# NCHRP

## REPORT 538

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

# Traffic Data Collection, Analysis, and Forecasting for Mechanistic Pavement Design

TRANSPORTATION RESEARCH BOARD
*OF THE NATIONAL ACADEMIES*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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# Traffic Data Collection, Analysis, and Forecasting for Mechanistic Pavement Design


**CAMBRIDGE SYSTEMATICS, INC.**
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**WASHINGTON STATE TRANSPORTATION CENTER**
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**CHAPARRAL SYSTEMS CORPORATION**
Santa Fe, NM


SUBJECT AREAS
Planning and Administration • Pavement Design, Management, and Performance


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The “TrafLoad” software developed as part of NCHRP Project 1-39 was implemented by Mr. Nate Clark, Dr. Dmitry Gurenich, and Mr. Ronald Powell of Cambridge Systematics, Inc. (CS) and Dr. Joe Wilkinson of Chaparral Systems, with the assistance of Ms. Cindy Cornell-Martinez of Chaparral. The user’s manual for the software (Part 3 of this report) was prepared by Ms. Frances Harrison of CS with the assistance of Mr. Anant Pradhan of CS. Specifications for the software (Part 4 of this report) were prepared by the Principal Investigator, Dr. Herbert Weinblatt of CS, with the assistance of Dr. Harry Cohen. Parts 1 and 2 of the report were prepared primarily by Dr. Weinblatt and Mr. Mark Hallenbeck of the Washington State Transportation Center (TRAC).

# FOREWORD

*By Amir N. Hanna*
*Senior Program Officer*
*Transportation Research Board*

This report includes guidelines for collecting traffic data to be used in pavement design and software for analyzing traffic data and producing traffic data inputs required for mechanistic pavement analysis and design. The software—designated TrafLoad—is available to users online (http://trb.org/news/blurb_detail.asp?id=4403). The report also describes the actions required at both the state and national level to promote successful implementation of the software. The report is a useful resource for state personnel and others involved in planning and designing highway pavements.

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Traffic information is one of the key data elements required for the design and analysis of pavement structures. In the procedure used in the 1993 AASHTO *Guide for Design of Pavement Structures*, a mixed traffic stream of different axle loads and axle configurations is converted into a design traffic number by converting each expected axle load into an equivalent number of 18-kip single-axle loads, known as equivalent single-axle loads (ESALs). Equivalency factors are used to determine the number of ESALs for each axle load and axle configuration. These factors are based on the present serviceability index concept and depend on the pavement type and structure. Studies have shown that these factors also are influenced by pavement condition, distress type, failure mode, and other parameters.

A more direct and rational approach to the analysis and design of pavement structures involves procedures that use mechanistic-empirical principles to estimate the effects of actual traffic on pavement response and distress. This approach has been used to develop a guide for the mechanistic-empirical design of new and rehabilitated pavement structures as part of NCHRP Project 1-37A (currently available on-line at http://www.trb.org/mepdg/). Because of the constraints on resources available in state and local highway agencies for traffic data collection, the guide allows for various levels of traffic data collection and analysis. The mechanistic-based distress prediction models used in this guide require specific data for each axle type and axle-load group. Because these traffic data inputs differ from those currently used in pavement design and analysis, there was an apparent need for research to provide clear information on traffic data and forecasting and to provide guidance on selection and operation of the equipment needed for collecting these data. NCHRP Project 1-39 was conducted to address this need.

Under NCHRP Project 1-39, "Traffic Data Collection, Analysis, and Forecasting for Mechanistic Pavement Design," Cambridge Systematics, Inc., was assigned the objectives of (1) developing guidelines for collecting and forecasting traffic data to formulate load spectra for use in procedures proposed in the guide for mechanistic-empirical design and (2) providing guidance on selecting, installing, and operating traffic data-collection equipment and handling traffic data. This report is concerned with the first objective; the latter objective was addressed in detail in an earlier agency report—published as *NCHRP Report 509: Equipment for Traffic Load Data*.

To accomplish the first objective, the researchers (1) prepared guidelines for collecting traffic data to be used in pavement design and (2) developed software—designated TrafLoad—for analyzing traffic data and producing the traffic data inputs required for the mechanic-empirical design. The researchers also developed the following information:

1. Results from analysis of the effect of the length of the data-collection period on the accuracy of pavement damage factors developed from short-duration weigh-in-motion data collection.
2. A discussion of three technical issues relating to the design of software for analyzing traffic: traffic ratios versus traffic factors, partial-day classification counts and truck traffic distribution factors, and simple averaging versus weighted averaging of traffic data.
3. A procedures manual documenting the algorithms used in the software.
4. A software user manual.
5. Recommendations for software improvements that could be made at a later time.
6. A discussion of the actions required, at both the state and national level, to promote a successful implementation of the TrafLoad software.

In addition, the researchers discussed procedures for forecasting traffic volumes and a procedure for estimating coefficients of variation for estimates of average annual daily traffic by vehicle class. TrafLoad—the software developed in this project—and related user and procedures manuals are available online (http://trb.org/news/blurb_detail.asp?id=4403).

The information contained in this report should be of interest to those involved in the planning and design of highway pavements. It will be particularly useful to agencies contemplating collection of traffic data for use in conjunction with the guide for the mechanistic-empirical design of new and rehabilitated pavement structures.

# Contents

*Part 1*

# Traffic Data Collection, Analysis, and Forecasting for Mechanistic Pavement Design

# 1.0 Introduction

The AASHTO Joint Technical Committee on Pavements has undertaken an effort to develop an improved guide for the design of pavement. This effort, undertaken under NCHRP Project 1-37A, *Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures*[1] (the "Pavement Design Guide"), will provide engineers with practical and realistic pavement design procedures and software that use existing mechanistic-empirical principles. The mechanistic-based distress prediction models used in the Pavement Design Guide will require the input of specific data for each axle type and axle-load group.

The goal of NCHRP Project 1-39 was to develop procedures and software for collecting and processing traffic data required by the Pavement Design Guide procedures. In addressing that goal, the Project 1-39 Team has produced the following:

- Guidelines for collecting traffic data to be used in pavement design. These guidelines are presented in Part 2 of this report.
- Software for analyzing traffic data and producing the traffic data inputs required by the Pavement Design Guide software (the "Design Guide software"). The software developed under Project 1-39 has been named "TrafLoad." TrafLoad is contained online at http://trb.org/news/blurb_detail.asp?id=4403. The use of TrafLoad is described in a user's manual, and algorithms used by TrafLoad are documented.
- A guide for choosing equipment for collecting classification counts and weigh-in-motion (WIM) data. This guide has been published as *NCHRP Report 509*.[2]

Recommended steps to be taken in the course of implementing the data-collection procedures are presented in Chapter 2.0 of Part 1. The following chapter presents the results of analyses of the effect of the length of the data-collection period on the accuracy of pavement damage factors developed from short-duration WIM data collection.

The fourth chapter of Part 1 discusses three technical issues relating to the design of software for analyzing traffic and presents recommended solutions that have been incorporated into TrafLoad. In Section 4.1, it is recommended that short-duration traffic counts be converted to estimates of annual average daily traffic (AADT) by dividing by "traffic ratios" rather than by multiplying by "traffic factors." In Section 4.2, it is recommended that, if use is made of partial-day classification counts, "truck traffic distribution factors" (TTDFs) not be used for converting these counts to estimates of 24-hour traffic volume by vehicle class; instead, it is recommended that "hourly traffic ratios" (or "hourly fractions") be used. Section 4.3 discusses some issues relating to the use of simple versus weighted averaging of traffic data.

[1] http://www.2002designguide.com/

[2] Hallenbeck, Mark, and Weinblatt, Herbert, *NCHRP Report 509: Equipment for Collecting Traffic Load Data*, Transportation Research Board of the National Academies, Washington, D.C., 2004.

The final chapter of Part 1 presents recommendations for potential improvements to TrafLoad to be made in the future as well as recommended areas for future research.

Part 1 also contains two appendixes. Appendix A discusses procedures for forecasting traffic volumes, including several relatively complex alternatives to the procedure that is recommended in Section 3.6 of Part 2. Appendix B presents a procedure that had been proposed for estimating coefficients of variation (CVs) for estimates of AADT by vehicle class.[3]

[3] The original design for the Design Guide software would have required users to provide these CVs. However, the final version of this software makes no use of these CVs.

# 2.0 Implementation Needs

Successful implementation of the TrafLoad software by state highway agencies will require several actions at both the state and the national level. The most important of these actions is an increased level of communication and cooperation between the traffic data-collection staff and the pavement design staff. Successful communication between these groups hinges, in part, upon better knowledge between both groups as to what traffic data are needed for pavement design, how variations in traffic loads affect pavement design, and how to account for those variations. Consequently, the implementation requirements at both the state and the national level involve the following:

- Development and execution of training programs to improve the knowledge of both groups, including both specific training in the TrafLoad software and more general instruction as to how traffic loads affect pavement design; and
- Removal of institutional barriers that limit the interaction between pavement design and traffic data-collection and analysis staff.

## 2.1 National-Level Implementation Actions

Three key actions are required at the national level:

- Development of training material,
- Financial support of training programs, and
- Agency support of the institutional changes required at the state level that encourage greater interaction between the pavement design and traffic data-collection groups in support of the implementation of the Pavement Design Guide procedures.

### Development of Training Material

Because of the national scope of the Pavement Design Guide's implementation effort, it is most appropriate for training material to be developed at the national level. The training material should cover the following topics:

- Variations in traffic loads with time and location,
- The effect of those variations on pavement design,

- The effect of those variations on traffic data-collection procedures,
- The analytical steps required to convert the raw data into inputs for the pavement design process,
- Instruction in the operation of the TrafLoad software, and
- The type and timing of interactions between the pavement design and traffic data-collection groups that are required to produce cost-effective traffic data-collection programs.

The training program should teach pavement design engineers about the need for traffic data and difficulties in its collection and analysis. And it should teach the traffic data-collection staff about how traffic data (and particularly variations in traffic data) affect pavement design.

### Financial Support for Training

National financial support for training is required in two areas. The first area is the creation of the primary training material described above. The second area is assistance in actually teaching the course material. This second level of federal funding includes both subsidizing the cost to state agencies of providing the courses and funding multi-state workshops that allow state personnel to learn from each other. Multi-state training workshops provide an excellent mechanism for exploring potential institutional and organizational changes that break down the communication barriers that exist between state agency personnel working in different offices.

### Support for State Agency Organizational/Institutional Change

Finally, the Federal Highway Administration (FHWA) should actively support and encourage the institutional changes that are needed to incorporate accurate traffic load estimates in the pavement-design procedures. Changes in state highway agency culture are difficult to achieve without "top-down" direction. The FHWA is the appropriate agency for providing this direction and for encouraging top-down direction within the highway agency itself.

## 2.2 State-Level Implementation Actions

The implementation tasks needed at the state highway agency level relate to the following:

- Training personnel,
- Changing internal work processes to institutionalize the communication needed to ensure the collection and use of accurate traffic load data, and
- Refining the current traffic data-collection and summarization process to improve the quality of the load estimates available for use in the Pavement Design software.

## Training

State highway agency staff will require training in the collection, summarization, and entry of traffic data into the TrafLoad software. The project team recommends the cross training of pavement design and traffic data-collection and analysis personnel. Members of both groups need to understand how traffic load and variations in that load affect pavement design and how traffic load varies with time and location. Only when both groups understand this interaction can cost-effective decisions be made as to how much traffic data to collect, where and when to collect the data, and how the data should be summarized and processed by the TrafLoad software for use in the Pavement Design Guide software.

## Institutional Changes to Improve Communication

Traditionally, interaction between the pavement design group and the traffic data-collection and analysis group is limited to the responses of one group to routine requests issued by the other. This lack of interaction is exacerbated by the fact that these groups are often separated physically (working in different buildings or on different floors of the same building) and report within different branches of the organization (design/construction versus planning).

To implement improvements in traffic-load data needed for successful use of the Pavement Design Guide, frequent and effective communication between the two groups is required. State highway agencies should adopt procedures that allow the following communications to take place between the pavement design and traffic data-collection groups:

- The pavement design group must communicate to the traffic data-collection group what and where data are needed for design purposes. This communication must take place in a timeframe that allows the traffic data-collection group to collect any required site-specific data cost-effectively.

- Not all traffic data that could be used by the Pavement Design Guide can be collected cost-effectively. Hence, the two groups must consider the resources available for traffic data collection and agree to compromises on when, where, and how much data are collected for pavement design purposes. (These compromises might include the use of design funds to supplement the routine data-collection budget.)

- Procedures must be developed that allow either group to communicate data quality concerns to the other and receive feedback about how those concerns are addressed.

- Both groups need to be involved in developing the procedures that allow a smooth flow of traffic data into the TrafLoad software and a smooth flow of data from that software into the Pavement Design Guide software.

- Annual reviews should be conducted of the traffic data being used for pavement design and of the processes used for collecting and summarizing the data and loading it into the TrafLoad and 2002 Pavement Design Guide software. These reviews should identify limitations in the processes (e.g., lack of data on specific highways or in specific parts of the state), so that weaknesses are identified and eliminated over time.

Many of these communications will require changes in the way that procedures are performed. Consequently, it will be necessary for upper-level management of the state highway agency to provide guidance and institutional support for changing current procedures to support these efforts.

Improvements in communication should also include other groups within the state government. For example, forecasting of future truck volumes and/or loads can be improved if the groups charged with support of statewide economic development are consulted about expected changes in statewide economic activity that might affect truck volumes. (Are there expected rail-line abandonments that would add substantial truck traffic to specific roads? Are there new factories being built in a specific area that will increase truck traffic?) Similarly, highway maintenance workers and others often can provide insight into the commodities being carried on specific roads and the presence of heavily loaded or overloaded trucks on those roads. Thus, implementation requires a thorough review of the many opportunities for improved communication.

## Changes in Collection and Summarization of Data

While the 2001 edition of the FHWA's *Traffic Monitoring Guide* (TMG) lists steps needed to supply the traffic load data needed for pavement design, most states are still in the early stages of implementing the procedures described in the TMG and in the NCHRP 1-39 reports. Support for continued improvements in the data-collection process will be needed. In particular, a careful review of the data-collection procedures described in Part 2 should be performed, and required changes to the state's current data-collection program should be identified. Improving the process will result in improving the quality of the truck volume and axle-load values used as input to the design process and will affect the volume of data collected, the sites that are monitored, and the handling of the data that are collected.

The refinement process should be an ongoing effort. Much remains to be learned about truck volume and weight, and data-collection resources are not sufficient to fill all the knowledge gaps quickly. Therefore, states should expect their ongoing review of truck volumes and weights, combined with their need for pavement designs, to result in periodic shifts in data-collection resources as priorities change, as new needs become apparent, and as weaknesses in the current system are identified and eliminated. These refinements will be most effectively performed if they involve significant input from the pavement design community. Pavement designers should indicate where their needs are greatest and the relative priorities that they place on the various components of the data-collection process.

# 3.0 The Effect of Length of Collection Period for WIM Data

Several analyses were performed to estimate the accuracy of estimates of annual pavement loads that are developed from short periods of WIM data collection. The data-collection periods consisted of either 7 consecutive days or 2 consecutive weekdays. The analyses of 7-day periods were conducted as part of NCHRP Project 139, while those of 48-hour periods were conducted under a recently completed project performed for FHWA.[1] This chapter presents the results of both sets of analyses.

The analyses require the use of unidimensional measures of pavement load. For this purpose, the pavement load created by any given set of axle loads was measured in terms of 18,000-pound equivalent single-axle loads (ESALs) for flexible pavement, and the analyses focused on the resulting values of average ESALs per vehicle (AEPV) and annual AEPV (AAEPV).

The methodology used for the analyses is described in the first section of this chapter, and the results of the analyses are described in the second section.

## 3.1 Methodology

All analyses were conducted using WIM data collected in 2000 by the state of California's traffic monitoring program and stored by the University of California's Pavement Research Center. The analyses used data for 55 sites for which there were at least 8 months of available data that met the checks on consistency of calibration.[2] Estimates of AAEPV were developed for each of the 55 sites using a procedure that attempts to minimize the effects of missing days of the week and missing months.[3] For each site, separate estimates of AAEPV were developed for each of three groups of FHWA vehicle classes (VCs): Class 5; Classes 6 and 7; and Classes 8–13.

The effectiveness of using short-duration WIM data to estimate annual conditions was evaluated by comparing the estimates of AAEPV derived from "annual" data with estimates derived from data collected over a 48-hour or 7-day period. For each of the 55 sites, estimates

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[1] Cambridge Systematics, Inc., *Accuracy of Traffic Load Monitoring and Projections,* Volume II: The Accuracy of ESALs Estimates, February 2003.

[2] Ibid., Chapter 2.0.

[3] Ibid., Appendix.

of AAEPV were obtained using data from pairs of consecutive weekdays (or from periods of 7 consecutive days) that exclude federal holidays, Christmas Eve, and the days before and after Thanksgiving.

The use of 48-hour periods was analyzed using all possible pairs of weekdays, with a maximum of four pairs per week. The use of 7-day periods was analyzed using all periods of 7 consecutive days for which data were available that did not include any of the above holidays. For most sites, the database contains data for a maximum of 12 weeks (1 week per month). Hence, with a few exceptions, data were available for a maximum of 48 estimates for each site and VC group when 48-hour data were used and a maximum of 12 estimates when 7-day data were used.

Each of the resulting estimates was compared to the "true" value of the AAEPV for the site, producing one estimate of the resulting error. The absolute values of the errors were obtained and were converted to percentages and averaged, producing values of mean absolute percent error (MAPE). Since MAPE uses absolute percent errors (rather than signed values of percent errors), large positive errors are not offset by large negative errors. Separate statistics were obtained for each of three VC groups (5, 6 and 7, and 8–13).

One complete set of AAEPV estimates was developed using data for each 48-hour period without adjustment to produce estimates of AAEPV for each VC group; a second set was similarly developed using data for each 7-day period.

In addition, several sets of AAEPV estimates were produced using ESAL ratios to "factor" the data. For 48-hour data, this factoring process involved three major steps performed separately for each VC group distinguished:

1. For each of the 55 sites for which good estimates of AAEPV have been obtained, a set of seven day-of-week (DOW) ESAL ratios is developed, as well as a set of 12 or fewer monthly ESAL ratios, as described subsequently.

