
Part 4

Procedures Manual

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1.0 Introduction

1.0 Introduction

This Procedures Manual presents operational definitions of the substantive algorithms that are incorporated into the NCHRP Project 1-39 software, TrafLoad. These algorithms are applied to classification counts and weigh-in-motion (WIM) data that are assumed to have passed state quality-control procedures.

TrafLoad is capable of processing classification counts that are provided in either C-record or 4-card format and WIM data that are provided in either W-record or 7-card format. For consistency with the 2002 Design Guide software (the “2002 software”), all internal processing of weight data is performed using pounds and thousands of pounds (kips). However, TrafLoad is also capable of converting load spectra expressed in kilograms (e.g., in W records) to approximately equivalent load spectra expressed in pounds.

Following this Introduction, this Procedures Manual contains two chapters. Chapter 2 presents procedures for processing vehicle classification counts and related data, and for converting this information into the form required by the 2002 software. Chapter 3 presents corresponding procedures for processing data collected by WIM equipment and converting these data into the axle-load spectra and estimates of axle groups per vehicle required by the 2002 software. A Glossary, presenting definitions of all abbreviations used, follows Chapter 3.

The primary purpose of the Procedures Manual is to present operational definitions of TrafLoad’s algorithms and to serve as a guide to the developers of that software. However, we have found it convenient to include brief descriptions of various types of information (such as definitions of factor groups) that will be required by the user of the software. These descriptions are expanded upon in the User’s Manual.

2.0 Classification Counts

2.0 Classification Counts

This chapter presents procedures to be used for processing hourly and daily classification counts. Most of the procedures presented in this chapter are identified by a pair of letters starting with the letter “C” (CA, CB, CC, ...).

■ 2.1 Types of Classification Systems

TrafLoad eventually will place only two limitations on the vehicle classification systems used:

1. There will be a maximum number of truck and bus classes that can be distinguished by the system; and
2. For each system, it must be possible to assign the classes to two *classification groups* that distinguish between single-unit vehicles and combinations.

The FHWA’s standard 13-class system will be used for all Level 3B sites (a requirement of the 2002 Design Guide software). However, some states may wish to use a more aggregate length-based system for some urban sites.

■ 2.2 $AADT_{it}$ and Monthly Distribution Factors

The following procedures are used to estimate *annual average daily traffic by vehicle class and lane* ($AADT_{it}$ ¹) for FHWA Classes 4 - 13 or for any other set of up to 20 user-defined vehicle classes, as well as corresponding monthly distribution factors (MDFs). All sites except Level 3B classification sites are treated as one-way sites; i.e., two-way roads are treated as pairs of one-way roads, with separate traffic data collected for each lane in each direction.

¹ $AADT_{it}$ is called AADTVC in the Phase I Report. The term $AADT_i$ or $AADT_{it}$ is used in all subsequent reports.

Level 1A Classification Sites

Level 1A classification sites are sites for which classification counts are available for periods of at least one week for at least 12 consecutive months. For each such site, the following procedures are applied to quality-checked classification counts collected at the site (i.e., classification counts that have passed a quality-assurance process).

CA. $AADT_{it}$

1. For each vehicle class (i), each lane, each month, each day of the week, and each hour of the day, obtain an average hourly count. For each vehicle class and lane, 2,016 such average hourly counts are produced (24 hourly values for each of 12 months and seven days of the week).
2. For each vehicle class, lane, month, and day of the week, obtain *monthly average day of the week class volume* ($MADW_{it}$) for the lane by summing the 24 average hourly counts for that vehicle class, lane, month, and day of the week. For each vehicle class and lane, this step produces 84 $MADW_{it}$ values (seven values for each of 12 months). This procedure will not produce a value of $AADT_{it}$ if any of the 84 $MADW_{it}$ values cannot be derived because of missing counts.
3. For any 12 consecutive months and for each day of the week, obtain *annual average day of the week traffic volumes for each class and lane* ($AADW_{it}$) by averaging the 12 corresponding $MADW_{it}$ values for that day of the week. This step normally produces one value of $AADW_{it}$ for each class and each of the seven days of the week.
4. For these 12 months, obtain *annual average daily traffic by vehicle class and lane* ($AADT_{it}$) by averaging the corresponding $AADW_{it}$ for each of the seven days of the week.

CB. *Monthly Distribution Factors*

1. For each vehicle class and each month, obtain *monthly average daily traffic by vehicle class* ($MADT_i$) for all lanes by summing the corresponding $MADW_{it}$ (from Step CA1) for all lanes and then averaging the seven sums.
2. For each vehicle class, obtain the sum of $AADT_{it}$ (from Step CA3) over all lanes.
3. For each vehicle class, obtain *monthly distribution factors* (MDF_i) by dividing $MADT_i$ by the result of Step 2.

CC. *Reserved*

CD. *Combined Monthly/DOW Traffic Ratios*

For each user-defined *Type 1 vehicle classification group*, I , obtain combined monthly/day-of-week (DOW) traffic ratios by direction, q , ($MDWTR_{Iq}$):

$$MDWTR_{lq} = \frac{\sum_{\ell \sim q} \sum_{i \in I} MADW_{i\ell}}{\sum_{\ell \sim q} \sum_{i \in I} AADT_{i\ell}} \quad (CD)$$

where the sums are taken over all lanes (ℓ) in direction q and all vehicle classes (i) in I .

Level 1B Sites

Level 1B classification sites are classification sites that are on the same road as an associated Level 1A site and are sufficiently close to the Level 1A site so that most trucks that pass one of the two sites pass both sites. For each such site, Procedure CG and either Procedure CE or CF are applied to quality-checked classification counts collected at the site.

