage computations or performance predictions. The traffic module uses a monthly interval for determining the traffic inputs. If an agency has no regional data or knowledge on the traffic characteristics for a segment of highway, the lot size should be one month until sufficient data are collected and analyzed. However, some agencies have sufficient historical data to determine the seasonal effects, if any, and which months can be combined into one season. For these cases, the traffic-sampling plan can be revised and those months with similar truck traffic can be combined into one season. Table 2.4.16 can be used as a guide to estimate the number of days of AVC data per season.

Stratified Random Sampling Plan

A stratified random sampling plan should be developed and implemented to identify any monthly (or seasonal) and annual differences that may be present in the traffic population.

Traffic Volume Data

Collection of the traffic volume data should be consistent with the AVC data.   Table 2.4.17 can be used as a guide to estimate the number of days of vehicle count data per year. The number of days should be stratified by season and day of week (weekends versus weekdays).

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