2. For any site of interest, a second set of DOW and monthly ESAL ratios is obtained as an unweighted average of the Step 1 ESAL ratios obtained at some or all of the other 54 sites. In this step, Monday ratios are obtained as averages of Monday ratios from Step 1, Tuesday ratios as averages of Tuesday ratios from Step 1, etc.

3. For a particular site, all raw (i.e., unfactored) AEPV values for pairs of consecutive weekdays are converted to factored estimates by

    a) Using the raw data to obtain separate AEPV estimates by DOW and, if necessary, by month;

    b) Dividing each AEPV estimate by the corresponding monthly and DOW ESAL ratios obtained for the site in Step 2; and

    c) Taking a weighted average of the factored AEPV estimates produced in Step 3(b).

The weights used in Step 3(c) are the sums of the monthly average day-of-week (MADW) volumes for the site and VC group.

For each site, VC group, and day of the week, the DOW ESAL ratio developed in Step 1 is obtained as follows:

- For each month for which a MADW ESAL value exists, divide this value by the corresponding value of monthly AEPV (MAEPV) and
- Average the resulting ratios.

Similarly, for each site, VC group, and month for which MAEPV exist, a monthly ESAL ratio is obtained in Step 1 by dividing MAEPV by AAEPV.

For 7-day data, DOW factoring is unnecessary. Accordingly, for 7-day data, the above factoring process was used without any DOW factoring.

The results reported here were developed using "statewide factoring" and simple (as opposed to weighted) averages. For this purpose, simple averages are produced in Step 2 using ratios obtained from all sites except the site from which the data to be factored were obtained.[4]

## ■ 3.2 Results

The results of the above analyses are summarized in Table 3.1. Although the errors for VCs 6 and 7 are appreciably larger than they are for the other two VC groups, the results are otherwise similar for the three VC groups.

The use of 48 hours of unfactored data produces moderate MAPEs in the estimates of AAEPV, ranging from 7.3 percent for VCs 8–13 to 13.0 percent for VCs 6 and 7. The table indicates that moderate reductions can be obtained by factoring and/or extending the data collection period to 7 days. For combinations (VCs 8–13), factoring produces a slightly larger improvement than does extending the period to 7 days. However, for single-unit trucks (SUTs) (VC 5 and VCs 6 and 7), extending the collection period produces an appreciably greater improvement than does factoring. The use of 7 days of factored data produces MAPEs that range from 5.5 percent (for VC 5) to 9.9 percent (for VCs 6 and 7).

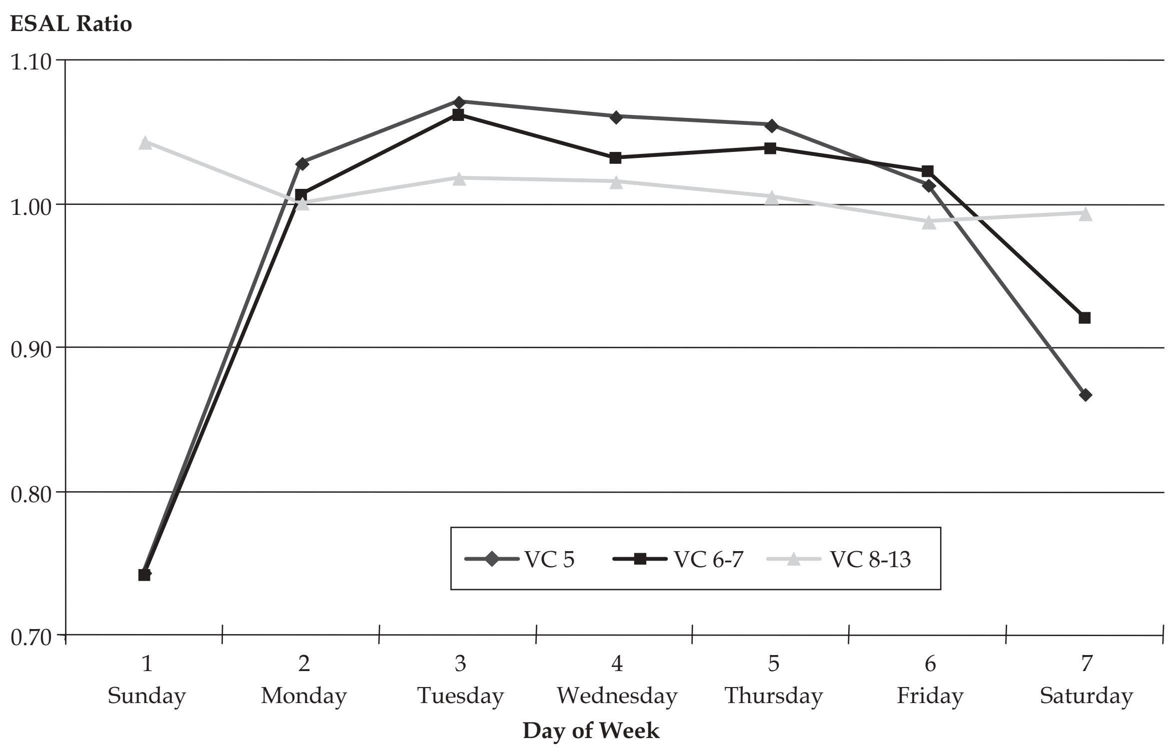
The switch from 48 hours to 7 days produces greater improvements in the estimates for SUTs than in the estimates for combinations, particularly when unfactored data are used. This difference is due to differences in the extent of DOW variation in AEPV for SUTs and combinations. The daily ESAL ratios shown in Figure 3.1 reflect statewide average values of AEPV for each day of the week that have been normalized by dividing by annual AEPV. As can be seen

[4] The FHWA report also presents results for several variants of the procedure. The use of weighted averages produced very slight reductions in the MAPEs. The use of several factor groups (instead of statewide factoring) did not produce any consistent improvement, but the factor groups used in the tests were created for another purpose and not specifically designed to be used as factor groups. It is likely that more carefully designed factor groups could produce small reductions in the MAPEs.

## Table 3.1 Errors Produced by Using Short-Duration WIM Data to Estimate Average ESALs per Vehicle

| | Mean Absolute Percentage Error | | |
|---|---|---|---|
| **Vehicle Classes** | **5** | **6 and 7** | **8–13** |
| Unfactored Data | | | |
| 48 hours | 8.1% | 13.0% | 7.3% |
| 7 days | 5.7% | 10.1% | 6.6% |
| Factored Data | | | |
| 48 hours | 7.0% | 12.7% | 6.4% |
| 7 days | 5.5% | 9.9% | 5.7% |

## Figure 3.1 Daily ESAL Ratios




Source: Cambridge Systematics, Inc., *Accuracy of Traffic Load Monitoring and Projections*, Volume II: The Accuracy of ESALs Estimates, prepared for FHWA, February 2003, Figure 5.1.

from the figure, AEPV for SUTs drops sharply on weekends, but AEPV for combinations varies only slightly by DOW, reaching its highest level on Sunday.

The effectiveness of factoring depends on the consistency of the DOW and month-of-year patterns in AEPV. When using 48-hour data, factoring produces a 1.1-percent reduction in MAPE for VC 5 and smaller reductions for the other VC groups. However, when using 7-day data, factoring produces only a 0.2-percent reduction in MAPE for VC 5. These results imply that there is a substantial degree of similarity in the DOW patterns of AEPV for VC 5 for different sites but much less similarity in the month-of-year patterns.

On the other hand, for VCs 8–13, factoring produces the same 0.9-percent reductions in MAPE when using either 48 hours of data or 7 days of data. This result implies that, for VCs 8–13, there is a substantial degree of similarity in the month-of-year patterns in AEPV at different sites but relatively little similarity in the DOW patterns.

For VCs 6 and 7, factoring produces relatively small (0.2- to 0.3-percent) error reductions, implying that there is relatively little site-to-site consistency in the DOW and month-of-year patterns in AEPV for these vehicles. Indeed, for VCs 6 and 7, AEPV at most sites is likely to vary with the percentages of these vehicles contributed by construction-related dump trucks. These percentages, in turn, vary with the level and type of activity at nearby construction sites. Since there is little relationship between the levels of activity at different construction sites, there is likely to be little correlation between the DOW and month-of-year AEPV patterns at different WIM sites; therefore, for VCs 6 and 7, factoring produces relatively small reductions in the error.

# 4.0 Three Technical Issues

This chapter addresses three technical issues that arise in the development of software, such as TrafLoad, that is designed for analyzing traffic data.

Short-duration counts of total traffic (or traffic by VC) can be converted into estimates of AADT (or AADT by VC) by multiplying the counts by appropriate "factors" or by dividing them by "traffic ratios." Section 4.1 discusses these two options and explains why the use of traffic ratios is likely to produce slightly better estimates of AADT. For this reason, TrafLoad uses monthly and day-of-week traffic ratios (rather than factors) for converting short-duration classification counts into estimates of AADT by VC.

TrafLoad also uses "hourly traffic ratios" (rather than "truck traffic distribution factors," or TTDFs) for converting partial-day classification counts into estimates of 24-hour traffic volumes by VC. Section 4.2 explains why TTDFs produce upwardly biased estimates of truck volumes at most urban sites.

Finally, there is the issue of how to average data collected at several sites that have been assigned to a specific group (such as a "factor group"). Averaging can be performed by taking simple averages of values (e.g., traffic ratios) obtained at each site in the group; alternatively, weighted averages can be obtained, most frequently using traffic volumes at the sites as weights. With two exceptions, TrafLoad uses simple averages. Section 4.3 summarizes the use of simple and weighted averages by TrafLoad, discusses the two cases in which weighted averages are used, and explains why simple averages (rather than weighted averages) are used for developing load spectra for "Truck Weight Road Groups."

## ■ 4.1 Traffic Ratios versus Traffic Factors

A 24-hour traffic count can be converted to an estimate of annual average daily traffic (AADT) by multiplying the count by an appropriate factor or by dividing it by an appropriate traffic ratio. The two processes are both commonly referred to as "factoring," and there are several variants of both processes. One common variant (used by TrafLoad for counts from Level 2 classification sites) uses a day-of-week (DOW) traffic ratio (or factor) to convert the count to an estimate of monthly average daily traffic (MADT) and a monthly (or seasonal) traffic ratio (or factor) to convert the MADT to an estimate of AADT.[1] When estimating AADT by VC, the counts used are classification counts, and separate traffic ratios

[1] Another variant (used by TrafLoad for counts from Level 1B classification sites) uses a combined monthly and DOW traffic ratio (or factor) to convert the count directly to an estimate of AADT.

(or factors) should be used for major groups of VCs (e.g., personal-use vehicles, single-unit trucks, and combinations).[2]

Factoring procedures that use traffic ratios produce AADT estimates that generally differ only slightly from those produced by the corresponding procedures that use traffic factors. However, to the extent that the estimates differ, those produced using traffic ratios are likely to be the better ones. For this reason, TrafLoad uses traffic ratios rather than traffic factors.

This section presents information about why traffic ratios produced very slightly better estimates than traffic factors. To simplify the presentation, the research team focuses on the use of monthly traffic ratios and monthly traffic factors for converting MADT estimates to AADT estimates, and the research team focuses on estimates of total traffic volume. The cases of developing estimates for individual VCs, or for VC groups, are completely analogous.

## Traffic Factors

For any month of the year, $m$, a monthly factor, $MF_m$, can be developed using data from a single continuous-count site, $i$:

$$MF_m = \frac{AADT_i}{MADT_{mi}} \qquad (4.1)$$

Alternatively, $MF_m$ can be developed using data from a specified group of continuous-count sites:

$$MF_m = \underset{i}{Avg}\left(\frac{AADT_i}{MADT_{mi}}\right) \qquad (4.2)$$

where the average is taken over all sites, $i$, in the group.

To convert an estimate of MADT for any short-duration count site, $i'$, to an estimate of AADT, the former estimate, $MADT_{mi'}$, is multiplied by the appropriate monthly factor:

$$AADT_{i'} = MF_m = MADT_{mi'} \qquad (4.3)$$

## Traffic Ratios

The process for developing and using traffic ratios is similar to that of developing and using traffic factors. For any month of the year, $m$, a monthly traffic ratio, $MTR_m$, can be developed using data from a single continuous-count site, $i$:

$$MTR_m = \frac{MADT_{mi}}{AADT_i} \qquad (4.4)$$

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[2] The formation of VC groups to be used for factoring classification counts is discussed in Part 2, Section 3.3.

Alternatively, $MTR_m$ can be developed using data from a specified group of continuous-count sites:

$$MTR_m = \underset{i}{\mathrm{Avg}}\left(\frac{MADT_{mi}}{AADT_i}\right) \quad (4.5)$$

where the average is taken over all sites, $i$, in the group.

To convert an estimate of MADT for any short-duration count site, $i'$, to an estimate of AADT, the former estimate, $MADT_{mi'}$, is divided by the appropriate monthly traffic ratio:

$$AADT_{i'} = \frac{MADT_{mi'}}{MTR_m} \quad (4.6)$$

## Comparing the Two Processes

A comparison of Equations 4.3 and 4.6 indicates that the two processes will produce identical estimates of $AADT_{i'}$ whenever

$$MF_m = \frac{1}{MTR_m} \quad (4.7)$$

If the factors and traffic ratios are derived using data from a single continuous-count site (i.e., if they are derived using Equations 4.1 and 4.4), Equation 4.7 always holds. However, if they are derived using data from a group of continuous sites, Equation 4.7 generally does not hold. When using data from a group of sites, one actually gets

$$MF_m \geq \frac{1}{MTR_m} \quad (4.8)$$

or

$$\underset{i}{\mathrm{Avg}}\left(\frac{AADT_i}{MADT_{mi}}\right) \geq \underset{i}{\mathrm{Avg}}\left(\frac{MADT_{mi}}{AADT_i}\right) \quad (4.9)$$

with equality holding only for months for which the ratios $AADT_i/MADT_{mi}$ are the same for all continuous-count sites in the group.

To shed light on this inequality, consider a pair of sites, both of which have the same value of AADT, say 10,000. Assume that, for month $m$, the values of the MADT are different, say 9,000 and 11,000. The individual MTRs for these sites are 0.9 and 1.1, and the average MTR for this group of sites is 1.0. The individual MFs for these sites are 1.11 and 0.91, and the average MF is 1.01. Hence, when using short-duration counts for this month for sites in this group, the AADT estimates produced using MFs will be about 1 percent higher than those produced using MTRs. The information presented also suggests that a "neutral value" of 1.0 for the traffic ratio or factor is likely to be slightly preferable to the actual value of 1.01 for the MF.

It is useful to view the averaging process used in the development of traffic ratios and factors as attempts to determine the extent to which these quantities should differ from the neutral value of 1.0. The averaging process used for deriving the MF applies extra weight to differences from 1.0 for any site for which these differences are positive (producing, in the above example, the value of 1.0 + 0.11 = 1.11 for Site 1), with this weight increasing nonlinearly as these differences grow. Similarly, the process applies reduced weight to differences from 1.0 for any site for which the differences are negative (producing the value of 1.0 – 0.09 = 0.91 for Site 2). From this perspective, the averaging process used for deriving traffic factors produces a (generally small) upward bias in the values produced for these factors. This upward bias is a mildly undesirable characteristic of traffic factors produced using Equation 4.2.

The bias that exists in traffic factors does not exist in the development of traffic ratios. Thus, in the above example, the MTRs for the two sites are 1.0 – 0.1 = 0.9 and 1.0 + 0.1 = 1.1, producing an average of 1.0 for this group of two sites. The research team concludes that traffic ratios are likely to work better than traffic factors. For this reason, all factoring performed by TrafLoad is performed using traffic ratios.

## ■ 4.2 Partial-Day Classification Counts and Truck Traffic Distribution Factors

In order to classify vehicles reliably on the basis of axle-spacing criteria, automatic vehicle classifiers must be located where vehicles are neither accelerating nor decelerating and where the spacing between vehicles is sufficient to allow consecutive vehicles to be readily distinguished. Because these conditions are difficult to meet in urban areas, urban classification counts frequently are collected manually. (Alternatively, classification on urban streets and roads may be limited to length classification.) Manual classification counts are usually collected only during daylight hours, usually for a period of 6 to 12 consecutive hours.

The first step in using the resulting partial-day classification counts is to convert each of these counts to estimates of volume by VC for the day in which the count was collected. For this purpose, TrafLoad uses a time-of-day factoring procedure that uses hourly traffic ratios (or, as they are called in Part 2, "hourly fractions") that are analogous to the monthly and day-of-week traffic ratios used by other TrafLoad factoring procedures.[3] This factoring procedure was chosen over the more commonly used truck traffic distribution factor (TTDF) procedure because the latter procedure produces upward biases in truck volume estimates for sites at which most truck traffic is "business-day" truck traffic—a characteristic of most urban sites. This bias is discussed below.

The TTDF procedure uses a partial-day classification count as the basis for distributing a machine count of total daily traffic among VCs. The procedure implicitly assumes that this distribution is approximately the same during the daytime hours when manual counting is performed as it is during the remainder of the day. However, this assumption does not hold for most urban sites. At these sites, most truck traffic occurs on weekdays between 6:00 a.m. and 6:00 p.m. Figure 4.1a shows how weekday truck and automobile volumes are distributed over a 24-hour day on a typical urban street; and Figure 4.1b shows how the percent trucks (i.e., the percentage of vehicles that are in FHWA Classes 4–13) varies by hour of day.

[3] See Part 2, Section 3.4.