CE. Direct Scaling

Consider hours and dates for which quality-checked classification counts have been obtained for the Level 1B site. If quality-checked classification counts have also been obtained for the same hours and dates at the associated Level 1A site and the road has no more than one lane per direction at both sites, then for each vehicle class and each lane:

1. Obtain the total number of class i vehicles observed in the lane at the Level 1B site during these hours.
2. Obtain the total number of class i vehicles observed in the lane at the Level 1A site during these hours.
3. Divide the first result by the second result and multiply by $AADT_{i\ell}$ for the Level 1A site to produce $AADT_{i\ell}$ for the Level 1B site. If the second result is zero, set $AADT_{i\ell}$ for the Level 1B site to zero.

CF. Factored Counts

If Procedure CE cannot be used then, for each vehicle class and each lane:

1. Obtain quality-checked hourly counts by lane at the site.
2. Divide each count by the appropriate combined monthly/DOW traffic ratio (from Step CD) for the associated Level 1A site. (If this divisor is zero, print an error message.)
3. For each hour of the day, average the adjusted counts obtained for that hour on the different days.
4. Sum the 24 values obtained in Step 3 to produce $AADT_{i\ell}$ for the Level 1B site.

CG. Monthly Distribution Factors

The monthly distribution factors for any Level 1B site are the same as the MDFs for the associated Level 1A site.

Factor Groups

For each user-defined factor group, monthly and DOW traffic ratios are obtained for each user-defined Type 1 vehicle classification group. A simple set of two such groups would have single-unit or “short” truck classes assigned to one group and buses and combination or “long” truck classes assigned to a second group. States with significant volumes of multi-trailer combinations may assign these vehicles to a third group.

CH. Monthly Traffic Ratios and Monthly Distribution Factors

Each state should identify three or more *seasonal factor groups* and assign each Level 1A site to one of these groups. A simple set of three seasonal factor groups would consist of the rural Interstate System, all other rural roads, and all urban roads. For each Type 1 classification group, *I*, and each seasonal factor group, *J*, a set of *monthly traffic ratios* is obtained:

$$MTR_{IJ} = \text{Avg}_{j \in J} \frac{\sum_{i \in I} MADT_{ij}}{\sum_{i \in I} AADT_{ij}} \quad (\text{CH})$$

where the sums are taken over all vehicle classes (*i*) in *I* and the averages are obtained over all Level 1A sites (*j*) in *J*, and the $MADT_{ij}$ and $AADT_{ij}$ represent totals over all lanes (from Steps CB1 and CB2). The resulting MTR_{IJ} are used for factoring short-duration classification counts obtained at Level 2 sites assigned to seasonal factor group *J*. For each vehicle class, *i*, in *I* and each site, *j*, in *J*, the *monthly distribution factor* (MDF_i) is set equal to the monthly traffic ratios. All Level 2 sites must be assigned to a seasonal factor group.

CI. DOW Traffic Ratios

Each state should identify two or more *DOW factor groups* and assign (most or all) Level 1A sites to one of these groups. A simple set of two DOW factor groups would consist of: a group consisting of sites at which most trucks serve relatively nearby origins and destinations; and a second group consisting of sites at which significant numbers of trucks operate that serve origins or destinations that are more than 200 miles apart. For each Type 1 classification group, *I*, and each DOW factor group, *K*, a set of *DOW traffic ratios* is obtained:

$$DTR_{iK} = \text{Avg}_{k \in K} \frac{\sum_{i \in I} AADW_{ik}}{\sum_{i \in I} AADT_{ik}} \quad (\text{CI})$$

where the sums are taken over all vehicle classes (i) in I and the averages are obtained over all Level 1A sites (k) in K . All Level 2 sites for which there exist classification counts that are less than seven days long must be assigned to a DOW factor group.

CJ. Time-of-Day Traffic Ratios

Time-of-day (TOD) traffic ratios, or “hourly fractions,” are used for estimating AADT from manual partial-day classification counts. Each state requiring such traffic ratios should establish a minimum of two *TOD factor groups*: one for sites with TOD patterns for combinations that are relatively flat and one or more for sites with TOD patterns that are less flat. For each TOD factor group, a set of 24 *hourly fractions* (HF_{gh}) is developed for each Type 1 classification group. (The subscripts, g and h , refer to the TOD factor group and the hour of the day, respectively.)

For each TOD factor group and each Type 1 classification group, hourly fractions are developed using all quality-checked weekday classification counts from a user-specified set of Level 1A classification sites. The hourly fractions are obtained:

1. For each site, the weekday hourly counts are used to produce average hourly weekday volumes for each hour of the day.
2. For each site, 24 hourly fractions are obtained by dividing the 24 hourly volumes (from Step 1) by the sum of these 24 values.
3. The 24 hourly fractions, HF_{gh} for the entire group are obtained by averaging the corresponding Step 2 values obtained for each of the sites.

Level 2 Sites

Level 2 classification sites are classification sites that do not qualify as Level 1 classification sites. These sites can be analyzed using Level 2A procedures if at least one 24-hour classification count is available, though it is recommended that Level 2A procedures be used only if there is a count that covers at least 48 weekday hours. Procedures CK - CN are used for analyzing Level 2A sites. As implied in the descriptions of these procedures, TrafLoad distinguishes four types of Level 2A sites with internal codes: 2S7, 2M7, 2S48, and 2M48.

CK. Single Seven-Day Classification Counts

Consider “2S7” sites for which quality-checked classification counts are available for a single period of at least one week. For each such site, each lane, ℓ , and each vehicle class, i , the $AADT_{i\ell}$ are estimated in three steps.