**Figure 4.1a Typical Time-of-Day Patterns for Urban Sites at which Most Trucks are Business Day Trucks**

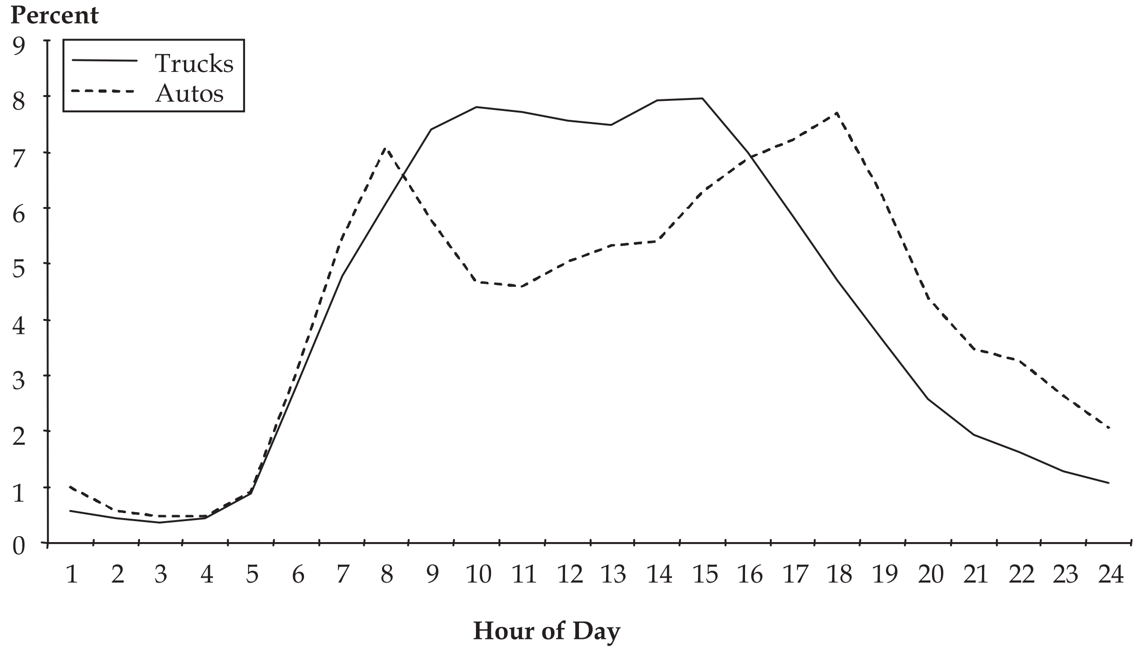
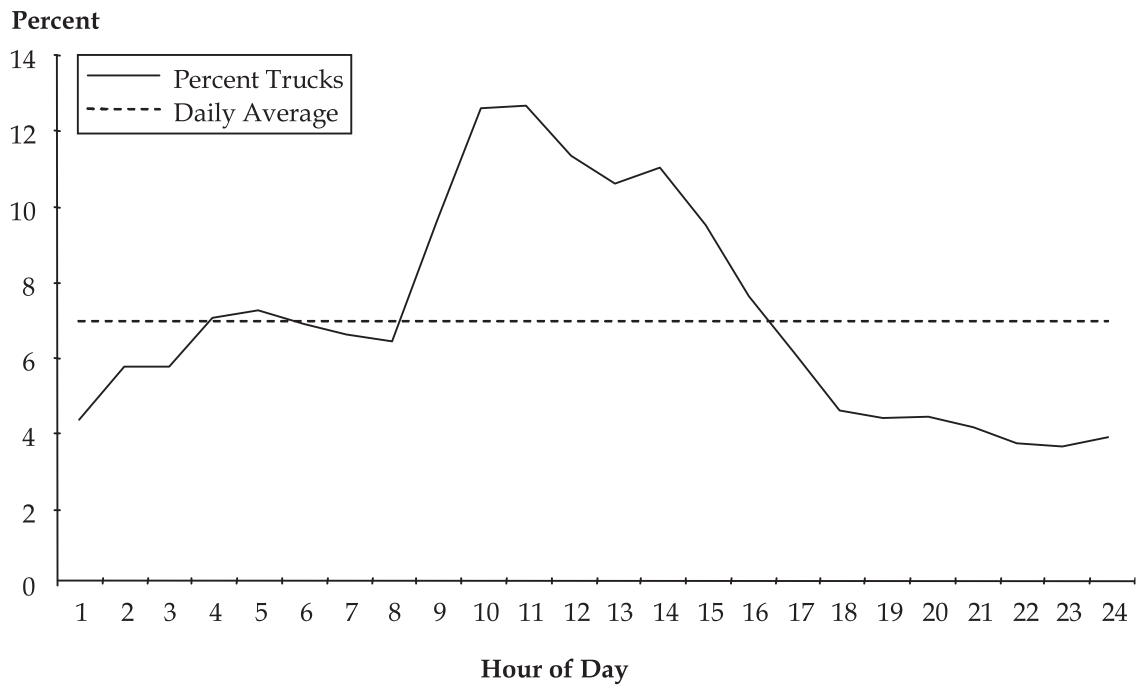



**Figure 4.1b Percent Trucks by Hour of Day**




Derived from data for urban other principal arterials (Functional System 14) in Mark Hallenbeck et al., *Vehicle Volume Distributions by Classification,* Chaparral Systems Corporation and Washington State Transportation Center, June 1997, for FHWA, FHWA-PL-97-025, pp. 79-80.

TTDFs derived from counts collected during periods when truck percentages are high (particularly between 9:00 a.m. and 3:00 p.m.) and excluding periods when these percentages are low (particularly after 5:00 p.m.) will produce overestimates of daily truck traffic. Table 4.1 shows how the choice of a time period for collecting partial-day classification counts affects the resulting estimates of the overall percentage of trucks. The table shows the expected value of the estimated percent trucks that will be obtained if classification counts are allocated for various daytime periods. All periods shown result in upwardly biased estimates. The smallest upward bias shown in the table (5 percent) occurs for counts taken between noon and 6:00 p.m.; the largest (44 percent) occurs for counts collected between 8:00 a.m. and 2:00 p.m.

## 4.3 Simple versus Weighted Averages

In several situations, traffic data analysis software, such as TrafLoad, is required to average data obtained from several sites in a group. An example is the averaging of factors or traffic ratios obtained for continuous-count sites belonging to a factor group. Any of these averages can be obtained as

- A simple average of the values obtained for each site in the group;
- A weighted average of these values, using as weights the volume of relevant vehicles observed during a specified time period; or
- A weighted average of these values, using as weights the total number of relevant vehicles observed at each site.

**Table 4.1 Truck Traffic Percentages Derived from Partial-Day Weekday Classification Counts Collected for Various Periods of Time**

| Hours Counted | Period Counted | Percent Trucks |
|---|---|---|
| 6 | 6:00 a.m. - Noon | 8.7 |
| | 8:00 a.m. - 2:00 p.m. | 10.1 |
| | 10:00 a.m. - 4:00 p.m. | 9.3 |
| | Noon - 6:00 p.m. | 7.35 |
| 8 | 8:00 a.m. - 4:00 p.m. | 9.4 |
| | 10:00 a.m. - 6:00 p.m. | 8.1 |
| 10 | 8:00 a.m. - 6:00 p.m. | 8.4 |
| 12 | 6:00 a.m. - 6:00 p.m. | 8.0 |
| 24 | | 7.0 |

Source: See Figure 4.1.

The first option has the advantage of computational simplicity.[4] The second and third options have the advantage of applying low weights to values obtained from sites at which few vehicles belonging to the relevant VC(s) were observed. The second and third options thus minimize the effects of potentially misleading values derived from small sample sizes. The second option has the further advantage of weighting the values obtained for each site in approximate proportion to the relative volume of vehicles in the relevant class(es) at each site.

Consider a group that consists of several sites for which some type of data (such as load spectra or monthly and annual traffic volumes) are available and a larger number of sites for which these data are not available. The goal of the averaging process is to use data from the first set of sites to produce values (for load spectra, monthly traffic ratios, etc.) that are reasonably representative of the (unknown) values that exist at the second set of sites. In the case of TWRGs, the goal is to use load spectra developed from site-specific WIM data collected at several sites in order to produce a set of "average" load spectra that produces pavement loads that are reasonably representative of the loads that exist at sites that are in the group and for which site-specific data are not available.

In the case of TWRGs, the research team originally hypothesized that weighted averages would work somewhat better than simple averages. However, a study for FHWA[5] found that simple averages produced somewhat better results than weighted averages.[6] This result appears to be caused by a significant positive correlation between the volume of trucks in a particular VC operating at a site and the average loads of these trucks. Because of this correlation, weighted averages generally produce higher estimates of average pavement load per vehicle than do simple averages. But the highest traffic volumes and truck loads exist only at a few sites, leading to estimates of average pavement load that overestimate loads at most sites.[7] For this reason, TrafLoad was designed to use simple averages when developing a set of load spectra for a TWRG.

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[4] Although the derivation of weighted averages usually is more complex than the derivation of simple averages, the difference in complexity is sometimes quite small. For example, traffic ratios for a group of $n$ sites are obtained as

$$\frac{1}{n}\sum_{j=1}^{n}\frac{\text{MADT}_j}{\text{AADT}_m} \text{ using simple averages, and as}$$

$$\frac{\sum_{j-1}^{n}\text{MADT}_j}{\sum_{j-1}^{n}\text{AADT}_j} \text{ using weighted averages.}$$

[5] Cambridge Systematics, Inc. *Accuracy of Traffic Load Monitoring and Projections,* Volume II, February 2003, pp. 16-18.

[6] The measure of pavement stress used in this study was equivalent single-axle loads (ESALs). However, the result is likely to hold for load spectra as well.

[7] The analysis only used data from continuous WIM sites. Since these sites are likely to have higher-than-average truck volumes, the actual tendency for weighted averages to overestimate average pavement load per truck is likely to be even stronger than indicated by the analysis.

Most other averaging performed by TrafLoad is also performed using simple averages. In particular, the factor-group averages of monthly, day-of-week, and hourly traffic ratios are obtained as simple averages. Similarly, TrafLoad uses monthly and day-of-week adjustment factors to modify the load spectra obtained for 1 month (or day of week) to be more representative of another month (or day of week);[8] when the resulting "load spectra adjustment factors" are averaged, simple averaging is used.

There are, however, two situations in which TrafLoad generally obtains weighted averages. One is the development of a set of statewide default load spectra to be used by the Design Guide software when designing pavement for any site that has not been assigned to a TWRG and for which site-specific load spectra are not available. These statewide default load spectra are obtained by TrafLoad as averages of the TWRG load spectra. For this purpose, the TrafLoad user is allowed to assign weights to the TWRGs so that, in this averaging process, the load spectra for TWRGs that are relatively large or are believed to be particularly representative of statewide conditions can be weighted more heavily than the load spectra for other TWRGs.

The second situation in which TrafLoad uses weighted averages is the development of day-of-week adjustment factors to be applied to the load spectra. The procedure used for developing these factors uses truck volumes by day of week as weights in the averaging process.[9] The process used is designed to develop average monthly load spectra that are not unduly influenced by load characteristics observed on days (usually weekend days) when truck volumes are low.

[8] See Part 2, Section 2.2.

[9] Part 4, Section 3.3, Step WB, available online at http://trb.org/news/blurb_detail.asp?id=4403.

# 5.0 Areas for Future Work

The first section of this chapter presents brief discussions of some areas for future research relating to the collection and analysis of traffic data. The second section discusses several potential improvements to TrafLoad.

## 5.1 Areas for Future Research

The following sections briefly discuss some areas for future research relating to the collection and analysis of traffic data to be used in pavement design. The discussion excludes most research into improvements in WIM equipment and WIM technologies, although continued improvement in those areas is extremely important for improving the quality of data used in pavement design. The one exception to this exclusion is research into the accuracy and reliability benefits of multi-sensor WIM systems discussed immediately below.

### Calibration of WIM Equipment

There is a clear need for research into better procedures for calibrating WIM equipment and for maintaining calibration over time. In particular, both the Pavement Design Guide procedure and TrafLoad's load spectra factoring procedure place substantial reliance on maintaining WIM calibration over time. In the case of the Design Guide procedure, temporal variations in WIM calibration may result in monthly load distribution factors that reflect the effects of variations in calibration rather than variations in axle load, thus compromising the use of these distribution factors in pavement design. In the case of TrafLoad, these temporal variations have the further effect of producing seasonal adjustments to the load spectra for an individual site that may be more influenced by variations in calibration than by actual variations in axle loads, compromising the effect of the seasonal adjustments in estimating annual average load spectra.

For these reasons, further research into improving WIM calibration is strongly recommended. In particular, research should assess the costs and benefits of using multiple sensors, both as a means of calibrating a WIM installation in a manner that is not overly influenced by the dynamic characteristics of one or two test trucks and as a means of collecting more accurate axle-load information. A clear set of standards should be developed to ensure that, if autocalibration procedures are used for a particular WIM site, they are used only after the initial calibration of the WIM equipment and only after the autocalibration procedures themselves have been calibrated to reflect site-specific characteristics (such as front-axle weight) of vehicles observed at the site. Finally, there should be testing, validation, and refinement of the process being developed by the Long-Term Pavement Performance Project for using the results of historically collected data as a means of identifying WIM scales that are in need of calibration.

## Factoring Procedures for WIM Data

TrafLoad uses traffic ratios to convert classification counts into estimates of AADT by VC in a manner that attempts to minimize the effects of monthly and day-of-week (DOW) variations in the volume of vehicles in several VC groups. Similarly, TrafLoad develops sets of load spectra adjustment factors that are used to modify load spectra collected on certain days of the week and/or certain months so that they better reflect the overall pavement-damaging effects of loads traversing a site on an annual basis or during a particular month. This load spectra factoring procedure is a generalized version of the ESAL factoring procedure described in Chapter 2.0 that was developed and tested as part of a recent study for FHWA.[1] These two procedures are the first procedures developed for adjusting WIM data for the effects of seasonal and DOW variations in axle loads.

Tests of the ESAL factoring procedure (see Table 3.1 of Part 1) indicate that the procedure produces moderate improvements in the resulting estimates of pavement damage, and the research team believes that the same is true of the load spectra factoring procedure that is incorporated into TrafLoad. However, the latter procedure has not been subjected to systematic testing. Also, the benefits of both procedures are reduced if the seasonal adjustments are derived from data collected at sites at which the WIM equipment has not been consistently calibrated over the 12-month collection period. (In the research team's previous research, the team was able to identify and eliminate a few sites at which the calibration changed significantly, and the research team assumed that calibration at the remaining sites was reasonably consistent over the year.)

TrafLoad's load spectra factoring procedure also warrants further review. In developing this latter procedure, the research team did not have the time or resources needed to consider possible variants of the procedure. In particular, the TrafLoad factoring procedure is based on the earlier ESAL factoring procedure. Accordingly, as the basis for all factoring, it uses the fourth root of average ESALs per vehicle by vehicle-class group.

A possible alternative to the current TrafLoad procedure would use average weight by axle-group type and vehicle-class group. This alternative would be somewhat easier to understand than the current procedure, and it would likely allow for a moderate reduction in computation time. However, implementation of this alternative procedure would require a moderate programming effort as well as development of more complete specifications of the procedure.

Additional development and testing of procedures for factoring load spectra (and other WIM data) is warranted. One possible line of research would involve implementation of the average-weight factoring procedure and comparing its performance to the current TrafLoad procedure.

## Development of TWRGs

Both the Pavement Design Guide procedure and the earlier ESAL-based procedure presume a good understanding of the axle loads that will be incurred by the new pavement. This

[1] Cambridge Systematics, Inc., *Accuracy of Traffic Load Monitoring and Projections,* Volume I, Chapter 5, and Volume II, Section 5.1, prepared for FHWA, February 2003.

understanding can best be obtained from site-specific data collected by well-calibrated WIM equipment using in-pavement sensors—an expensive and relatively time-consuming option.

A less expensive option is to use as defaults data from permanent WIM installations at other sites at which the axle loads (ESALs or load spectra) are believed to be similar to those occurring at the site for which pavement is being designed. For this purpose, the research team's procedures (as well as those recommended by the 2001 TMG) require the states to develop a set of TWRGs and the research team provides some simple recommendations for forming these TWRGs (see Part 2, Section 2.4). However, testing of these procedures[2] indicates that the resulting default values obtained from the resulting TWRGs are only moderate improvements over those that would be obtained from statewide data and they are appreciably poorer than values obtained from site-specific WIM, even if the site-specific data are collected for only a short period of time. Clearly, further research would be desirable into the development and use of TWRGs.

## Seasonal Variations in Truck Weights

Analysis[3] indicates that in California the weights of combination trucks generally are higher during the spring and summer than during the fall and winter. However, there is relatively little published information on the weight patterns in other states or on how these patterns may vary with functional system or location. Such information would provide an improved understanding of the value of TrafLoad's seasonal adjustments for load spectra and would be helpful in the review and interpretation of WIM data. More information on day-of-week variations in weights (which can be quite significant for single-unit trucks) would also be useful.

## Sensitivity Analyses of Designs Produced by the Pavement Design Guide

The Pavement Design Guide requires an extensive amount of environmental and traffic data, but there is little published information on the relative importance of the many variables to the resulting pavement designs. A good set of sensitivity analyses would provide a better understanding of the extent to which the collection of good traffic data is warranted. These analyses could also provide the basis for modifying procedures for collecting traffic data so as to improve the resulting estimates of the input variables to which the Pavement Design Guide procedures are most sensitive.

## Averaging Procedures

In several situations, systems for analyzing traffic data create averages of data obtained from a specified group of sites, such as a factor group. These averages may be developed as simple averages of the values obtained for each monitored site in the group, or they may be obtained as weighted averages of these values, using the volume of relevant vehicles observed at each site

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[2] Ibid., Volume II, Section 4.4.

[3] Ibid., Volume II, Section 5.2.

as weights. The latter option is preferable if it is believed that values obtained for high-volume monitored sites are more representative of values for unmonitored sites in the group than are values obtained for low-volume monitored sites. Otherwise, the former option is preferable.

In one specific case, it has been determined that values from high-volume monitored sites probably are *less* representative of values from unmonitored sites than are values from low-volume monitored sites. This is the case of TWRGs, in which ESALs or axle-load data from WIM sites in a TWRG are used to provide default values for other sites in the TWRG.[4] For most TWRGs, site-specific values of ESALs and axle loads per vehicle for combination trucks tend to be positively correlated with truck volumes, so that weighted averages will produce higher values for ESALs and load spectra than will unweighted averages. However, there is also a tendency to install WIM equipment at sites with relatively high truck volumes. Therefore, unmonitored sites are likely to have somewhat lower-than-average values of ESALs and axle loads per vehicles, and weighted averages are likely to produce poorer load spectra values for a TWRG than are unweighted averages. For this reason, TrafLoad uses unweighted averages for developing a set of average load spectra for a TWRG.

TrafLoad also uses unweighted averages in several other cases, including developing sets of average monthly, DOW, or time-of-day traffic ratios for a factor group and averaging the monthly and DOW load spectra adjustments developed from different seasonal load spectra datasets. The use of unweighted averages is simpler, and, for these purposes, unweighted averages are likely to produce results that are at least as good as weighted averages. However, this last assertion has not been tested. Some further evaluation of the effectiveness of weighted and unweighted averages for these purposes may be warranted.

### Classifying Trucks in Urban Areas

Most automatic vehicle classifiers require vehicles to travel at relatively constant speed with clear gaps between vehicles. In urban areas, there generally are few locations at which these conditions exist, particularly during peak periods. Development of classifiers that work better in urban conditions would allow substantial improvement in the estimates of the numbers and types of trucks operating on urban streets.

## 5.2 Potential Improvements to TrafLoad

TrafLoad is a software system that is designed to analyze traffic data and load spectra and to produce outputs to be used by the Design Guide software. Although several TrafLoad analyses are based on analyses performed by existing systems for analyzing traffic data,[5] other TrafLoad analyses have been designed to meet the specialized requirements of the Design Guide procedures. Much of the effort expended in the design of TrafLoad was consumed in the design of procedures to perform the latter analyses, and more could have been expended if additional time and resources had been available.

[4] Ibid., Volume II, p. 18.

[5] E.g., the TRADAS traffic data analysis system developed by Chaparral Systems.

This section identifies several ways in which the implementation of TrafLoad can be improved in the future. This section is divided into three subsections. The first identifies some steps that can be taken (including some improvements to the user interface) to improve the learning experience for new users. The second subsection lists some recommended improvements to TrafLoad's functional capabilities that have clear value. These improvements should be implemented in the near future. The final subsection lists potential improvements whose value is less clear or whose precise design may be better determined after some experience is gained in using TrafLoad.

It is assumed that additional useful improvements will be identified by TrafLoad users in the course of using the system.

## Making TrafLoad Easier to Learn

TrafLoad beta testers have offered some suggestions for making TrafLoad easier to learn:

- **Develop a Tutorial.** The initial steps in using TrafLoad (the Setup and Loading phases described in Sections 2.2 and 2.3) are somewhat involved. A tutorial presentation of these steps would be helpful.

- **Re-Sequence Menu Items.** Some re-sequencing of items on TrafLoad's menus would be helpful to first-time users.

- **Assign Sites to Groups.** Currently, the **Maintain Site Information** screen is used for providing TrafLoad with a complete set of characteristics for each site, including its assignment to factor groups and to a TWRG. Thus, assignments to groups are performed for each site separately.

  An alternative would be to use a set of matrices for this purpose, one matrix for each type of group. Each matrix would list all sites in the system and have columns corresponding to all groups of a particular type, e.g., all TWRGs. The user could then identify the sites that should be assigned to a particular TWRG and enter checks in the appropriate columns. This alternative would allow the user to see, on a single screen, how the sites have been grouped and provide visual cues for assigning the remaining sites. A capability for copying the resulting matrices into a spreadsheet (or, possibly, for printing the matrices directly) should also be provided.

- **Group Test.** A group testing session could be attended by potential users from several states as well as by software developers. This would permit the developers to identify system characteristics that users find confusing. Such a session is likely to enable the developers to identify additional improvements to the interface and/or documentation that would be helpful to subsequent users.

## Highly Recommended Improvements to Functional Capabilities

The following improvements to TrafLoad's functional capabilities are recommended for implementation in the near future:

- **User-Defined VCs.** The initial version of TrafLoad estimates the AADT and load spectra only for FHWA VCs 4–13 and aggregates of these VCs. Several states collect data for more refined sets of VCs. In particular, some states subdivide Class 9 vehicles into tractor semi-trailers with conventional tandem rear axles and semi-trailers with spread tandem rear axles. And some states that allow the operation of longer combination vehicles collect separate data for seven-axle (Rocky Mountain) doubles, nine-axle ("turnpike") doubles, and triples. Use of this additional information will allow the development of improved estimates, for any site, of the numbers of axles of each type and the weights on these axles.

- **TWRGs and VC Groups.** The initial version of TrafLoad requires that the assignment of sites to a TWRG be independent of VC group, i.e., all sites assigned to a particular TWRG for one VC group (e.g., for combinations) are automatically assigned to that TWRG for all other VC groups. This requirement creates an undesirable restriction on the way TWRGs are formed.[6] Therefore, it would be desirable to eliminate this requirement. The same undesirable restriction also applies to the assignment of sites to load spectra factor groups.

- **Load Spectra and "Direction."** Consider a site for which load spectra are available for two design lanes, one for each direction of travel. TrafLoad currently allows the two sets of load spectra to be processed separately, but it does not allow the two lanes to be assigned to separate factor groups or to separate TWRGs. The latter limitation can be significant, since there are many sites at which vehicles are loaded more heavily in one direction than in the other. It would be desirable for TrafLoad to allow two design lanes at a site to be assigned to TWRGs and seasonal load spectra factor groups independently of each other.[7]

- **Quality Control Checks.** The software assumes that the vehicle classification and weight records have been through a quality-control process. This assumption may be restrictive in many cases. Some legacy systems may do little, if any, checking of the incoming data. Addition of quality-control checks would be an economical enhancement for users who have such systems. The checks to be implemented should include at least the type and range of checks used in the FHWA Vehicle Traffic Information System (VTIS) (http://www.fhwa.dot.gov/ohim/ohimvtis.htm). In addition, some of the checks from the traffic data editing pooled fund study might be a useful addition. The quality checks should produce a statement of the number of data records read into the system and the number rejected because of the quality checks. With some additional design and coding, an option could be provided to reject an entire data file if the number of rejected records exceeds a user-specified threshold.

- **Traffic Growth Between Base Year and Year in Which Pavement Will Be Improved.** It would be desirable to provide TrafLoad users with a simple facility for telling TrafLoad the number of years that will pass between the last year for which traffic data have been

[6] For example, consider the sites at which the most heavily loaded combinations operate. When looking at combination trucks, these sites are appropriately assigned to a single TWRG. However, the same degree of uniformity does not necessarily exist for the weights of single-unit trucks (SUTs) operating at these sites. If SUTs at some of these sites are heavy and SUTs at other sites are light, it would be desirable to assign these sites to separate TWRGs when analyzing SUTs.

[7] In the absence of this improvement, it is possible to treat the two design lanes as belonging to separate sites (with separate site identification numbers).

collected (e.g., Design Guide) and the year in which redesigned pavement is expected to go into service (e.g., 2005). With this information, TrafLoad would be able to generate forecasts that automatically take traffic growth during this period into account, eliminating the need for a work-around for this limitation.

## Other Potential Improvements

Other potential improvements to be considered for future implementation include the following:

- **User-Defined VC Groups for Forecasting.** TrafLoad currently allows users to specify one set of forecast information for VCs 4–7 and a separate set for VCs 8–13. It would be desirable to allow users to define their own VC groups for this purpose.

- **Allow Form of Forecast to Vary by VC Group.** TrafLoad currently allows users to specify exponential growth for all classification VC groups or linear growth for all such groups, but not exponential growth for one VC group and linear growth for another. It would be desirable to remove this restriction.

- **AADT by VC for Level 3A Sites.** TrafLoad currently estimates AADT by VC and direction at Level 3A sites by using estimates of AADT by VC and direction at a nearby "associated" site on the same road. A somewhat better procedure for developing estimates for Level 3A sites is described in Part 2, Section 3.5.

- **Monthly Distribution Factors (MDFs) for Level 1 Sites.** TrafLoad could be modified to produce separate MDFs by lane (or by direction) for Level 1 sites (but not for Level 2 sites). Such MDFs might be marginally better than the non-directional MDFs that are currently developed for these sites.

- **"Direct Scaling" by Direction.** TrafLoad has an optional "direct scaling" procedure that may be used (at the user's request) for estimating AADT by VC at Level 1B sites that have only one lane per direction.[8] The scale factors used by this procedure are developed by lane. A variant of this procedure would develop scale factors by direction and could be applied at multi-lane Level 1B sites.

- **DOW ESAL Ratios.** TrafLoad's procedure for adjusting load spectra to reflect DOW variations in axle weights (for a given VC group) uses a set of DOW load spectra ESAL ratios.[9] For any site, these ratios are developed for any month for which WIM data exist for each day of the week. There is at least one relatively unusual situation (when data are available for only 1 week and that week contains a holiday) when the resulting ratios might produce relatively unreliable adjustment ratios. It would desirable for TrafLoad to identify this situation and to ignore the resulting ESAL ratios. Another alternative would be for the annual average load spectra to be developed as a weighted average of the adjusted monthly load

[8] See Part 4, Section 2.2, Procedure CE, available online at http://trb.org/news/blurb_detail.asp?id=4403.

[9] See Part 4, Section 3.3, Procedure WB, available online at http://trb.org/news/blurb_detail.asp?id=4403.

spectra using weights that vary with the number of observations for the individual months. Also, rules could be developed that would enable TrafLoad to develop DOW ESAL ratios using data for months for which data exist for some, but not all, of the five weekdays.

- **Sorting Input Files.** TrafLoad's procedure for loading a set of weight or vehicle-classification records is most efficient when the set is sorted by site. (This is because of problems that arise when a pair of consecutive records contains data for two different sites.) An optional procedure for sorting these records before loading could be helpful to users whose weight and vehicle-classification files are not already sorted.

# Glossary

| | |
|---|---|
| AADT | Annual average daily traffic. |
| AAEPV | Annual average ESALs per vehicle. |
| AEPV | Average ESALs per vehicle. |
| CV | Coefficient of variation. |
| DOW | Day-of-week. |
| ESALs | (18,000-pound) equivalent single-axle loads. |
| MADT | Monthly average daily traffic. |
| MADW | Monthly average day-of-week. |
| MAEPV | Monthly average ESALs per vehicle. |
| MAPE | Mean absolute percent error. |
| SUT | Single-unit truck (or bus). |
| TMG | *Traffic Monitoring Guide*. |
| TrafLoad | The traffic-data analysis software developed under this project. |
| TTDFs | Truck traffic distribution factors. |
| TWRG | Truck weight road group. |
| VC | Vehicle class. |
| WIM | Weigh-in-motion. |

# Levels of Classification Site

| | |
|---|---|
| 1A | Site for which AVC data are available for periods of at least 1 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 6 weekday 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. |

# Appendix A: Forecasting

The Pavement Design Guide software requires forecasts of linear or exponential rates of change in truck volumes over the design life of the pavement. For this purpose, TrafLoad allows the user to provide these rates of change separately for single-unit trucks (SUTs) and for combination trucks (CTs). A simple procedure for estimating these rates is presented in Section 3.6 of Part 2. This procedure is recommended for use by most users of TrafLoad. This appendix presents a more extensive discussion of potential forecasting procedures that was developed in Phase I of the current project.

The simplest approach to forecasting truck traffic for a particular road is to estimate the average percentage rate of past growth in truck vehicle-miles of travel (VMT) on a set of similar roads and to assume that truck traffic on the road in question will grow at this rate in the future. A minor variant of this procedure is to adjust the estimated rate of growth to reflect information that suggests that truck traffic on the road is likely to grow faster or slower than implied by the estimated growth rate (e.g., because of the expected opening or closing of a major generator of truck traffic). For most pavement-design efforts, this approach is likely to be the most cost-effective to use. Because of differing influences on the use of SUTs and combinations, the procedure should be applied separately to SUTs and combinations (or to small and large trucks), but the procedure can also be applied to total truck volumes to produce a single growth rate for all trucks.

Section A.1 describes the above approach in some detail. Also described in that section is a related approach in which a linear trend in truck VMT is estimated and the road in question is assumed to receive a proportional share of this linear growth.

Section A.2 discusses some more sophisticated procedures that can be used for forecasting truck traffic. These procedures may be used by highway planners to estimate traffic on a proposed new road or to evaluate the likely effects of other significant changes in the highway network. When forecasts have been developed for such purposes using these procedures, they may also be used for pavement design.

Section A.3 discusses issues relating to forecasting changes in the distribution of vehicles in use, as characterized by their axle configuration, and the load spectra of these vehicles.

TrafLoad accepts separate forecasts of SUTs and CTs. Nearly all SUTs are used primarily in local service, and changes in SUT volumes tend to closely relate to changes in the local economy. On the other hand, many CTs are used for longer hauls, so changes in CT volumes tend to be influenced by a mix of local and non-local economic factors. Accordingly, in many areas, SUT traffic and CT traffic exhibit different growth rates. For this reason, it usually will be better to develop separate growth rates for SUTs and CTs. However, for conciseness, the forecasting procedures presented in this appendix frequently refer simply to truck volumes and truck AADT. It should be borne in mind that these procedures can, and usually should, be applied separately to SUT volumes and CT volumes.

## A.1 Simple Trend Analysis

Trend analysis is a methodology for forecasting future truck volumes that relies solely on historical estimates of truck volume or truck AADT. While it is theoretically possible to develop trends of volumes from only 2 years of data, more data points are desirable so that the impacts of non-representative data points can be minimized. Trend analysis formulas are very simple to develop and apply and can be contained in a single spreadsheet.

### A.1.1 The Procedures

The simplest form of trend analysis is a linear regression method that forecasts future truck volumes based solely on historical truck volumes, developing a trend line of volumes into the future. This method can be used to estimate either the annual change in truck volume (linear trend) or the annual percentage change in truck volume (exponential trend). Exponential trends incorporate the compounding effect of growth and generally are the more appropriate assumption for truck growth. Because of the compounding effect, exponential trends generally produce higher forecasts. For roads that have experienced high growth rates, the differences in forecasts between the two methods can be significant.

A linear trend analysis uses the formula

$$V_i = a + b \cdot Y_i + \varepsilon_i \qquad \text{(A.1)}$$

where:

$V_i$ is the $i$th observation of the dependent variable (to be predicted);

$Y_i$ is the $i$th observation of the independent variable (explanatory); and

$a$ and $b$ are parameters to be estimated by linear regression in a manner that minimizes $\varepsilon_i$ (the error term).

In this analysis, $V_i$ could be annual VMT of SUTs or CTs in the state or in the region of interest, and $Y_i$ could be the corresponding calendar year of the observation.

An exponential trend analysis incorporates a *compound annual growth rate* and follows the formula

$$V_i = a(1 + r)^{Y_i} \qquad \text{(A.2)}$$

where $r$ is the annual rate of growth and the other variables are defined above. Equation A.2 is estimated by first taking logarithms of both sides of the equation to produce

$$\text{Log}(V_i) = \text{Log}(a) + Y_i * \text{Log}(1 + r) \qquad \text{(A.3)}$$

and then using linear regression.

As implied above, truck forecasts generally are developed using data on total truck VMT on a set of roads, rather than truck AADT on the road in question. Although the latter option may seem appropriate, its use poses several problems. In particular, data on truck volumes on a given road usually are not collected annually, and even if they are, the factoring process used to convert short-duration truck counts to estimates of truck AADT introduces artifact into the resulting time series that adversely affects the regression results.

When an exponential trend analysis is performed using truck VMT, the growth rate that is estimated for VMT on an entire set of roads usually is assumed to be valid for any road in the set. However, as discussed below, if there is a good reason to believe that the future growth rate for truck traffic will differ from the past rate, or that the growth rate for the road of interest differs from that of the entire set of roads, it may be desirable to adjust the rate judgmentally before applying it.

When an estimate of *linear* growth in VMT on a set of roads is developed, this estimate has to be scaled before it can be used to forecast truck AADT on a particular road. This scaling can be performed using the equation

$$g = \frac{T_o}{V_o} b \qquad \text{(A.4)}$$

where:

$T_o$ is AADT of SUTs or CTs in the last year for which historical data are available (usually also used as the base year for forecasts),

$V_o$ is the corresponding value of VMT in that year,

$b$ is the linear growth rate for VMT estimated in Equation A.1, and

$g$ is the resulting estimate of annual growth in AADT of SUTs or CTs on the road in question.

As observed above, there are some circumstances in which a small judgmental adjustment to an estimated growth rate may be appropriate. Some circumstances that may warrant such an adjustment are the expected diversion of existing truck traffic to a new road that is being built or the expectation that new industrial facilities being built on the road will accelerate the growth of truck traffic on the road. In making such adjustments, analysts should bear in mind that upward adjustments will produce more conservative (and expensive) pavement designs with a reduced likelihood of premature failure, while downward adjustments will produce less conservative designs with an increased likelihood of premature failure. For this reason, downward adjustments should be made only with great care.

In performing a trend analysis, the historical data used should be selected to provide a reasonable indicator of likely future growth on the road in question. The beginning and end years of the historical data should be selected to be in corresponding phases of the business cycle. Starting the time series in a recession year and ending it in a boom year will result in overestimating likely future growth, while starting in a boom year and ending in a recession will have the opposite effect.

The historical data used in a trend analysis should be plotted and examined to ensure that they exhibit a relatively steady growth rate over time. If the year-to-year changes appear erratic, then the assumption underlying the simple procedure—a relatively constant growth rate over time—is called into question. In addition, the analyst should examine the plotted data to determine outlier observations that differ significantly from the trend of other observations.

### A.1.2 Examples

Data for two numeric examples of trend analyses are presented in Table A.1. The third column of the table shows assumed estimates of statewide VMT of CTs for 1992 through 1999, and the fourth column shows the natural logs of the VMT estimates. (Logs to the base 10 could also be used.) No VMT estimate is shown for 1996, reflecting an assumption that data for this year are unavailable or have been found to be unreliable.

The following shows first how the above procedures can be used to forecast statewide VMT of CTs and then how these results can be used to estimate the AADT of CTs ($AADT_c$) on a particular road.

Most commercial spreadsheet programs incorporate a linear regression function. Applying such a function to the second and third columns of Table A.1 produces the equation

$$V = 25.38 + 0.4085Y$$

where:

$V$ is estimated VMT of CTs, in billions; and

$Y$ is the number of years since 1992, the year of the first observation.