1. Divide each hourly count by the DOW traffic ratio, DTR_{IK} , for the day of the week in which the count was taken (from Step CI) and the monthly traffic ratio, MTR_{IJ} , for the month in which the count was taken (from Step CH). In this step, I is the Type 1 classification group containing i , K is the DOW factor group to which the site is assigned, and J is the seasonal factor group to which the site is assigned.
2. For each hour of the week, obtain an average of the (one or more) factored hourly counts obtained in Step 1.
3. Sum the 168 values obtained in Step 2 and divide by seven. The results are the estimated values of the $AADT_{i\ell}$.

CL. Multiple Seven-Day Classification Counts

Consider “2M7” sites for which quality-checked classification counts are available for n periods of at least one week ($n \geq 3$) spaced with fair uniformity over the course of a year. For each such site, the $AADT_{i\ell}$ are estimated by applying Procedure CK to counts for each of the n periods and averaging the results.

CM. Single 48-Hour Classification Counts

Consider “2S48” sites for which quality-checked classification counts are available for a period of at least 48 consecutive hours (but less than seven days). For each such site, each lane, ℓ , and each vehicle class, i , the hourly counts are used to estimate the $AADT_{i\ell}$ in three steps:

1. For each vehicle class, i , divide each hourly count by:
 - DTR_{IK} for that DOW (from Step CI); and
 - MTR_{IJ} for the corresponding month (from Step CH);where I is the Type 1 classification group containing i , J is the seasonal factor group to which the site is assigned, and K is the DOW factor group to which the site is assigned.
2. For each hour of the day, obtain an average of the hourly counts obtained in Step 1.
3. Sum the 24 values obtained in Step 2 to produce $AADT_{i\ell}$.

CN. Multiple 48-Hour Classification Counts

Consider “2M48” sites for which quality-checked classification counts for n periods of at least 48 consecutive hours (but less than one week) spaced with fair uniformity over the course of a year. For each such site, the $AADT_{it}$ are estimated by applying Procedure CM to the counts obtained for each of the n counting periods and averaging the results.

CO. Partial-Day Classification Counts

Level 2B sites are sites for which a manual classification count of at least six hours has been collected.² Such counts are converted to estimates of 24-hour truck traffic and then converted to estimates of $AADT_{it}$ using Procedure CP. The conversion to estimates of 24-hour traffic volume is performed by vehicle class using a user-specified set of hourly fractions developed in Step CJ. (See Part 1, Section 4.2 for a discussion of the development and use of sets of hourly fractions.) This conversion requires two steps:

1. For any vehicle class for which hourly counts by lane have been obtained for n hours, divide each of these counts by the hourly fraction for that hour of the day.
2. For each vehicle class, sum the Step 1 results and divide by n . The results are estimates of 24-hour traffic by vehicle class and lane.

CP. Converting 24-Hour Traffic Estimates to $AADT_{it}$

The estimates of 24-hour traffic by vehicle class produced by Step CO are converted to estimates of $AADT_{it}$ by dividing by:

- DTR_{IK} for that DOW (from Step CI); and
- MTR_{IJ} for the corresponding month (from Step CH);

where I is the Type 1 classification group containing i , J is the seasonal factor group to which the site is assigned, and K is the DOW factor group to which the site is assigned.

Level 3 Sites

CQ. Level 3A Sites

Level 3A sites are sites that are on the same road as a Level 1 or Level 2 site and that are sufficiently close to such an “associated” site to carry a traffic mix that is similar to the traffic at the associated site. For Level 3A sites, estimates of two-way annual average daily truck traffic ($AADTT$) either are supplied by the user or they are developed by TrafLoad from user-specified estimates of annual average daily traffic ($AADT$). The estimates of

² TrafLoad refers to Level 2B sites internally as “Level 2SM” sites.

AADT_i for the associated site (aggregated over all lanes) are then used to distribute AADTT for the Level 3A site over vehicle classes and directions.

The monthly distribution factors (MDF_i) for each Level 3A site are set equal to the corresponding factors for the associated Level 1 or Level 2 site.

CR. Level 3B Sites

Level 3B sites are sites for which information on base-year trucks is limited either to estimates of two-way AADTT or to estimates of two-way AADT and overall percent trucks. In the latter case, AADTT estimates are obtained by multiplying AADT by percent trucks.

For each Level 3B site, users are required to specify to which of the 17 “Truck Traffic Classification” (TTC) groups described in the 2002 Design Guide documentation³ the site belongs. The specified TTC will be passed to the 2002 Design Guide software (the “2002 software”) and used by that software to distribute estimated AADTT to FHWA Classes 4 - 13.

■ 2.3 Hourly Distribution Factors

The Project 1-39 software does not develop *hourly distribution factors* (HDFs) for Level 3B sites or for some Level 2B or 3A sites. For these sites, the 2002 software will use its own default HDFs. For all other sites, HDFs are developed using one of the following three procedures. If the user has requested the AADT_i by lane, the HDFs are produced by lane; otherwise they are produced by direction.

CS. Sites at Which Classification Counts Have Been Collected for Periods of at Least 24 Hours

For Level 1A sites and for all Level 2 sites except Level 2B sites, HDFs are derived directly from the hourly truck and bus counts collected at the site. For these sites, all quality-checked hourly classification counts are used to produce the average volume of trucks and buses by lane or direction (for all vehicle classes, combined) for each hour of the day. For each lane or direction at each such site, a set of 24 HDFs is obtained by dividing the 24 hourly averages by the sum of these averages.