**Table A.1 Historical Truck Volumes**

| Year of Observation | Number of Years Since First Observation | Truck VMT (Billions) | ln (Truck VMT) |
|---|---|---|---|
| 1992 | 0 | 25.61 | 23.97 |
| 1993 | 1 | 25.24 | 23.95 |
| 1994 | 2 | 26.23 | 23.99 |
| 1995 | 3 | 27.42 | 24.03 |
| 1997 | 5 | 26.76 | 24.01 |
| 1998 | 6 | 27.33 | 24.03 |
| 1999 | 7 | 28.85 | 24.09 |

The regression output generally also contains statistical variables that indicate how well the equation explains the observed data. For the example, in addition to the values of the coefficients, the output indicates that the $R^2$ (which indicates the portion of the total variation in the observation that is explained by the equation) is 0.76 and that the t-statistics are 60.4 for the constant term and 4.09 for the variable term. (A t-statistic greater than 1.96 indicates that the coefficient is statistically significant to a confidence level of 95 percent.) Using this result, forecast VMT in 2022 is estimated as

$$25.38 + 30 \times 0.4085 = 37.64 \text{ billion}$$

The same data can also be used to estimate an exponential trend or growth rate. Here the regression is performed using the natural log of truck VMT as the dependent variable and the number of years from 1992 as the independent variable. In this case, the resulting coefficients in the output are also natural logs of the desired variables and are transformed to the desired terms by using the exponential function, $e^x$ or exp(). The estimated equation is

$$\ln(\mathrm{V}) = 23.96 + 0.0151\mathrm{Y}$$

Exponentiating both sides of the equation produces

$$V = \exp(23.96)\exp(0.0151)^Y$$

which can then be simplified to

$$V = 25.4 \times 1.0152^Y$$

where $Y$ is the number of years from 1992, the first observation. The estimated annual growth rate is 1.52 percent (1.0152 – 1.0). The $R^2$ for this regression is 0.77, and the t-statistics are 1,548 for the constant term and 4.13 for the variable term.

For the purpose of forecasting the AADT of combination trucks ($\mathrm{AADT}_c$) on a single road, the exponential growth rate (1.52 percent per year) can be applied directly to $\mathrm{AADT}_c$ for any base year for which $\mathrm{AADT}_c$ is available. Thus, if $\mathrm{AADT}_c$ for a given road is estimated to be 1,000 in 1999, then the forecast for any subsequent year is

$$\mathrm{AADT}_c(n) = 1{,}000 \times 1.0152^n$$

where $n$ is the number of years between 1999 and the year of interest. For 2022, the forecast is

$$\mathrm{AADT}_c(23) = 1{,}000 \times 1.0152^{23} = 1{,}415$$

When using TrafLoad, it is only necessary to specify that 1.0152 is the estimated exponential growth ratio for the road.

On the other hand, if linear growth is assumed, Equation A.4 must be used to convert the above estimate of linear growth in statewide VMT (408.5 million VMT per year) to an estimate of the linear growth rate for the road in question. Substituting this value in Equation A.4, along with the 1999 estimates of $\mathrm{AADT}_c$ and statewide VMT of combinations, produces a linear growth rate of

$$\frac{1,000 \times 0.4085 \times 10^9}{28.85 \times 10^9} = 14.17 \text{ CTs/year}$$

The forecast for any subsequent year is

$$\text{AADT}_c(n) = 1,000 + 14.17n$$

where $n$ is the number of years between 1999 and the year of interest. For 2022, the forecast is as follows:

$$\text{AADT}_c(23) = 1,000 + 14.17 \times 23 = 1,326$$

This value is appreciably lower than the 1,415 produced using an exponential growth rate. When using a linear growth rate with TrafLoad, the software requires only this growth rate, 14.17 CTs per year.

## A.2 More Sophisticated Approaches

This section describes three more sophisticated approaches for forecasting truck volumes:

- Multivariate linear regression,
- Growth-factors methods, and
- Travel demand models.

The first of these is a somewhat more sophisticated alternative to the univariate regression analysis procedure presented in the preceding section. Multivariate linear regression may be a useful alternative to the earlier procedure when forecasting truck traffic in areas where there are identifiable factors other than time that influence truck volumes.

The second and third approaches, and particularly the third, are appreciably more complex and generally not warranted for forecasts that will be used only for designing pavement. However, these approaches may be of interest to highway planners who are developing forecasts to be used for multiple purposes. In particular, the third approach (the development of travel demand models, or TDMs) is commonly used for estimating the traffic diversion effects of the construction of a new road or of other significant changes in an area's highway network. Pavement designers frequently will be able to use either existing forecasts developed using these approaches or others. In the case of a planned new road, a TDM may be the best source of a forecast.

The three approaches are described in the first three subsections below. A fourth subsection then describes several potential sources of data that may be used with these approaches. Additional information about potential data sources is contained in Appendix A of *NCHRP Report 388*[1] and in Appendixes G–L of the *Quick Response Freight Manual*.[2]

The approaches presented in this section generally produce forecasts for a specified future year. For use by TrafLoad, these forecasts must be converted to estimates of either annual growth rates or constant annual growth. The conversion is described in the last subsection below.

### A.2.1 Multivariate Linear Regression

Multivariate linear regression allows the use of multiple independent variables. This approach is useful if there are multiple independent factors that are believed to cause growth or fluctuations in truck traffic. In agricultural areas, one such factor would be the size of the harvest.

In general, independent variables should be chosen that represent a set of significant and distinct influences on truck traffic for which historical data exist and for which reasonable forecasts are available. If influences are not distinct, the variables will be correlated, the regression analysis will not be able to distinguish the influences, and the procedure will produce unreliable coefficients. Population, employment, personal income, and time are potential independent variables that tend to be correlated with each other and that generally should not be used as separate independent variables in an ordinary least-squares regression (though it may be possible to use them together when more sophisticated techniques, such as two-stage least-squares regression, are used[3]).

For this regression, $R^2$ is 0.85, and the t-statistics are 2.68 for the year, 1.54 for grain, and 10.8 for the constant term.

An example of a simple multiple variable regression using a trend term and an additional independent variable, grain production, uses the data in Table A.2.

Using a spreadsheet regression function, one obtains the estimated equation

$$V = 22.27 + 0.3018Y + 2.15G$$

where:

$V$ is estimated VMT of CTs, in billions;

$Y$ is the number of years since 1992, the year of the first observation; and

$G$ is grain production in billions of bushels.

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[1] Cambridge Systematics, Inc., et al., *NCHRP Report 388: A Guidebook for Forecasting Freight Transportation Demand,* Transportation Research Board, National Research Council, 1997.

[2] Cambridge Systematics, Inc., COMSIS Corporation, and University of Wisconsin-Milwaukee, *Quick Response Freight Manual,* prepared for the U.S. DOT and U.S. EPA, September 1996.

[3] E.g., see Peter Kennedy, *A Guide to Econometrics,* Fourth Edition, MIT Press, 1998. Additional discussion of econometric techniques for forecasting truck traffic is also contained in *NCHRP Report 388.*

**Table A.2 Historical Truck Volumes and Grain Production**

| Year of Observation | Number of Years Since First Observation | Truck VMT Billions | Grain Production (Billion Bushels) |
|---|---|---|---|
| 1992 | 0 | 25.61 | 1.365 |
| 1993 | 1 | 25.24 | 1.643 |
| 1994 | 2 | 26.23 | 1.456 |
| 1995 | 3 | 27.42 | 1.756 |
| 1997 | 5 | 26.76 | 1.462 |
| 1998 | 6 | 27.33 | 1.626 |
| 1999 | 7 | 28.85 | 1.986 |

If there is a forecast for grain production in 2022 of 2.1 billion bushels, the forecast of CT VMT in that year will be

$$22.27 + 30 \times 0.3018 + 2.15 \times 2.1 = 35.8 \text{ billion}$$

The use of a separate grain-production term in this example makes it possible to distinguish the effects of growth and fluctuations in grain production from other influences that cause truck VMT to trend upward. The assumed data indicate that the 1993 harvest was poor and the 1999 harvest was particularly good. The indicated sharp growth in grain production over the 7-year period appears to be responsible for a significant share of the observed VMT growth. With a separate grain term, the estimated coefficient of $Y$ (0.3018) is appreciably lower than the 0.4085 value obtained in the earlier example without a term for grain. With a fairly modest forecast for future growth in grain production, the resulting VMT forecast for 2022 (35.8 billion) is somewhat lower than the forecast that was produced using a simple linear trend (37.6 billion).

Conversion of this forecast to an estimate of either linear annual growth or an exponential annual growth rate is discussed in Section A.2.5.

## A.2.2 Growth-Factor Methods

Growth-factor methods use forecasts of growth in specific economic sectors as indicators of corresponding growth in related truck traffic. For this purpose, the most desirable indicator variables are those that measure goods output or demand in physical units (tons, cubic feet, etc.). However, forecasts of such variables frequently are not available. More commonly available indicator variables are constant-dollar measures of output or demand; employment; or, for certain categories of truck traffic, population or real personal income.

### *The Procedure*

There is considerable flexibility in determining how to determine growth factors, but the basic procedure is as follows:

1. **Select the commodity or industry groups that will be used as the economic indicators in the analysis. Obtain base-year and forecast-year estimates for the selected indicators.**

   The groups should be selected to distinguish the most important commodities carried on the road, but should be aggregated to reflect a manageable number of groups for analysis purposes. Generally 10 or fewer commodity/industry groups are appropriate. Forecasts of dollar-valued output or commodity production can be obtained from the U.S. Department of Commerce's Bureau of Economic Analysis (BEA), from input/output models, from state agencies or other public forecasting groups, and from private vendors. Forecasts of employment can often be obtained from state labor departments and from private vendors.[4]

2. **Allocate the base-year truck volume to commodity/industry group.**

   A key to growth-factor forecasting is determining how the truck traffic is allocated among the different commodity or industry groups in the base year. One method for allocating truck traffic to different commodity or industry groups is to estimate VMT for each group. The principal source of information for this is the Vehicle Inventory and Use Survey (VIUS) dataset.[5] However, VIUS is an imperfect source of information about truck operations in a particular state, because state-level VIUS data reflect all operations of trucks *based* in that state (including out-of-state operations) and excludes all in-state operations of trucks based elsewhere.

   An alternative is to obtain this information from a roadside survey. In addition to providing data on the commodity or industry group for each vehicle, surveys can provide information on trip origin and destination, vehicle routing, trip frequency, etc. These surveys are not routinely available for roadway sections, and the expense of conducting these studies would not be justified for pavement design projects. The conduct of such surveys is discussed briefly in Section A.2.4 (below) and discussed further in the *Quick Response Freight Manual*.[6]

3. **Determine the growth factor for each commodity or industry group.**

   For each commodity/industry group, an annual growth factor, $g_i$, is obtained from the equation

$$g_i = \left(\frac{X_{if}}{X_{io}}\right)^{\left(\frac{1}{Y_{if} - Y_o}\right)} \qquad \text{(A.5)}$$

[4] These data sources are described further in Section A.2.4.

[5] VIUS is described further in Section A.2.4.

[6] Chapter 6.

where $X_{io}$ and $X_{if}$ are the values of the $i$th indicator variable in the base year, $Y_o$, and in some future year, $Y_{if}$, respectively, for which a forecast for this variable is available. (Note that the $Y_{if}$ may vary by indicator variable.)

4. **Apply the growth factor to the base-year truck volume for each commodity/industry group.**

   The growth factors for each commodity are applied to the truck volumes allocated to each commodity group in the base year to estimate future volumes. The general formula is

$$V_{if} = V_{io} g_i^n \quad \text{(A.6)}$$

   where:

   $V_{io}$ is the share of base-year truck volume allocated to indicator variable $i$;

   $V_{if}$ is the forecast of corresponding truck volume in the forecast year;

   $g_i$ is the annual growth factor for this indicator variable (obtained from Equation A.4); and

   $n$ is the number of years in the forecast period.

5. **Aggregate the forecasts across the commodity/industry groups.**

   The forecast-year truck volumes are obtained by summing the truck volume forecasts across all commodity/industry groups.

### *A Numeric Example*

An illustrative example is shown in Table A.3. The total base-year volume is the 1999 average daily truck volume from the previous examples. The distribution of the base-year traffic was obtained from 1997 VIUS data for six-tire trucks. The annual growth factors for each industry sector are assumed to have been obtained from employment forecasts produced by a local economic development agency. The growth factors are applied to the base-year truck volumes using Equation A.6, with $n$, the number of years in the forecast period, set to 23 (2022 – 1999).

The annual growth factors in Table A.3 can be converted to annual growth rates by subtracting 1.0. Most of the resulting growth rates are higher than the 1.98 percent obtained in the second example in Section A.1.2; accordingly, they produce a higher forecast of truck traffic: 2,879 trucks per day. Conversion of this forecast to an estimate of either linear annual growth or an exponential annual growth rate is discussed in Section A.2.5.

### *Recent Use by States*

Brief descriptions of three states' use of growth factors for truck forecasting are presented below. Section A.2.4 contains additional information about the data sources mentioned.

### Table A.3 Growth-Factor Example

| Commodity/Industrial Category | Daily Truck Traffic (Base Year 1999) | Annual Growth Factor | Daily Truck Traffic (Forecast Year 2022) |
|---|---|---|---|
| Agriculture (Farming) | 105 | 1.017 | 150 |
| Forestry and Lumbering | 37 | 1.059 | 123 |
| Mining and Quarrying | 21 | 1.031 | 40 |
| Construction | 190 | 1.016 | 265 |
| Manufacturing | 119 | 1.031 | 226 |
| Wholesale Trade | 175 | 1.03 | 326 |
| Retail Trade | 121 | 1.033 | 239 |
| Transportation and Public Utilities | 723 | 1.03 | 1,345 |
| Services | 96 | 1.026 | 165 |
| **TOTAL** | **1,587** | | **2,879** |

#### Texas

As part of the Texas Strategic Plan,[7] the state used growth factors to forecast VMT generated by trucks for several multi-county districts. The TRANSEARCH commodity-flow database was used to develop growth rates of economic activity by industry sector. Growth rates were applied to base-year truck average annual daily traffic (AADT) to estimate the future-year truck AADT by functional class and district.

#### West Virginia

West Virginia employs a growth-factor approach to forecast truck traffic. Growth factors are applied to baseline truck traffic data in order to project future truck activities. Growth factors are developed for each county based on socioeconomic forecasts, if the data are available, or historical traffic growth trends, otherwise.

#### Colorado

During 1998 and 1999, the Colorado Freight Infrastructure Study[8] developed detailed information on the state's freight infrastructure at both the state and transportation planning region (TPR) level. This project developed regional- and county-level growth rates for different

[7] Texas Department of Transportation, *Texas DOT Strategic Plan FY 2001–2005*.

[8] HNTB, Inc., *Colorado Freight Infrastructure Study*, prepared for the Colorado Department of Transportation, Division of Transportation Development, 2000.

commodities that could be used for growth-factor forecasting. The 1993 Commodity Flow Survey (CFS) was used to identify statewide commodity flow origins and destinations; the 1992 Truck Inventory and Use Survey (a predecessor to VIUS) was used to develop factors to convert origin and destination commodity flows to truck trips; and the 1995 County Business Patterns (CBP) data (from the U.S. Bureau of Census) were used to allocate the commodity flows and truck trips for both origins and destinations from the state to county level. County-level commodity flows and truck trips were then aggregated to represent TPR activities. Statewide forecasts of employment by industry group were used as the basis for predicting county-level growth factors.

### A.2.3 Travel Demand Models

A well-established and relatively sophisticated technique for forecasting traffic volumes for an entire region is through the use of travel demand models (TDMs). These models are most commonly used for forecasting total traffic volumes in metropolitan areas, but some TDMs have been developed for forecasting truck volumes for a state or region. If separate forecasts of truck volume are not produced by a TDM, future truck volumes can be estimated by multiplying the forecasts of total volume by current percentages of trucks in the traffic stream and adjusting the result upward to reflect the tendency of truck volumes to grow faster than volumes of other vehicles. Truck forecasts produced by existing TDMs may be used for the purpose of pavement design, but the development of new models is too complex to be justified solely on the basis of their potential use in the pavement-design process.

TDMs estimate demand through the use of one or more economic-indicator variables (employment, economic production, etc.) associated with specific units of geography (traffic analysis zones, or TAZs) together with a computerized network representing individual sections of road connecting the zones. In sequence, these models estimate

1. How many truck trips begin and end in each zone (trip generation),

2. How many of those trips travel between each pair of zones (trip distribution), and

3. What specific sections of road are used to travel between zones (assignment).

As network models, TDMs are capable of estimating the traffic to be carried by a proposed new road as well as the effects on other roads of diversion to the new road.

Users of TDMs should be familiar with several issues:

- Travel demand models produce forecasts for various scenarios. When obtaining information from TDMs, care should be taken to determine exactly which economic and transportation scenarios are represented in each forecast.

- Travel demand models are validated to groups of highway sections, referred to as screenlines, not to individual highway sections. When obtaining a forecast, the analyst should obtain the base-year observed truck count, the base-year model volume, and the future-year model volume. Common practice is to assume that the ratio of base-year observed volume to base-year model volume can be used to adjust future-year model volume to produce an appropriate estimate of future-year volume.

- Travel demand models load truck traffic from a TAZ to the highway network through a centroid connector. The loading of all traffic from an area to the highway network through these discrete points causes high volumes near these points that are an artifact of the model process and do not reflect reality. The use of truck model volumes near these loading points should be done with the assistance of the staff responsible for the model.

- While some agencies' models have specific truck models, many TDMs include trucks only as a percentage of all vehicle trips. The analyst should obtain all relevant information from the model concerning the methodology used for trucks and make any post-processing adjustments that appear necessary.

Additional information about TDMs can be obtained from the U.S. DOT's Travel Model Improvement Program web site (http://tmip.fhwa.dot.gov).

### *Recently Developed TDMs*

Brief descriptions of several TDMs that have recently been developed by the states are presented below. Section A.2.4 contains additional information about the data sources mentioned.

#### Arizona

As part of the Arizona Long-Range Transportation Plan, the state is developing passenger and freight travel demand forecasting capabilities. Base and future estimates of VMT are being developed using available state and regional population, employment, and traffic data. The TRANSEARCH database is being used to identify base-year freight flows, and the VIUS dataset is being used to convert these flows to truck trips. These truck trips are then allocated to the highway network using data from the Highway Performance Monitoring System. Sources of socioeconomic forecasts are being identified as part of the project and are being used to develop forecasts of freight movements.

#### Colorado

The Colorado DOT is sponsoring the Eastern Colorado Mobility Study to develop passenger and freight modeling capabilities in the eastern part of the State. The study is using a hybrid modeling approach for trucks, using commodity flow data to develop interregional freight-trip tables to be disaggregated to the zonal level and a more traditional truck-trip generation and distribution process to capture truck traffic generated locally by activities such as service and utility businesses, construction, and local parcel delivery.

#### New Jersey

New Jersey includes a vehicle-based truck model as part of the statewide travel demand model.[9] The truck model develops truck trips for individual zones using trip rates for zonal

[9] URS Greiner Woodward Clyde, *Statewide Model Truck Trip Table Update Project*, prepared for the New Jersey Department of Transportation, January 1999.

households and employment by category; estimates of truck trips generated by special generators, such as truck terminals and intermodal facilities; and observed volumes at border crossings. Gravity models are used to distribute medium and heavy trucks separately. Forecasts for truck trips at major intermodal facilities were developed using forecasts from terminal operators, and external station forecasts were developed using trend analysis.

**Indiana**

The Indiana statewide freight model[10] was developed by Professor William Black at Indiana University in the 1990s. The model was originally developed to provide forecasts of both truck and rail shipments of freight throughout the state and includes zones for each county and 53 external zones representing other states. The model is based on publicly available data from the 1993 Commodity Flow Survey, supplemented with proprietary county-level data from Woods and Poole and the Federal Railroad Administration (FRA) Rail Waybill Sample. Future growth in commodity flows depends on estimates of growth in population and employment within each county or state.

**Michigan**

The Michigan statewide truck model[11] was developed in the mid-1990s as part of a statewide model for all highway travel. Portions of the truck model were developed at various levels of geographic detail ranging from entire states outside Michigan to commodity analysis zones and TAZs within the state. The model uses REMI model forecasts to project growth in employment for 14 industry groups.

**Wisconsin**

The Wisconsin statewide truck model[12] was developed in the early 1990s to provide truck volume predictions on state highways and to explore the potential for shifts in the future from truck-only to intermodal (truck/rail) flows for a portion of the present commodity movements. The model uses TRANSEARCH as the basis for commodity distribution. Future projections of freight flows were obtained by applying growth factors to individual data elements based on expected changes within Wisconsin in industrial output measures, in employment, and in productivity forecasts by county and industry and on BEA forecasts for other states. Forecasts of future productivity levels were obtained from REMI model forecasts.

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[10] W. R. Black, *Transport Flows in the State of Indiana: Commodity Database Development and Traffic Assignment, Phase 2*, Transportation Research Center, Indiana University, Bloomington, July 1997.

[11] Parsons Brinckerhoff Quade and Douglas, Inc., *The Michigan Statewide Truck Travel Forecasting Model*, Final Report, February 1996; Parsons Brinckerhoff Quade and Douglas, Inc., *Analysis of the 1994 Michigan Truck Survey Data*, Technical Report, March 1995; Parsons Brinckerhoff Quade and Douglas, Inc., *Statewide Travel Demand Model Update and Calibration*, Phase II, February 1996, Chapter 3.

[12] Wisconsin Department of Transportation, *Translinks 21 Technical Report Series: Multimodal Freight Forecasts for Wisconsin*, Draft No. 2, 1995.

## A.2.4 Data Sources

The three procedures presented in this section all require some form of economic forecasts; growth-factor methods also require data for allocating base-year truck volumes to industry/commodity groups; and TDMs have additional data requirements. This section discusses several useful sources of data. Additional information about potential data sources is contained in Appendix A of *NCHRP Report 388*.

### *Economic Forecasts*

The procedures presented in this section all require some form of economic forecasts. Indeed, the availability of appropriate forecasts is an important consideration in the selection of independent variables to be used in multivariate regressions and economic-indicator variables to be used in growth-factor methods.

All states have data centers that maintain economic data, many states also produce statewide employment forecasts,[13] and some also have groups (frequently based at universities) that develop more detailed forecasts of employment and/or production by industry. Economic forecasts can also be purchased from several private vendors, including

- Global Insight,[14] which provides an extensive variety of economic data and forecasts;
- Woods and Poole,[15] which develops long-term economic forecasts by county;
- Regional Economic Models, Inc.,[16] which develops regional economic and demographic forecasting models; and
- The Minnesota IMPLAN Group,[17] which also produces software for economic forecasting.

Until recently, the Bureau of Labor Statistics and the Bureau of Economic Analysis produced forecasts of several economic variables by state and industry at 2.5- and 5-year intervals.[18] However, these forecasts are no longer available.

### *Allocation of Truck Volumes to Commodities and Industries*

#### Vehicle Inventory and Use Survey

The Vehicle Inventory and Use Survey (VIUS) is a U.S. Census Bureau dataset collected every 5 years that provides extensive information on truck activity. The VIUS data file includes

[13] Links to state websites that provide employment forecasts can be found at http://www.projectionscentral.com

[14] http://www.globalinsight.com

[15] http://www.woodsandpoole.com

[16] http://www.remi.com

[17] http://www.implan.com

[18] *NCHRP Report 388*, p. 14.

information on annual truck VMT by axle configuration, commodities carried, and state in which the trucks are based (but not the states in which they operate). The industries to which the trucks' owners belong are also identified; however, for many combination trucks, the industry is identified simply as "for-hire trucking." For these trucks, information about commodities carried generally is more useful.

VIUS data are not reported below the statewide level. Thus, commodity or industry-group estimates of VMT that are derived from VIUS could reflect statewide averages, averages for a group of states, or nationwide estimates. If a road carries a significant percentage of long-distance, nonlocal commodity movements, it may be appropriate to use nationwide data or data for a group of states for estimating VMT.

**TRANSEARCH**

TRANSEARCH is a proprietary transportation-related database developed by Reebie Associates (in Greenwich, Connecticut) by combining data from a variety of public sources and supplementing these with information from their own surveys, including an annual survey of motor carriers. The data include estimates of tonnage of manufactured goods transported by transport mode and commodity group, between multi-county regions, and, with somewhat less detail and accuracy, between individual counties.

**Surveys**

More specific information about trucks operating on a given road can potentially be obtained via a roadside survey. Such surveys are unlikely to be warranted solely for use in the pavement-design process. However, the results of previously conducted surveys may be available for this purpose, and, in some cases, there could be other reasons for conducting a new survey.

The conduct of roadside surveys entails both public-sector and private-sector costs. Surveys usually require the active participation of police officers to flag trucks to be surveyed and to ensure the safety of motorists and surveyors alike. Also, surveys can be conducted only at locations that have sufficient space to allow trucks to stop safely to be surveyed.

There are also issues related to the sampling of vehicles. Most roadside surveys are collected during daylight hours only, while many long-haul commodity-carrying trucks travel at night. So a daylight survey may not report local truck traffic characteristics accurately. There may also be significant seasonal or day-of-week variation in truck traffic that would not be captured by a single sample. If not all trucks are to be surveyed, then a sampling plan should be developed that does not introduce bias into the results.

For roads whose truck traffic is all locally generated, or nearly so, another option is to survey the local businesses that operate these trucks. This type of survey is appreciably less expensive than a roadside survey. However, it generally is difficult to select a truly representative sample of truck operators, so it may be necessary to extend such a survey to cover all operators of trucks operating to or from the area.

**Other Sources**

Other sources of data that may be used for allocating truck volumes to commodity/industry groups are the following:

- The Commodity Flow Survey (CFS),[19] a U.S. Census Bureau dataset that contains information on freight flows by origin, destination, transportation mode, commodity group, distance shipped, and shipment size. Data are collected from a quinquennial survey of manufacturing, mining, and wholesale establishments and selected types of retail and service establishments. No data are collected on imports received directly from foreign sources or on shipments from farms.

- *County Business Patterns*,[20] published annually by the U.S. Census Bureau, contains data on employment and wages by county and industry. The data are obtained from Federal Insurance Contributions Act (FICA) reports and exclude data on employment that are exempt from FICA. For employees in the construction, mining, transportation, communications, and utilities industries, place of employment generally refers to a firm's relatively permanent offices rather than to actual worksites.

#### *Truck-Trip Generation*

TDMs require estimates of truck trips generated (i.e., originating or terminating) in each TAZ. Extensive information about truck-trip generation is contained in the *Quick Response Freight Manual*, which includes a compilation of truck-trip generation rates from a number of studies. Tables are provided listing trip generation rates by employee, by square feet of office space, by developed acre, and by linear regression formulas. Rates are listed by land-use category and vehicle size where available. Because of the availability of regional economic forecasts expressed in terms of number of jobs, employment growth is the most common basis for forecasting truck volume growth. However, localized forecasts (such as site development proposals and regional economic development plans) may instead use units of developed acres or square feet of developed space.

Two additional sources of trip-generation data are published by the Institute of Transportation Engineers.[21] The latest editions of these publications contain information obtained from studies released since the *Quick Response Freight Manual* was published. Recent information is available in *NCHRP Synthesis of Highway Practice 298: Truck Trip Generation Data*.

### A.2.5 Conversion to Linear or Exponential Annual Growth Rates

The procedures presented above generally produce forecasts of truck volume for a single future year. For use by the Pavement Design Guide software, these forecasts must be converted to

[19] http://www.census.gov/econ/www/se0700.html

[20] http://www.census.gov/epcd/cbp/view/cbpview.html

[21] Institute of Transportation Engineers, *Trip Generation,* 7th ed., 2003, and *Trip Generation Handbook*, 2nd edition, 2004.

forecasts of either exponential annual growth rates or linear annual growth rates. This conversion will be performed by TrafLoad or by using the formulas presented below.

### *Exponential Growth Rate*

The formula for deriving an exponential annual growth rate using estimates of AADT of SUTs or CTs for any 2 years is

$$r = \left(\frac{T_f}{T_o}\right)^{\left(\frac{1}{Y_f - Y_o}\right)} - 1 \tag{A.7}$$

where:

$Y_o$ is the base year,

$Y_f$ is the future year,

$T_o$ and $T_f$ are the corresponding estimates of AADT of SUTs or CTs (or any other variable of interest), and

$r$ is the estimated exponential growth rate.

In the example of Section A.2.2 (shown in Table A.3), AADT was estimated to be 1,587 in 1999 and forecast to be 2,879 in 2022. With these values, Equation A.7 becomes

$$r = \left(\frac{2,879}{1,587}\right)^{\left(\frac{1}{23}\right)} - 1 = 0.0288$$

In percentage terms, the resulting exponential growth rate is 2.88 percent.

### *Linear Growth Rate*

The corresponding formula for linear growth is

$$b = \frac{T_f - T_o}{Y_f - Y_o} \tag{A.8}$$

where $b$ is the estimated linear growth rate and the other variables are defined as in Equation A.7. Substituting data from the example of Section A.2.2 into Equation A.8 produces the following estimate of linear annual growth rate:

$$b = \frac{2,879 - 1,587}{2022 - 1999} = 61.52 \text{ trucks per year}$$

## ■ A.3 Changes in Vehicle Use

The previous sections of this appendix present procedures for forecasting changes in the numbers of SUTs and CTs operating on a given road. Such changes can be expected to have corresponding effects on the stresses on a pavement over its lifetime—increases in the daily number of trucks operating on the road generally result in increases in the daily stresses on the pavement. However, these changes are not the only ones that may affect these stresses. Daily (or annual) stresses on pavement may also be affected by changes in the following:

1. *Commodity mix.* A shift in the mix of commodities carried on the road toward (or away from) dense commodities will tend to increase (or decrease) pavement stresses.

2. *Payload density.* For an appreciable number of manufactured products, increasing use of protective packaging has caused shipment density to decline. If this trend continues, it will tend to reduce pavement stresses produced by trucks carrying these products.

3. *Size and weight limits.* Changes in truck size and weight limits can have significant effects, in either direction, on truck configurations used and the load spectra of these configurations.

Each of these three types of change in vehicle use will affect the load spectra of affected vehicle classes, and changes in size and weight limits also can have significant effects on the number of trucks in affected vehicle classes. Because the current version of the Pavement Design Guide software is not designed to use forecast changes in load spectra, TrafLoad has no capability for developing such forecasts. However, the effects of these potential changes in vehicle use do warrant some further discussion.

Of the three types of change, the last is potentially the most significant and also is the least predictable. Possible changes in size and weight limits include the following:

- Increases in size limits for existing configurations (with no change in weight limits). For cube-limited shipments, such increases would allow increasing shipment sizes, resulting in heavier axle loads and increasing pavement stresses. For vehicles whose gross vehicle weight (GVW) is limited by the bridge formula, increased length limits may also allow increasing GVWs for weight-limited shipments, also resulting in heavier axle loads and increasing pavement stresses.

- Changes in axle-weight limits. Increases in axle-weight limits would increase pavement stresses; decreases would decrease these stresses.

- Elimination of the 80,000-pound cap on gross vehicle weight (GVW) that currently exists on most roads in the Interstate system. The effects of such a change would depend on the limits that would control GVW in the absence of the 80,000-pound cap. However, most proposals for eliminating this cap (and the limits that currently apply on most roads that do not have this cap) would result in converting some traffic from five-axle semi-trailer combinations to longer combination vehicles (LCVs) with seven to nine axles. On a per-vehicle basis, this change would result in increasing both payloads and pavement stresses, with the increase in payloads generally being greater than the increase in pavement stresses per vehicle. The result generally would be a modest shift in VMT from Class 9 to Class 13 vehicles and a small reduction in total VMT of CTs that would more than balance the increase in pavement stresses per vehicle.

We observe that the Pavement Design Guide software will be capable of analyzing *some* of the effects of changes in size and weight limits. For example, forecasts of AADT for Class 9 and Class 13 trucks could be adjusted to reflect the effects of a shift in usage that is expected to result from possible lifting of the 80,000-pound cap. However, such an analysis would be incomplete. The change in weight limits would have a significant effect on the load spectra of Class 13 trucks (and, most likely, a small effect on the load spectra of Class 9 trucks). Because the results of such a partial analysis could be misleading, it should not be used. More generally, **for the purpose of pavement design, forecasts of AADT by vehicle class should *not* be adjusted for expected shifts between vehicle classes.** Partly for this reason, TrafLoad has not been designed to allow users to specify separate growth rates for each vehicle class (though it is designed to allow separate rates for SUTs and combinations).

A more significant issue relating to size and weight limits stems from the difficulty that exists in forecasting likely changes in these limits and in determining whether such future changes are likely to increase or decrease total pavement stresses. Except in the special case of changes in size and weight limits that have already been enacted but that were not in effect during the most recent year for which historical data are available, it is not possible to predict with confidence whether such changes will increase or decrease pavement stresses. Accordingly, the inability of the current version of the Pavement Design Guide software to use forecast changes in load spectra is of little consequence, and addressing this limitation should be a low priority.

# Appendix B: Coefficients of Variation

The coefficient of variation (CV) is a statistic that is designed to measure the likely error in an estimate in percentage terms. The CV of a variable is obtained by dividing its standard deviation (*s*) by the estimate.

As originally designed,[1] the Pavement Design Guide software would have required estimated CVs for each value of annual average daily traffic (AADT) by vehicle class. Accordingly, a preliminary set of procedures for estimating the required CVs was developed; it was subsequently redesigned so that no use was made of CVs. Accordingly, there is no current need to estimate CVs, and TrafLoad does not produce CVs. However, there is some possibility that a future version of the Pavement Design Guide software will require CVs. For this reason, a slightly edited version of the preliminary procedures for estimating the CVs is presented in this appendix.

In the case of the AADT, there are several sources of error. One source, the use of factor groups in the factoring of Level 2 classification counts, generates enough data to permit estimation of the standard deviation and the associated CV *from this source*. However, other sources (discussed below) do not provide such information. In order to avoid underestimating the overall error in the AADT estimates, the proposed procedure combines a statistical estimate of the CV resulting from the use of factor groups (if used) with subjective estimates of the additional error due to other sources. The application of this procedure to Level 2 sites is described, in some detail, in the first section of this appendix. The estimation of CVs for Level 1 and Level 3 sites is discussed in the second and third sections. And a concluding section discusses an issue relating to how the CVs should be applied by the pavement-design software.

## B.1 Level 2 Sites

Consider a Level 2 classification site for which AADT estimates are developed for each vehicle class (VC) using combined seasonal/day-of-week (DOW) factoring, and assume that the factor group to which it is assigned consists of $n$ Level 1A sites. If factors are developed separately for each of the Level 1A sites, they can be applied to a classification count from the Level 2 site to produce $n$ sets of AADT estimates. These estimates, in turn, can be averaged to produce mean values of AADT for each VC. By construction, these mean values of AADT are identical to the AADT estimates produced by a combined seasonal/DOW factoring procedure.

[1] ERES Consultants and FUGRO-BRE, Draft Report, prepared for NCHRP Project 1-37A, 2000, pp. 414–415.

For each VC, differences between the original $n$ estimates of AADT and the overall mean can be used to infer information about the major source of error in the overall mean, the "within-group" variance among the seasonal and DOW patterns occurring at different sites in the factor group.

The first subsection below presents a procedure for estimating the CV due to the major source of error. TrafLoad can be readily modified to perform all computations required by this procedure. The second and third subsections present more qualitative discussions of other potential sources of error. And the fourth subsection proposes a procedure that could be incorporated into a future version of TrafLoad that would estimate overall CVs for AADT for all Level 2 sites.

## Within-Group Variance

Consider a combined seasonal/DOW factor group[2] consisting of $n$ Level 1A sites, and consider one or more short-duration classification counts obtained at a Level 2 site for a particular vehicle class. Let

$x_i$ = the estimate of AADT for this vehicle class produced by applying factors obtained from site $i$ ($i = 1, \ldots, n$) to the count(s) in question and

$\bar{x}$ = the mean of the $x_i$ (= the estimate produced by applying the seasonal/DOW factors obtained from the entire group of Level 1A sites).

Then the differences between the $x_i$ and $\bar{x}$ can be used to compute the standard deviation, $s$, of $\bar{x}$:

$$s = \sqrt{\frac{\sum_i \left(x_i - \bar{x}\right)^2}{n-1}} \qquad \text{(B.1)}$$

The CV resulting from the use of factors that are derived using data from an entire factor group can be estimated as follows:

$$\text{CV} = \sqrt{\frac{\sum_{i=1}^{n} \left(x_{ij} - \bar{x}\right)^2}{(n-1)\bar{x}^2}} \qquad \text{(B.2)}$$

Similarly, assume that separate seasonal and DOW factors are being used, with the seasonal factors derived using data from n Level 1A sites and the DOW factors derived using data from m Level 1A sites (which may or may not overlap the first n sites). Then the above derivation yields a similar formula for estimating the CV due to the use of seasonal and DOW factors from these two groups:

[2] The current version of TrafLoad uses separate seasonal and DOW factor groups. The development of CVs for these factor groups is presented at the end of this subsection. (See Equation B.3.)

$$CV = \sqrt{\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\left(x_{ij} - \bar{x}\right)^2}{(nm-1)\bar{x}^2}} \qquad \text{(B.3)}$$

It may be noted that the CVs produced by Equations B.2 and B.3 depend, in part, on the days and months on which the short-duration classification counts are obtained. For example, it is likely that, for many factor groups, there will be more variance in the Friday factors than in the Wednesday factors. This difference in variances will result in higher CVs for counts obtained on Fridays than for those obtained on Wednesdays.