The HDFs for any Level 1B site are set equal to the HDFs for the associated Level 1A site.

³ ERES Consultants and FUGRO-BRE, Draft Report, prepared for NCHRP Project 1-37A, 2000, pp. 4-8 - 4-10.

CT. Level 2B Sites Dominated by Business-Day Trucking

For Level 2B sites identified by the user as being ones at which nearly all truck traffic is business-day traffic, the HDFs are set to the typical business-day values shown in Table 2.1. For other Level 2B sites, HDFs are not generated; instead, the 2002 software will use its own default HDFs.

Table 2.1 Hourly Distribution Factors for Level 2B Sites with Business-Day Trucking

Hour	Hourly Distribution Factor
0	0.6%
1	0.4
2	0.4
3	0.4
4	0.9
5	2.8
6	4.8
7	6.1
8	7.4
9	7.8
10	7.7
11	7.6
12	7.5
13	7.9
14	8.0
15	7.0
16	5.9
17	4.7
18	3.6
19	2.6
20	1.9
21	1.6
22	1.3
23	1.1

CU. Level 3A Sites

All Level 3A sites have an associated Level 1 or 2 site (see Procedure CQ), and most of these associated sites have HDFs established by Procedures CS or CT. For every Level 3A site with such an associated site, the HDFs are set equal to the HDFs for the associated

site. For other Level 3A sites, HDFs are not generated; instead, the 2002 software will use its own default HDFs.

■ 2.4 Directional Distribution Factors

For all sites except Level 3B sites, the procedures presented in Section 2.2 produce separate estimates of the $AADT_{i\ell}$ by direction. Therefore, for these sites, the *directional distribution factors* (DDFs) are set to 1.0.

For Level 3B sites, TrafLoad does not estimate DDFs. Instead, the 2002 software will use its own defaults for these sites.

■ 2.5 Growth Rates

For each site, the 2002 software requires either a linear or exponential growth rate. TrafLoad allows the use of separate user-specified growth rates for single-unit trucks and for combination trucks. For each required growth rate, the user must:

- Specify whether the growth rate will be linear or exponential; and
- Provide either the growth rate or data from which the growth rate can be readily computed.

Exponential Growth Rates

In the case of exponential growth rates, the user may provide:

1. The estimated growth rate (percent per year);
2. Base year, forecast year, and an overall percentage increase that has been forecast over this period; or
3. Base year, forecast year, average forecast-year daily traffic for the relevant classification group (single-unit trucks or combinations), and (optionally) corresponding values of average base-year daily traffic. (If base-year values are not provided by the user, the base-year values developed using the procedures of Section 2.2 are used.)

If the third option is used, a percentage annual growth rate will be derived using the formula:

$$P = 100 \left(\left(\frac{T_f}{T_o} \right)^{\left(\frac{1}{Y_f - Y_o} \right)} - 1 \right) \quad (2.5.1)$$

where

Y_o and Y_f are the base year and forecast year, respectively;

T_o and T_f are the corresponding estimates of AADT (T_o is obtained from Section 2.2); and

P is the estimated percentage annual growth rate.

If the second option is used, a percentage annual growth rate will be derived similarly using the formula:

$$P = 100 \left(\left(1 + \frac{Q}{100} \right)^{\left(\frac{1}{Y_f - Y_o} \right)} - 1 \right) \quad (2.5.2)$$

where Y_o , Y_f , and P are defined as above and Q is the overall percentage increase in single-unit trucks or combinations between Y_o and Y_f .

Linear Growth Rates

In the case of linear growth rates, the user may provide:

1. The estimated growth rate (an annual increase in average daily traffic of single-unit trucks or combinations);
2. Base year, forecast year, and total increase in average daily traffic for the relevant classification group over the forecast period; or
3. Base year, forecast year, average forecast-year daily traffic for the relevant classification group, and (optionally) corresponding values of average base-year daily traffic. (If base-year values are not provided by the user, the base-year values developed using the procedures of Section 2.2 are used.)

If the third option is used, two linear annual growth rates (annual increase in average daily trucks) will be derived, one for single-unit trucks and one for combinations, using:

$$b = \frac{T_f - T_o}{Y_f - Y_o} \quad (2.5.3)$$

where b is the estimated linear growth rate and the other variables are defined as above. Similarly, if the second option is used, the above formula becomes:

$$b = \frac{\Delta T}{Y_f - Y_o} \quad (2.5.4)$$

where ΔT is the total increase in average daily traffic for the relevant classification group and the other variables are defined above.

In all three cases, the linear annual growth for single-unit trucks is distributed among the corresponding vehicle classes in proportion to the corresponding values of $AADT_i$ that have been developed using the procedures of Section 2.2, and the linear annual growth for combinations is distributed similarly among the corresponding classes of combinations.

■ 2.6 Coefficients of Variation

The following procedures were developed for estimating *coefficients of variation* (CVs) for the $AADT_{it}$ estimated for each site. However, since the 2002 software does not currently require the CVs, these procedures have not been implemented in TrafLoad.

CV. Level 1 Sites

The CVs are set to 0.01 for Level 1A sites and to a user-specified value between 0.02 and 0.04 for Level 1B sites. In the case of Level 1B sites, the user should specify 0.02 if the only intersections/interchanges between the site and its associated Level 1A site are ones at which relatively few trucks enter or leave the road. If moderate numbers of trucks enter or leave the road at any intermediate intersections or interchanges, the user should specify a CV of 0.03 or 0.04. (If significant numbers of trucks enter or leave the road at any intermediate intersections or interchanges, the two sites should not be associated with each other, and the site in question should not be treated as a Level 1B site.)