## Other Sources of Error

There are several sources of error in the AADT estimates developed for Level 2 sites in addition to those due to within-group variance. The additional sources of error include the following:

1. Equipment errors at the site in question or at the Level 1A sites used as a source of factors.

2. Random variation in the seasonal and DOW patterns of truck volumes at a Level 1A site that is atypical of other sites belonging to the same factor group.

3. The use of a single set of factors developed using data for several vehicle classes (e.g., Classes 8–13) to produce separate AADT estimates for each of the vehicle classes.

4. Some other minor approximations used in the factoring process. (For example, in an area in which the harvest season ends in early November, counts collected early in the month are likely to be higher than counts collected later in the month. Accordingly, use of a November/Tuesday factor is likely to produce an upward bias in AADT estimates obtained from counts collected during the first Tuesday in November.)

5. Deficiencies in the process of associating Level 2 sites with factor groups (discussed below).

Of the above sources of error, the least significant is the third. This limitation in the factoring procedure does not affect the estimates of AADT of combination trucks as a group, but only the distribution of AADT among the individual classes of combinations. Thus, the errors (as in Classes 8–13) tend to cancel each other, though they may influence pavement design.

There are two types of site at which the second source of error, random variation, may be an issue. One type consists of sites with relatively low truck volumes. Random variation in these volumes can produce patterns that are atypical of other sites belonging to the same factor group. For this reason, factoring generally is performed using data that come only from sites with relatively high truck volumes.

Random variation can also be a problem for Level 1A sites at which a significant portion of total truck traffic is influenced by a small number of decision-makers. For example, if a significant portion of truck traffic at a particular site serves a nearby construction site, the seasonal volume pattern at the site may be very different from the patterns at other sites in the state and also from the pattern at the site in the following year (when the construction project may be completed).

The last source of error requires additional discussion. There are two issues: the degree of ambiguity in the assignment of Level 2 sites to factor groups and the representativeness of Level 1A sites in the factor group of the Level 2 site to be factored.

The representativeness issue arises for Level 2 sites in the lower functional systems. As an example, assume there is a single "Rural Other" (RO) factor group that is used for all rural non-Interstate sites. Most or all of the Level 1A sites in this factor group are likely to be principal arterials. Truck traffic at these sites is likely to include some traffic that both originates and terminates at relatively distant locations, as well as traffic that originates or terminates nearby—two types of traffic that can have somewhat different seasonal and DOW patterns. Almost all truck traffic at sites in the lower functional systems, on the other hand, are likely to be locally generated. Accordingly, *if* the two types of truck traffic actually do have different seasonal or DOW patterns, the RO factors (obtained from principal arterials) will tend to produce some unknown bias in the AADT estimates produced for Level 2 sites on the lower systems.[3]

The issue of ambiguity in the assignment of Level 2 sites to factor groups is one that only arises for certain types of factor groups. If a factor group is defined to apply to all sites in one or more functional systems, there is no ambiguity in the process. On the other hand, it may be desirable to use other information in developing the factor groups. Factor groups developed in this way may have lower variances than ones that are based entirely on a functional system, and so Equations B.2 and B.3 will produce lower CVs. However, some additional error may be created in the AADT estimates for individual Level 2 sites because of ambiguity in the definitions of the factor groups.

As an example, consider a state with truck activity on the RO that has distinctly different seasonal patterns in the eastern and western parts of the state, with a blend of the two patterns in the middle. If the RO group is divided into an eastern RO group and a western RO group, some decision will be required as to where to place the boundary between the two groups. Because seasonal patterns at all Level 1A sites are known, it generally will be easy to make sure that all Level 1A sites are placed in the appropriate group. However, seasonal patterns at Level 2 sites generally are unknown, so it is likely that some of these sites will not be placed in the appropriate group. The resulting misassignment will produce a (generally small) additional error in the AADT estimates that is not captured by Equations B.2 and B.3.

## Level 2B Sites

Level 2B sites are Level 2 sites at which only a partial-day manual classification count is available. Procedures for using a partial-day classification count to estimate full-day truck volumes

[3] The alternative of creating a separate factor group for the lower functional systems may be considered. However, this alternative would increase data collection costs and, because of the random variation in truck volumes at sites with relatively low truck volumes, could produce even poorer estimates of AADT.

(by class) for the day of the count are presented in Part 2, Section 3.4. In addition to the errors discussed in the preceding subsection, AADT estimates developed for Level 2B sites incorporate errors that result from the conversion of partial-day counts to estimates of full-day truck volumes. There are two types of site:

1. Sites that are dominated by business-day trucking and for which truck traffic distribution factors (TTDFs) are derived directly from the partial-day counts and

2. Other sites.

As discussed in Part 2, the estimates of full-day truck volumes that were developed for the first type of site will almost always be conservative; for these sites, the probability of underestimating truck volumes for the day in question is negligible. Thus, for these sites, the probability that errors in the partial-day/full-day conversion process will contribute to underestimating AADT will be negligible. However, the Pavement Design Guide software requires error estimates for the AADT *primarily* as an indicator of the extent to which the AADT may have been *under*estimated. Because the errors in this conversion process are almost certain not to contribute to underestimates of AADT, they need not be reflected in CVs that are produced by the Pavement Design Guide software.

The same cannot be said for the other type of site. For these sites, the conversion process may result in either underestimating or overestimating full-day truck volumes on the day in question, and the extent of any underestimation could be fairly significant. Hence, for these sites, this source of error cannot be ignored.

## CVs for Level 2 Sites

The preceding discussion identified several reasons why the AADT estimates are likely to incorporate some errors that are not reflected in the CVs produced by Equations B.2 and B.3; the actual CVs generally will be slightly larger than those indicated by Equations B.2 and B.3. Accordingly, it is recommended that CVs for Level 2 sites incorporate small upward adjustments to the value produced by Equation B.2 (for combined seasonal/DOW factoring) or B.3 (for separate seasonal and DOW factoring). The suggested adjustments are

- 0.01 for all sites,
- An additional 0.03 for sites with ambiguous assignments to factor groups,
- An additional 0.02 for sites in functional systems that are unrepresented or significantly underrepresented among the Level 1A sites from which the seasonal and DOW factors are developed, and
- An additional 0.05 for Level 2B sites that states believe fit into some state-defined composite of the business-day and through-truck TOD patterns.

These adjustments are all *added* to CVs produced by Equation B.2 or Equation B.3.

## B.2 Level 1 Sites

### Level 1A Sites

Level 1A sites are sites at which base-year values of AADT are obtained from classification counts collected at the site during all of, or most of, a 12-month period. The only errors in these values are those resulting from equipment malfunction and from the approximation procedures that are used to estimate truck volumes during any periods of time when the equipment was malfunctioning or out of service. For such sites, 0.01 is a suggested conservative value for the CVs.

### Level 1B Sites

Level 1B sites are sites on the same road as an associated Level 1A site. AADT at Level 1B sites is estimated by obtaining a set of short-duration classification counts at the site and applying factors obtained from the associated Level 1A site. Errors in the AADT estimates at Level 1B sites can be caused by the following: equipment malfunction at either the site or the associated Level 1A site, some of the inherent limitations of the factoring process (such as the use of an average "November/Tuesday" factor for any Tuesday in November), and differences in the seasonal and DOW patterns at the two sites. The CVs at these sites are clearly higher than those at Level 1A sites. If the associated Level 1A site were reasonably close to the Level 1B site in question, it would appear reasonable to assume a CV of 0.02. If the two sites are more distant, with some intersections/interchanges with significant truck routes occurring between the two sites, the CV is likely to be somewhat larger. Accordingly, for Level 1B sites, 0.02 is a suggested default value for the CV, and the user should increase this value (typically to 0.03 or 0.04) when the associated Level 1A site is relatively distant or lies beyond intersections or interchanges with one or more major truck routes.

## B.3 Level 3 Sites

### Level 3A Sites

Level 3A sites are sites that are on the same road as an associated Level 1 or 2 site and for which a volume count exists (for a time period during which traffic was also being counted at the associated site) but for which classification counts do not exist. Traffic volumes at Level 3A sites are sufficiently different from those at their associated sites to warrant separate analyses of the Level 3A sites, but a Level 3A site and its associated site are presumed to have fairly similar percentages of vehicles in the major truck classes.

Two sources of error affect AADT estimates developed for a Level 3A site but do not affect the estimates developed for the associated site:

- The ratio of the short-duration volume counts obtained at the two sites may not accurately reflect the ratio of AADT at the two sites and

- The distribution of total traffic among vehicle classes is likely to differ somewhat at the two sites.

Because of these differences, and particularly because of the second difference, CVs for Level 3A sites should exceed the CVs at the associated sites by 0.10 for associated Level 1 sites and by 0.08 for associated Level 2 sites.[4]

### Level 3B Sites

Level 3B sites are sites for which TrafLoad produces only an estimate of annual average daily truck traffic (AADTT) and identification of the site's Truck Traffic Classification (TTC) group. There are two kinds of Level 3B site.

The first kind of Level 3B site is one for which a recent traffic count exists. For such sites, AADT is estimated by factoring the traffic count, and AADTT is estimated by multiplying AADT by a non–site-specific estimate of percent trucks. As stated in Part 2, Section 3.5, this procedure should only be applied at sites with very low volumes of trucks and buses. Errors in the factoring process and in the estimate of percent trucks are likely to produce fairly high CVs. CVs of 0.30 should be used for these sites.

The second kind of Level 3B site is on a planned new road. For these sites, estimates of total traffic and truck volumes are, at best, developed from travel demand models. Errors in the resulting estimates of AADTT are likely to be quite high. For these sites, use CVs of 1.0.

## B.4 Applying the CVs

The factoring procedure presented in Part 2, Section 3.3 uses one set of factors for each Type 1 VC group. For purposes of discussion, assume that there is one VC group for all SUTs and a second group for all combination trucks (CTs). As a result, for any Level 2 site, the procedures for estimating CVs will produce the same value for the CV for the four SUT vehicle classes and a different value for the CV for the six CT classes. The same will be true for Level 3A sites whose associated site is a Level 2 site. For any other Level 3 sites, and for any Level 1 site, the above procedures produce a single value for the CV for all 10 vehicle classes.

Consider the AADT estimates produced for the six CT classes for a Level 2 site. These errors will be correlated with each other (because of imperfections in the factors applied to the six classification counts), but the correlations will not be perfect (in part, because of differences in the seasonal and DOW patterns exhibited by the six classes). The Pavement Design Guide soft-

[4] A lower increment is proposed for associated Level 2 sites because of the tendency of errors from independent sources to partially cancel each other. This tendency has very little effect for associated Level 1 sites (because Level 1 sites have very small CVs), but it is likely to have a moderate effect for associated Level 2 sites.

ware, on the other hand, can be designed to assume that the errors are totally uncorrelated or that they are perfectly correlated. Because uncorrelated errors tend to cancel each other, the former option will tend to understate the effects of the partially correlated errors while the latter option will tend to overstate these effects. The goal of producing conservative pavement designs suggests that it would be preferable for the Pavement Design Guide software to adopt the latter option, i.e., to assume that the errors for all CT classes are perfectly correlated. Though the discussion here focused on Level 2 sites, this assumption appears to be appropriate for Level 1 and 3 sites as well.

In the case of the SUT classes, the conclusion is somewhat different. In many areas, there is likely to be substantial correlation between the AADT errors for Vehicle Classes 6 and 7 (three-axle trucks and trucks with four or more axles). However, these two classes are likely to exhibit seasonal and DOW patterns that differ greatly from those exhibited by buses (Class 4) and by two-axle, six-tire trucks (Class 5). Hence, it would be preferable for the Pavement Design Guide software to use three independent estimates of AADT error for SUTs: one for Class 4, one for Class 5, and one for Classes 6 and 7.

*Part 2*

# Guidelines for Collecting Traffic Data to Be Used in Pavement Design

# 1.0 Introduction

The AASHTO Technical Committee on Pavements has undertaken an effort to develop an improved guide for the design of pavements. This effort, undertaken under NCHRP Project 1-37A, *Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures*[1] (the "Pavement Design Guide"), will provide engineers with practical and realistic pavement design procedures and software that use existing mechanistic-empirical principles. The mechanistic-based distress prediction models used in the Pavement Design Guide will require the input of specific data for each axle type and axle-load group.

Under NCHRP Project 1-39, a software system, TrafLoad, has been developed for generating the traffic data required by the Pavement Design Guide software. This part of the report presents guidelines for collecting traffic data required by TrafLoad and provides brief descriptions of some of the analyses that TrafLoad performs in the course of converting these data into inputs required by the Pavement Design Guide software. The presentation is designed to complement the more extensive discussion of the collection of traffic data that is contained in the FHWA's *Traffic Monitoring Guide* (2001).[2] A user's manual for TrafLoad is presented as Part 3, which is available online at http://trb.org/news/blurb_detail.asp?id=4403.

This introduction presents a brief summary of the data required by the Pavement Design Guide software, followed by an outline of the remainder of Part 2.

## ■ 1.1 Traffic Data Requirements for the Pavement Design Guide Software

The Pavement Design Guide distinguishes three broad levels of input data that vary with the quality of information that the designer has about the loads to be applied at the site. These input levels are described as sites for which the designer has 1) good, 2) fair, or 3) poor information about the truck volumes and axle loads to be applied, with Level 3 further divided into Levels 3A and 3B.

Corresponding to each input level, the Pavement Design Guide software requires site-specific, region-specific, or default values for several types of traffic data. In addition, there are other types of optional traffic data for which the software can use state-supplied values, or the software can use default values that have been developed in NCHRP Project 1-37A from national data.

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[1] http://www.2002designguide.com/

[2] http://www.fhwa.dot.gov/////ohim/tmguide/index.htm

**Table 1.1 Traffic Data Elements to be Produced by TrafLoad**

| |
|---|
| $AADT_i$[a] by direction for up to 13 VCs (*i*) (1, 2, and 3A)[b] |
| Annual Average Daily Truck Traffic (all classes, combined) (3B) |
| Truck Traffic Classification Group[c] (3B) |
| Monthly Traffic Distribution Factors by VC (1, 2, and 3A) |
| Axle-Load Distribution Factors – Site Specific (1) |
| Axle-Load Distribution Factors – Regional (2) |
| Axle-Load Distribution Factors – Statewide (3) |
| Linear or Exponential Growth Rates |
| Directional Distribution Factors[d] (1, 2, and 3A) |
| Axle Groups per Vehicle (for each VC) |
| Hourly Distribution Factors (1, 2, and 3A) |

[a] Annual average daily traffic by VC (*i*).

[b] Numbers in parentheses identify the input levels for which the data are used.

[c] Each Level 3B site is assigned by the user to a truck traffic classification group. This assignment is passed by TrafLoad to the Pavement Design Guide software without modification.

[d] Because all $AADT_i$ estimates will be provided separately by direction of travel, all corresponding directional distribution factors for Level 1, 2, and 3A sites will be set to 1.0.

TrafLoad has been designed to be the principal source of traffic data for the Pavement Design Guide software. A summary of the traffic data elements produced by TrafLoad for use by the Pavement Design Guide software is presented in Table 1.1. TrafLoad currently allows the use of the 13 standard FHWA vehicle classes (VCs) (see Table 1.2) and/or an aggregation of these classes into a smaller set of user-defined classes.[3] The latter option makes it possible to develop pavement designs for sites for which vehicle classification data are available only by length class.

## ■ 1.2 The Remainder of Part 2

Chapter 2.0 of Part 2 presents in some detail the development of a program for collecting the weight data that TrafLoad requires for generating axle-load distribution factors and estimates

[3] The Pavement Design Guide software currently allows the use of up to 13 classes.

**Table 1.2 FHWA Vehicle Classes**

| | |
|---|---|
| 1. | Motorcycles |
| 2. | Passenger cars |
| 3. | 4-tire trucks |
| 4. | Buses |
| 5. | 2-axle 6-tire trucks |
| 6. | 3-axle trucks |
| 7. | 4+ axle trucks |
| 8. | 3-4 axle single-trailer combinations |
| 9. | 5-axle single-trailer combinations |
| 10. | 6+ axle single-trailer combinations |
| 11. | 5-axle multi-trailer combinations |
| 12. | 6-axle multi-trailer combinations |
| 13. | 7+ axle multi-trailer combinations |

of axle groups per vehicle for each VC. TrafLoad is capable of using data provided by the state to generate these values for every site for which such data are requested, though the quality of the estimates will be higher for Level 1 sites (for which site-specific data are provided) than for Level 2 or 3 sites.

Chapter 3.0 presents a similar discussion of the development of a program for collecting the classification counts TrafLoad requires for generating most of the other traffic data required by TrafLoad. As indicated in a footnote to Table 1.1, all estimates of annual average daily traffic by VC ($AADT_i$) for Level 1, 2, and 3B sites are produced by direction, so the corresponding directional distribution factors are set to 1.0. For Level 3B sites, no directional information is supplied to TrafLoad, so it does not produce directional factors for these sites. Instead, the Pavement Design Guide software will use its own default values.

The final chapter discusses the collection and handling of the traffic data required to create the necessary datasets.

# 2.0 Weight Data

The Pavement Design Guide procedure, developed under NCHRP Project 1-37A, performs a detailed analysis of pavement deterioration caused by single, tandem, tridem, and quad axles of varying weights. Accordingly, instead of estimates of 18,000-pound equivalent single-axle loads (ESALs), the Pavement Design Guide software requires estimates of the numbers and weights of four types of axles: single, tandem, tridem, and quad.

For each VC and axle type, it is necessary to estimate the percentages of axles falling into each of several specified load ranges. These load ranges are listed in Table 2.1. For single axles, there are thirty-eight 1,000-pound load ranges covering the 3,000- to 41,000-pound weight range plus one range for lighter axles. For tandem axles, there are thirty-eight 2,000-pound ranges covering the 6,000- to 82,000-pound weight range, etc.

For each VC, the Pavement Design Guide software requires (and the Project 139 software, TrafLoad, produces) between one and four of these load distributions, also known as load spectra. The Pavement Design Guide software treats the load spectra for each VC as being constant over time. The load spectra are obtained by aggregating vehicle weight data collected at one or more weigh-in-motion (WIM) sites.