CW. Factor Groups

There are several sources of error in the $AADT_{it}$ estimates developed for Level 2 sites. One of the most significant is due to variance within the factor groups used in the $AADT_{it}$ estimation process. For each classification group distinguished, the contribution of this error to the CVs for $AADT_{it}$ estimates produced by Procedures CK and CM are estimated:

$$CV_G = \sqrt{\frac{\sum_{j=1}^n \sum_{k=1}^m (x_{jk} - \bar{x})^2}{(nm-1)\bar{x}^2}} \quad (CW1)$$

where

n is the number of Level 1A sites in the seasonal factor group used;

j is an index variable used to distinguish sites in the seasonal factor group;

m is the number of Level 1A sites in the DOW factor group used;

k is an index variable used to distinguish sites in the DOW factor group;

x_{jk} is the estimate of AADT_{it} that would be obtained for vehicles in the classification group if the seasonal factor used was obtained using only Level 1A site j data and the DOW factor was obtained using only site k data; and

\bar{x} is the actual estimate obtained using data from all sites in the seasonal and DOW factor groups.

The corresponding CVs for estimates produced by Procedures CL and CM (which do not involve DOW factoring) are estimated using a simplified version of this formula:

$$CV_G = \sqrt{\frac{\sum_{j=1}^n (x_j - \bar{x})^2}{(n-1)\bar{x}^2}} \quad (CW2)$$

CX. Level 2 Sites

CVs for Level 2 sites are obtained using the formula:

$$CV = CV_G + 0.01 + 0.03CV_a + 0.02CV_b + 0.05CV_c \quad (CX)$$

where

CV_G is produced by Procedure CW.

CV_a is set by the user to one for Level 2 sites whose assignment to factor groups involves some degree of ambiguity (as discussed in Part 1, Appendix B), and set to zero otherwise.

CV_b is set by the user to one for Level 2 sites belonging to functional systems that are unrepresented or significantly underrepresented among the Level 1A sites in the factor group(s) to which the site is assigned, and set to zero otherwise.

CV_c is set by the user to one for Level 2B sites whose counts were factored using hourly fractions (Procedure CP) that vary by hour of the day (i.e., that are not all equal to 1/24), and set to zero otherwise.

CY. Level 3A Sites

For Level 3A sites that are associated with a Level 1 site, the CV equals the CV of the associated site plus 0.10. For Level 3A sites that are associated with a Level 2 site, the CV equals the CV of the associated site plus 0.08.

CZ. Level 3B Sites

For Level 3B sites for which AADTT estimates are based on a recent traffic count, CV is set to 0.30. For all other Level 3B sites, CV is set to 1.0.

3.0 WIM Data

3.0 WIM Data

For each vehicle classification system used by a state (see Section 2.1), data from weigh-in-motion (WIM) sites are used to develop a set of *axle-load spectra* (LS) and related statistics.

For each classification system, either the individual vehicle classes must be coded in the WIM records or they must be obtained as user-defined aggregates of classes that are coded in the WIM records. Thus, the 13 classes of FHWA's axle-based classification system can be coded directly in the WIM records, while a second, length-based classification system that distinguishes "short trucks" from "long trucks" can use data from FHWA Classes 5 - 7 for "short trucks" and Classes 4 and 9 - 13 for "long trucks." Alternatively, WIM data can be used to classify all trucks as "short" or "long." For length-based classification systems, the latter alternative (direct classification from WIM data) will produce WIM statistics that correspond more closely to the classification data developed using the Chapter 2 procedures, so this alternative generally will produce more accurate pavement designs.

■ 3.1 Basic Statistics

For each WIM site, there is either one *design lane* or one design lane per direction. For each design lane, basic statistics to be collected and summarized by the data-collection software that provides inputs to TrafLoad are:

- V_i Vehicles by class - The number of vehicles of class i for which "quality-checked" WIM data (i.e., WIM data that have passed a quality assurance process) have been collected.
- A_{ij} Axle groups by type and vehicle class - The number of axle groups of type j (single, tandem, tridem, and quad) observed on vehicles of class i for which quality-checked WIM data have been collected.
- A_{ijk} Axle groups by type, vehicle class, and load range - The number of axle groups of type j in load range k observed on vehicles of class i for which quality-checked WIM data have been collected. Table 3.1 shows the load ranges defined for each of the four types of axle group. There are 39 load ranges defined for single and tandem axles, and 31 ranges for tridem and quad axles. The software will convert any values of A_{ijk} that are specified in terms of kilogram ranges to values that are specified in terms of the Table 3.1 ranges.

Table 3.1 Load Ranges Used for Load Spectra

Load Range	Upper Limit of Load Range (kips ¹) by Type of Axle Group			
	Single	Tandem	Tridem	Quad
1	3	6	12	12
2	4	8	15	15
3	5	10	18	18
4	6	12	21	21
5	7	14	24	24
6	8	16	27	27
7	9	18	30	30
8	10	20	33	33
9	11	22	36	36
10	12	24	39	39
11	13	26	42	42
12	14	28	45	45
13	15	30	48	48
14	16	32	51	51
15	17	34	54	54
16	18	36	57	57
17	19	38	60	60
18	20	40	63	63
19	21	42	66	66
20	22	44	69	69
21	23	46	72	72
22	24	48	75	75
23	25	50	78	78
24	26	52	81	81
25	27	54	84	84
26	28	56	87	87
27	29	58	90	90
28	30	60	93	93
29	31	62	96	96
30	32	64	99	99
31	33	66	102	102
32	34	68		
33	35	70		
34	36	72		
35	37	74		
36	38	76		
37	39	78		
38	40	80		
39	41	82		

¹ One kip = 1,000 pounds = 4.448 kN.

- $AGPV_{ij}$ Axle groups per vehicle = A_{ij}/V_i – The average number of axle groups of type j per vehicle of class i .
- F_{ijk} The fraction of axle groups of type j on vehicles of class i that are in load range k – obtained by dividing A_{ijk} by A_{ij} . (Defined only for pairs of i and j for which A_{ij} is not zero.)
- LS_{ij} The load spectrum for vehicle class i and axle-group type j – A vector of either 31 or 39 values. The vector may either be *normalized*, in which case it consists of 31 or 39 F_{ijk} , or *unnormalized*, in which case it consists of 31 or 39 A_{ijk} . Except as otherwise indicated, all computations are performed on unnormalized values.
- LS A set of load spectra, consisting of unnormalized load spectra for all combinations of vehicle class and axle-group type.

For vehicle classes that are defined as aggregates of directly coded vehicle classes, the V_i , A_{ij} , and A_{ijk} are obtained by summing the values obtained for the directly coded classes, and these values are then used to produce the LS_{ij} , F_{ijk} , and $AGPV_{ij}$.

■ 3.2 Equivalent Single-Axle Loads

Some manipulations of the load spectra require the use of a unidimensional pavement damage factor. For this purpose, TrafLoad uses 18,000-pound *equivalent single-axle loads*, ESALs, and *average ESALs per vehicle* by WIM vehicle-classification group (I), $AEPV_{Ip}$. The WIM vehicle-classification groups are user defined and may be different from the Type 1 and Type 2 classification groups used for analyzing classification counts. The subscript p in $ESALs_p$ and $AEPV_{Ip}$ refers to pavement type.

Load spectra collected at any site are used to derive separate values of ESALs and AEPV for rigid pavement and for flexible pavement. These quantities may subsequently be used in analyzing data at another site. For these analyses, the ESALs and AEPV values used are those corresponding to the type of pavement (rigid or flexible) to be designed at the latter site.

When adjusting load spectra, a fourth power relationship between axle weight and ESALs is assumed for each type of axle group for both flexible and rigid pavements. For typical pavements, this assumption produces equations of the form:

$$ESALs = a \times (\text{Axle Weight})^4 \quad (3.1)$$

While the values of a in this equation are different for flexible and rigid pavements and for different types of axle groups, the fourth power assumption provides an extremely good fit to the more complex ESAL equations presented in the *AASHTO Pavement Design Guide*.¹

■ 3.3 Level 1 WIM Data

Level 1 WIM data are WIM data collected with properly calibrated equipment in the design lane of a road for which pavement is being designed and at a site at which the heavy vehicles being weighed are essentially the same as those that will be using the design lane of the section of road to be paved. If Level 1 data are collected for one design lane in each direction of travel, the data are analyzed separately for each of the design lanes.

Seasonal LS Factors

Monthly adjustment indexes for LS are developed from user-supplied *seasonal LS datasets* for Level 1 WIM sites. These datasets contain LS for a period of 12 consecutive months. For each such site, any recent 12-month period may be used, provided that the WIM equipment at the site was consistently calibrated over the entire 12-month period.

Depending on the software used for preliminary processing of the weight data, the load spectra provided to TrafLoad for each month may or may not be available by day of the week (DOW). If they are available by DOW, Procedures WA and WB are usually used to produce monthly LS that minimize the effects of DOW variations in load. Otherwise, the monthly LS provided by the input software are used without adjustment.² In both cases, Procedure WC is applied to the monthly LS to produce the monthly adjustment indexes. These procedures are described below.

WA. Preliminary Steps

1. Create an array indicating the number of vehicles for which there are weight observations for each month and DOW. The array consists of 84 elements (12 months x 7 days).
2. Verify that the seasonal LS dataset contains sufficient observations for the calculation of monthly adjustment indices and daily adjustment ratios.

¹ American Society of State Highway and Transportation Officials, *AASHTO Guide for Design of Pavement Structures*, 1993.

² Monthly LS provided by the input software are also used under relatively rare circumstances in which the NCHRP 1-39 software fails to produce the DOW LS adjustment ratios that are required to derive monthly LS from DOW LS.

3. Create an array containing average ESALs per vehicle by month, day of the week, and pavement type (flexible or rigid). This array will contain up to 168 elements (12 months x 7 days x 2 pavement classes), some of which may be empty.

WB. DOW LS Adjustment Ratios

For each seasonal LS dataset that contains a complete set of seven DOW LS for at least one month, a set of DOW LS adjustment ratios, DAR_{Ipd} , is computed:

$$DAR_{Ipd} = \text{Avg}_m \left(\frac{AEPV_{Ipm}}{AEPV_{Ipd}} \right) \quad \text{WB}$$

where

I is a WIM vehicle-classification group;

p is pavement type (flexible or rigid);

m is month;

d is day of the week;

$AEPV_{Ipm}$ is average ESALs per vehicle for classification group I , pavement type p , month m , and day of week d ; and

the average is taken over all months for which a complete set of DOW LS exists. If either the numerator or denominator of any ratio in Equation WB is zero, the ratio is set to one.

For subsequent use, the DAR_{Ipd} are obtained for both flexible and rigid pavement regardless of the type of pavement at the site.

WC. Monthly Adjustment Indexes

For each site, s , for which a seasonal LS dataset exists, and each pavement type, p , a set of monthly adjustment indexes, MAI_{Ispm4} , is developed from data in the seasonal LS dataset. Each set of monthly adjustment indexes is computed:

$$MAI_{Ispm4} = \frac{AEPV_{Ispm}}{AEPV_{Isp4}} \quad \text{WC}$$

where

I is a WIM vehicle-classification group;

s is a site;

p is pavement type;

m is month; and

$AEPV_{Ispm}$ is average ESALs per vehicle for classification group I , site s , pavement type p , and month m .

For convenience, the denominator in Equation WC is set to AEPV for April (Month 4). In the unlikely event that the numerator of Equation WC is zero, MAI_{Ispm4} is set to one.

For future use, the MAI_{Ispm4} are obtained for both flexible and rigid pavement regardless of the type of pavement at the sites.

Similarly, for each user-defined seasonal LS factor group, S , and each pavement type, p , a set of monthly adjustment indexes, MAI_{Ispm4} , is obtained by averaging the corresponding values of MAI_{Ispm4} for all sites, s , in S .

WD. DOW LS Adjustment Ratios for Seasonal LS Factor Groups

For each seasonal LS factor group, S , obtain a set of DOW LS adjustment ratios, DAR_{Ispd} , as a simple average of the DAR_{Ipd} developed in Step WB for sites in S . If the factor group contains no sites for which such adjustment ratios were developed in Step WB, then the DOW LS adjustment ratios are developed from the associated sets of DAR_{Ipd} (if any) identified for the sites, or (if those do not exist) from all DAR_{Ipd} developed in Step WB for any site.

Site-Specific Load Spectra

Site-specific LS for pavement design are developed from user-supplied *current LS datasets* for Level 1 WIM sites. These datasets contain LS developed from WIM data collected over a recent period of up to 12 months. The data should be representative of current weight conditions at the site, and it should have been collected using calibrated WIM equipment. However, it is not necessary that LS be available for every month of the 12-month period. For sites for which *seasonal LS datasets* are provided (for use in Steps WA - WD), the *current* LS dataset may be identical to the seasonal LS dataset, or it may be a different (possibly smaller) dataset that is believed to be more reflective of current conditions.

The processing of the current LS datasets is described in Steps WE - WG.

WE. Deriving Monthly LS from DOW LS

For each vehicle class and axle type, the following procedure is used to develop load spectra for those months that contain site-specific LS data:

- Determine the number of axles by DOW for which there are weight observations.
- Calculate an ESAL per vehicle ratio (R_m) to use in adjusting site-specific axle weight distributions so that they represent average conditions for the month. The ratio is the weighted average of DAR values, with weights equal to the number of axles for each DOW in the month.
- Form axle weight distributions for all DOW in month combined.

The axle weight distributions for each type of axle are then adjusted as follows:

- For a given axle type, convert load spectra to a cumulative distribution.
- Modify axle weight interval boundaries to achieve the desired change in ESALs per vehicle. This is done using the fourth power relationship between axle weight and ESALs. For example, if the R_m is 1/1.4 (implying a 40 percent increase in ESALs per vehicle), then each axle weight interval boundary is multiplied by $1.0878 = 1.4^{1/4}$. In this example, if 50 percent of axles were below 20,000 pounds in the original distribution, then 50 percent of axles would be below 21,755 pounds ($20,000 \times 1.0878$) in the adjusted distribution.
- Using linear interpolation, renormalize the adjusted cumulative distribution to the original axle weight interval boundaries.
- Convert the adjusted cumulative distribution to a frequency distribution.

WF. Months with No Load Spectra Data

For months that do not contain site-specific load spectra data for a vehicle class and axle type, the following steps are carried out:

- Using the results of Step WE, produce an adjusted axle weight distribution for all data months combined. The distribution is a weighted average of the load spectra for individual months, with weights equal to the number of axles in each month.
- Calculate an ESAL per vehicle ratio for each month with no load spectra data that can be used to adjust the axle weight distribution for all data months to represent the axle weight distribution in the month with no data. The ratio is calculated as the weighted average (weighted by the number of axle groups in each month) of MAI for data months divided by the MAI for the no data month.
- Carry out the axle weight distribution adjustment procedure presented in Step WE, using adjusted axle weight distribution for all data months combined and the ESAL per vehicle ratio for each month with no load spectra data.

WG. Axle Groups per Vehicle

Each user-supplied current LS dataset is accompanied by a set of values, $AGPV_{ij}$, giving the expected number of *axle groups per vehicle* at the site to which the current LS dataset corresponds. Each of the $AGPV_{ij}$ in this set represents the expected number of axle groups of type j on vehicles in class i . Each of these values is obtained by dividing the original number of axle groups of Type i on vehicles in Class j (A_{ij}) (*prior* to the application of Steps WA - WF) by the number of vehicles in Class j (V_j).

Truck Weight Road Groups

A *Truck Weight Road Group* (TWRG) is a user-defined set of design lanes. Load spectra and AGPV values are developed, by pavement type, for each TWRG by obtaining an unweighted average of the individual elements of the load spectra and AGPV matrices ($F_{ijk\text{tmp}}$ and $AGPV_{ijt}$) developed for a user-specified set of design lanes for one or more WIM sites. All averages are simple averages, developed on an element-by-element basis.

In addition, a set of statewide load spectra are developed from the TWRG load spectra by applying user-specified weights to obtain weighted averages of the TWRG load spectra on an element-by-element basis. And a set of statewide AGPV values is obtained by applying the same weights to the AGPV values developed for each of the TWRGs.

Outputs for the 2002 Software

For each site corresponding to a current LS dataset, the AGPV matrix produced in Step WG is written to a file to be passed to the 2002 software. Also, for each such site, a complete set of normalized monthly load spectra is written to a separate file to be passed to the 2002 software.

The normalized load spectra that are passed to the 2002 software usually are those produced in Steps WE and WF. The exception occurs only for rare combinations of vehicle class and axle-group type for which there may be statewide values for at least one month, but for which, for a specific site, there are no values for one or more other months. For each such case, substitute values for the site for all such months are developed and then normalized. If substitute values are required, they are developed using one of the following procedures:

- a) A simple average is obtained of the load spectra for the site, vehicle class, and axle-group type that exist for other months and used for the missing months.
- b) A simple average is obtained of any monthly load spectra for the vehicle class and axle-group type that exist for the TWRG to which the site belongs. The resulting load spectrum is used for the site for the specific vehicle class and axle-group type for all months.

- c) A simple average is obtained of all monthly statewide load spectra for the vehicle class and axle-group type. The resulting load spectrum is used for the site for the specific vehicle class and axle-group type for all months.

The first of the above procedures is used whenever possible. Otherwise, the second is used if possible; or the third if neither of the other two procedures would produce LS values for the required combination of vehicle class and axle-group type.

The imputation procedures used in developing the load spectra depend, in part, on the pavement type specified for the site. Hence, the load spectra estimated for a particular site will depend, in part, on whether flexible or rigid pavement will be used at that site.

■ 3.4 Level 2 and 3 WIM Sites

Level 2 and 3 WIM sites are sites for which no site-specific WIM data exist. Level 2 sites are ones that have been assigned to a TWRG. For each of these sites, the load spectra and AGPVs developed for the TWRG are used as default values for the site.

Level 3 sites have not been assigned to a TWRG. For these sites, the statewide load spectra and AGPVs are used as default values.

Glossary

Glossary

This glossary contains definitions of all abbreviations used in more than one procedure in this Procedures Manual and identifies the section or procedure in which the more specialized abbreviations are defined.

A_{ij}	Number of axle groups of type j on vehicles in class i (3.1).
A_{ijk}	Number of axle groups of type j on vehicles in class i that are in load range k (3.1).
AADT	Annual average daily traffic (CQ).
$AADT_{il}$	Annual average daily traffic of class i vehicles in lane l (CA3).
AADTT	Annual average daily truck traffic (CQ).
$AADW_{il}$	Annual average day of the week traffic volume of vehicle class i in lane l (CA1).
$AEPV_{ip}$	Average ESALs per vehicle of class i for pavement type p (3.2).
$AGPV_{ij}$	Average number of axle groups of type j on vehicles in class i (3.1).
CV	Coefficient of variation (2.6).
CV_G	CV contribution due to variance within factor groups used in the $AADT_i$ estimation process (CW).
DAR_{lpd}	DOW LS adjustment ratio (for a given site) for WIM vehicle-classification group l , pavement type p , and DOW d (WA).
DDF	Directional distribution factor (2.4).
DOW	Day of week (CD).
DTR_{IK}	DOW traffic ratio for Type 1 vehicle-classification group I and DOW factor group K (CI).
ESAL	Equivalent single-axle load.
$ESAL_s_p$	Equivalent single-axle loads for pavement type p (3.2).

F_{ijk}	Fraction of axle groups of type j on vehicles in class i that are in load range k (3.1).
FHWA	Federal Highway Administration.
HDF	Hourly distribution factor (by hour and lane) (2.3).
HF_{gh}	Hourly fraction for hour h and TOD factor group g (CJ).
I	Type 1 vehicle-classification group (for classification counting) (CD) or WIM vehicle-classification group (3.2).
J	Seasonal factor group (a group of classification sites) (CH).
K	DOW factor group (a group of classification sites) (CI).
kip	1,000 pounds.
LS	Load spectra (3.0).
LS_{ij}	Load spectrum for vehicle class i and axle-group type j (3.1).
$MADT_i$	Monthly average daily traffic for vehicle class i (CB1).
$MADW_{il}$	Monthly average day of the week volume for vehicle class i and lane l (CA1).
$MAF_{ISpmm'}$	Monthly LS adjustment factor for producing a set of approximate month m LS from month m' LS for WIM vehicle-classification group I , seasonal LS factor group S , and pavement type p (WD).
MDF_i	Monthly distribution factor for vehicle class i for Level 1A and 1B classification sites (CB2 and CG).
$MDWTR_{lq}$	Combined monthly/DOW traffic ratio for Type 1 vehicle-classification group I and direction q (CD).
MTR_{IJ}	Monthly traffic ratio for Type 1 vehicle-classification group I and seasonal factor group J (CH) ($MTR_{IJ} = MDF_{IJ}$).
S	Seasonal LS factor group (a group of WIM sites) (WD).
TOD	Time of day (CJ).
TTC	Truck traffic classification group (CR).
$TTDF_{il}$	Truck traffic distribution factor for vehicle class i and lane l (CO).
TWRG	Truck weight road group (end of 3.3).

V_i Number of vehicles in class i (3.1).

WIM Weigh in motion.

Levels of Classification Site:

1A Site for which AVC data are available for periods of at least one week for at least 12 consecutive months.

1B AVC site that is reasonably near a Level 1A site on the same road.

2A Site for which an AVC count is available for a period of at least 48 hours.

2B Site for which a manual classification count for a minimum of six week-day hours is available.

3A Any other site for which volume counts are available and that is on the same road as a Level 1 or 2 site.

3B Any other volume-count site.

Levels of WIM Site:

1 Site for which site-specific WIM data are available.

2 Non-Level 1 WIM sites that have been assigned to a TWRG.

3 All other WIM sites.