The WIM data used for developing the load spectra also produce the average number of axles of each type associated with each class of vehicle. For example, a standard five-axle tractor semi-trailer has one single axle and two tandem axles. Thus, to compute the total load applied by 1,000 of these trucks, it is necessary to multiply the single-axle load spectrum by 1,000 and the tandem-axle spectrum by 2,000. The expected number of axles of each type for a given number of vehicles in a particular VC is developed from WIM data in conjunction with the development of the load spectra.

For any pavement project, the required load spectra are developed by TrafLoad using data collected from WIM equipment either on the same road at a site reasonably near the pavement project (Pavement Design Guide Level 1 data), or from WIM data collected elsewhere (Levels 2 and 3). From these same data, TrafLoad develops the number of axles of each type associated with each class of vehicle.

The first section of this chapter discusses potential sources of error in the load spectra so that readers can understand what is important to ensure accurate load estimates, why some data-collection plans are better than others, and why specific data are requested for developing accurate load estimates. Section 2.2 provides brief descriptions of the three levels of WIM data collection that TrafLoad supports. Sections 2.3–2.5 discuss in more detail the three levels of data collection and provide guidelines for collecting the required data. And the final section of this chapter presents additional information on the collection of weight data.

## Table 2.1 Load Ranges Used for Load Spectra

| Load Range | Upper Limit of Load Range (kips[a]) 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 | | |

[a] One kip = 1,000 pounds = 4.448 kN.

## 2.1 Sources of Estimation Error

To create a data-collection and analysis process that produces accurate axle-load distributions for pavement design, errors resulting from the following sources must be minimized:

1. The calibration of the data-collection equipment,
2. Differences in axle-weight distributions among different VCs,
3. Differences in vehicle loading rates between one road and another,
4. Differences in vehicle load by direction,
5. Variation in axle weights caused by changes in loading conditions by time of day,
6. Variation in axle weights caused by changes in loading conditions by day of the week,
7. Variation in axle weights caused by changes in loading conditions by time of year, and
8. Future changes in vehicle loading conditions.

The first of these sources of error, **calibration error**, is a function of equipment operation. It is important that highway agencies calibrate their data-collection equipment carefully and use that equipment in locations where it can operate correctly. WIM equipment is particularly sensitive to calibration error, and calibration error is affected by a variety of factors, including sensor installation and condition, pavement roughness and condition, environmental conditions, and even roadway geometrics. Individual WIM sensor technologies are affected differently by these factors. Additional information about the selection, calibration, and operation of WIM equipment is contained in *NCHRP Report 509*.[1]

The second source of error, **differences in weight among different VCs**, is handled by separating the axle-weight data of one class of vehicles from those of other classes. Thus, separate axle-load distribution tables are required for each class of vehicles. VC may be defined by each highway agency. TrafLoad currently allows the use of the 13 standard FHWA VCs and/or an aggregation of these classes into a smaller set of user-defined classes. The latter option makes it possible to develop pavement designs for sites for which vehicle classification data are available only by length class.

To compute accurate load estimates, a highway agency must also collect vehicle classification volume data using VCs that can be correlated directly to the weight data that the agency collects. Chapter 3.0 provides instructions on how to collect and manipulate the data needed to determine the number of vehicles, by class, that will operate on the pavement being designed.

The third and fourth sources of error arise because **different roads can serve similar trucks that have very different sets of loading characteristics. This is also true for different direc-**

[1] Hallenbeck, Mark, and Herbert Weinblatt, *NCHRP Report 509: Equipment for Collecting Traffic Load Data*, Transportation Research Board of the National Academies, Washington, D.C., 2004.

**tions of travel on the same road.** These variations in loading characteristics are caused by differences in the commodities being carried and by differences in the percentages of trucks that are loaded. For example, on a road leading to a gravel pit, the lane of travel leading away from the pit will experience heavier trucks than the lane of travel leading to that pit, because most trucks leave the pit full but return to the pit empty. For this example, the same number of trucks and the same type of trucks operate in both directions, but the load experienced in each direction is very different. This same effect occurs when two parallel county arterials of similar size carry very different heavy-vehicle loads. The loads are determined not by the size of the arterials but by the nature of the economic activity associated with each road. (For example, one arterial may lead through land zoned for residential use, while another leads through land zoned for warehouse use.)

The next three sources of error, **variation by time of day, day of week, and time of year**, also occur because the kinds of trucks using a road can change during these time periods. Weekday and weekend traffic can be very different because of the presence or absence of truck traffic generated by businesses that are open only during weekdays. Similarly, vehicle weights can change by time of day. Lastly, a number of phenomena can cause changes in vehicle weights over the course of a year. For example, in agricultural areas trucks may be very heavy during some times of the year (e.g., harvest time) and lighter during others. In some states, legal weight limits change over the course of the year; loads can be legally increased during the winter months when pavement is strong but must be reduced during the spring-thaw months when the subgrade strength is low and heavy loads cause serious pavement damage. (Note that spring load restrictions are also a source of variation from one road to another, as some states only apply load restrictions to minor roads or to roads in specific geographic areas of the state.)

Finally, loading rates can change over the years as weight laws change or as economic activity affecting a roadway changes. The Pavement Design Guide software assumes that the shapes of the normalized axle-load distribution curves do not change from year to year, and the research team makes the same assumption in TrafLoad. The research team adopts this assumption both for consistency with the Pavement Design Guide software and because the research team cannot accurately forecast these types of changes. While it is possible to forecast changes in truck volumes on the basis of expected changes in economic activity, it is extremely difficult to forecast the effects such changes will have on axle-load distributions. Load distributions are a function of

- Truck size and weight laws (will changes in regulations encourage heavier gross vehicle weights but cause those weights to be carried on more axles?),

- The commodity characteristics of specific routes (do the commodities "cube out," or are loads limited by weight laws?), and

- The fraction of loaded and unloaded trucks on the roadway (which is a function of both trucking fleet efficiency, types of haul, and the nature of truck ownership and use, all of which are difficult to forecast).

This chapter deals exclusively with creating a data-collection program that, in conjunction with the TrafLoad software, helps an agency account for variations in vehicle loads by location, time of day, day of week, and time of year. Estimating the number of vehicles (by class) is addressed in the next chapter, and equipment calibration is covered in a companion report.[2]

Seasonal variation in axle weights are of particular interest in pavement design because the pavement damage caused by axle loads is significantly affected by seasonal variations in soil conditions such as wetness, freezing, and thawing. As a result, the Pavement Design Guide software is designed to use separate sets of load spectra for each month of the year and to incorporate the effects of seasonal variations in the load spectra in the resulting pavement designs, and TrafLoad has been designed to produce such seasonally varying load spectra.

Because WIM data collection tends to be difficult and expensive, highway agencies cannot afford to collect all the data needed to precisely measure and account for each source of variation for all pavement design efforts. Consequently, a series of data-collection options are provided to help states optimize the amount of data they collect, given the accuracy of the load estimate they require and the funding available for data collection.

In general, the recommended program for collecting WIM data is stratified into three levels of data collection. Each level corresponds to how well an agency understands the location component of truck weight variation. Level 1 design is for sites where site-specific WIM data are available, and thus errors associated with locational differences are negligible. Level 2 design is for sites where some general knowledge of loading rates can be applied but actual WIM data have not been collected. Level 3 design is for sites where knowledge of loading rates is limited enough that statewide average loading rates are the best available. Each of these three general conditions is discussed further in the remainder of this chapter.

## ■ 2.2 Alternative Data-Collection Programs

There are three levels of axle-load distribution (or load spectra) data in the data collection and analysis:

- Site specific,
- Truck weight road group (TWRG), and
- Statewide averages.

These different levels of data collection and application are introduced below and discussed in more detail in subsequent sections of this chapter.

### Site-Specific Load Distribution Data

Site-specific data collection means that the state is able to accurately weigh trucks on the road on which the new pavement will be laid. The axle-weight data-collection site must be located

[2] Ibid.

so that the traffic measured by the WIM scale is basically the same as the traffic that operates in the design lane of the roadway segment being designed.

The intent of the definition of "site specific" is to allow a state to collect data on the same roadway as, but possibly at a location somewhat removed from, the pavement project's segment limits. For example, the WIM scale used to provide data on I80 in Wyoming might be located at the Utah-Wyoming border on I80. The corresponding pavement project could easily be 50 (or more) miles away on I80 in Wyoming. Because little change in trucking activity occurs between those locations, data from the border-crossing WIM would be considered site specific. However, data collected on I80 20 miles *east* of Salt Lake City would not be considered site specific for a pavement 20 miles *west* of Salt Lake City on I80 because considerable change in loading rates can occur within major metropolitan areas.

In addition, Level 1 data collection assumes that the highway agency will use the WIM data collected to calculate the axle-load distribution tables directly. This means that the agency must be satisfied with the performance of the WIM scale being used. *The scales used must be properly calibrated, and quality control checks must indicate that the data are valid.* (If the agency uses a device that is not adequately calibrated, the site-specific data should be used only to identify which TWRG dataset is most appropriate for that pavement project; and a Level 2 design, as discussed in Section 2.4, should be performed.)

TrafLoad accepts WIM data collected over a 12- to 24-month period as well as WIM data collected over shorter periods of time. The software uses seasonal load spectra datasets that contain data for the 12 months of the year as the basis for imputing seasonal adjustments to data collected for periods of less than 12 months. The process for performing these adjustments (presented in Part 4, which is available online at http://trb.org/news/blurb_detail.asp?id=4403) uses seasonal load spectra factor groups, which are discussed in Section 2.3. These factor groups are similar to automatic traffic recorder (ATR) factor groups except that sites are assigned to a group on the basis of seasonal variation in axle weights instead of seasonal variation in the traffic volume.

Errors in the axle distributions at site-specific locations usually are due to equipment and calibration errors and errors caused by sampling of the traffic stream. In general, these site-specific estimates are relatively good.

## TWRG Data

TWRG axle-load distributions are summary load distributions that represent axle loads found on roads with similar truck weight characteristics. These groups are similar to ATR factor groups, in which all roads in a group have similar seasonal volume patterns. In the case of TWRGs, however, all roads in a group have similar axle-load distributions. Because TWRGs are designed to have similar axle-load distributions rather than similar volume patterns, TWRGs generally will differ from the seasonal and day-of-week (DOW) factor groups.

The FHWA's *Traffic Monitoring Guide* recommends TWRGs as a way for highway agencies to collect, summarize, and report summary statistics for groups of roads. The intent is to group roads by their trucking characteristics so that the load spectra on all the roads in a group are fairly similar. Road characteristics that can be used to define road groups include the region of the state, particularly where the economic activity in a state differs from region to region (e.g., agricultural areas versus mining areas); the nature of the commodities being carried (e.g., roads leading to a port versus roads in other parts of an urban area); and sometimes the type and location of the facility (e.g., urban freeway versus suburban arterial).

The *Traffic Monitoring Guide* expects TWRGs to be state specific, but multiple states can work together to create regional load distribution tables if the states involved in the regional effort have similar truck weight laws. (Different truck size and weight laws would invariably lead to different truck weight characteristics and thus different axle-load distribution tables.)

TWRG axle-loading tables are needed because most states do not have (and cannot afford to collect) site-specific WIM data for the majority of pavements they design each year. However, these tables produce poorer estimates of pavement stresses than tables derived using site-specific data. Recent analyses of California data indicate that, for combination trucks, TWRGs produce mean absolute percentage errors (MAPEs) for pavement stresses (as measured in 18,000-pound equivalent single-axle loads) of 17–20 percent,[3] varying with the degree of disaggregation of the TWRGs and the care with which they are constructed. In contrast, the analyses indicate that site-specific WIM data collected over a 48-hour period produces a MAPE of only 7 percent (exclusive of equipment and calibration error).

Because load distributions vary significantly, it is important that the pavement designer understand the approximate range of loads being applied. Using such knowledge greatly improves the reliability of the pavement design. Figure 2.1 shows the tandem-axle distributions found at three different WIM scales. Figure 2.1(a) represents a site where a large percentage of trucks are operating empty or in a partially loaded condition. Figure 2.1(b) represents a moderate loading condition, while Figure 2.1(c) illustrates a site with very heavy (but predominantly legal) loading. Ideally, each of these three sites should be in a different TWRG.

If each of the three roads carries the same number of trucks, the different loading conditions should result in three very different pavement designs. The challenge for each state is to determine which roads (and directions of travel in some cases) are typified by which of these (or other) basic loading conditions. This grouping process requires analysis of a state's existing weight data and trucking patterns, and it results in the creation of appropriate TWRGs. (Note that states may easily have more than three loading conditions. Also note that the TWRGs generally will not correspond to the groups used for factoring classification counts. The number of TWRGs distinguished in the analyses of California data varied between 3 and 10, with the best results obtained using a set of 10 TWRGs that distinguished functional system, region, and direction of travel.)

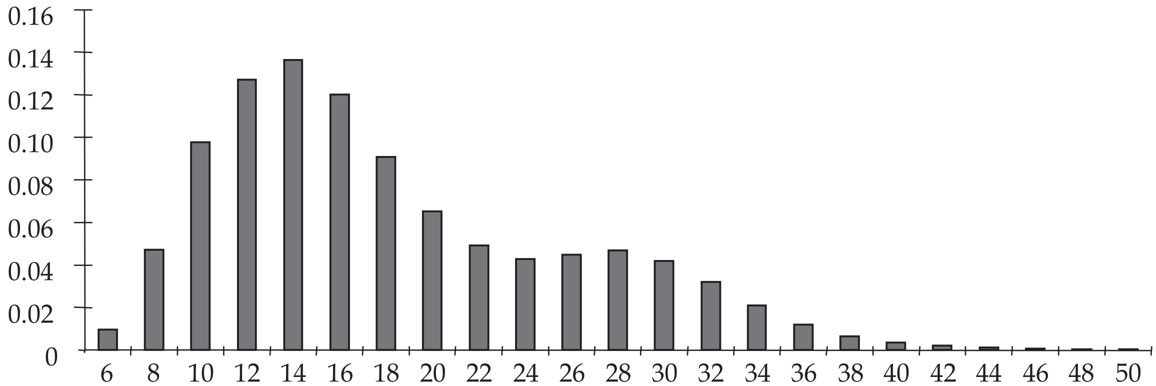
For each TWRG, a set of tables for the axle-load spectra will be created by the software. These tables summarize the distribution of all axle loads measured for trucks weighed at scales within each group of roads. In addition, for each TWRG, the average number of axles for each VC will be computed.

All or most WIM scales in a state or multi-state region should be assigned to a TWRG. For each truck class, the axle weights of all trucks in the class weighed at the scales in a given TWRG are then used by the software to compute a corresponding set of load spectra.

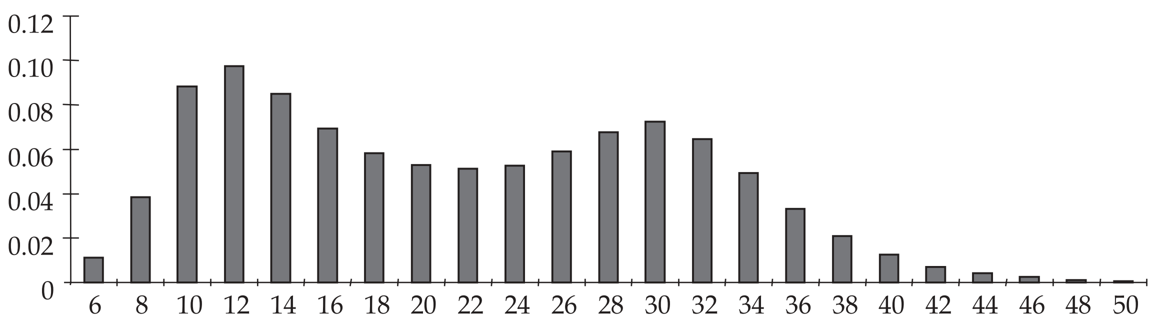
[3] Cambridge Systematics, Inc., *Accuracy of Traffic Load Monitoring and Projections*, Volume II, The Accuracy of ESALs Estimates, prepared for FHWA, February 2003, Tables 4.5 and 5.1.

## Figure 2.1 Load Distributions for Tandem Axles of FHWA Class 9 Trucks at Three Different Sites

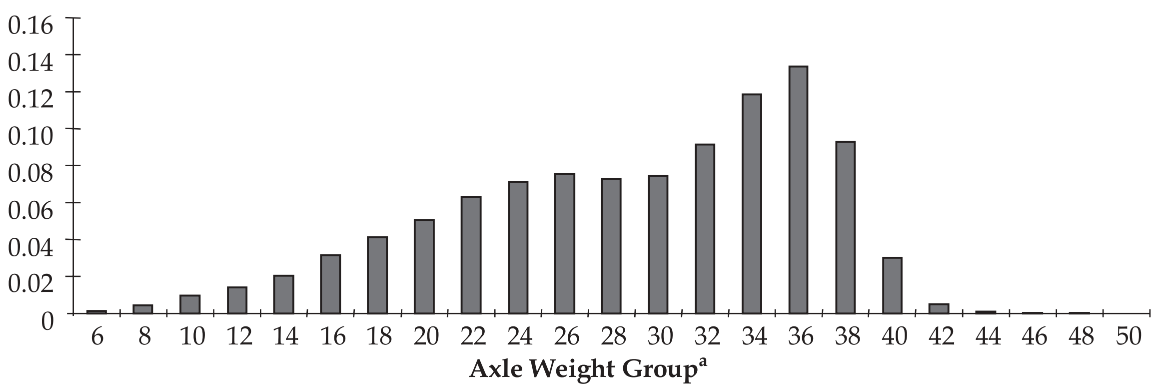
### Figure 2.1(a) Lightly Loaded Trucks
**Fraction of Tandem Axles in Weight Group**




### Figure 2.1(b) Moderately Loaded Trucks
**Fraction of Tandem Axles in Weight Group**




### Figure 2.1(c) Heavily Loaded Trucks
**Fraction of Tandem Axles in Weight Group**




[a] Each group is identified by the maximum weight, in thousands of pounds, for the group.

The error associated with applying the load spectra calculated using TWRG data is caused by the error sources that affect site-specific load distributions (i.e., the equipment error and the sampling error associated with less than complete annual data being collected at each of the TWRG WIM sites) and by two additional error sources: the error associated with using an average condition for several roads to represent a specific road and the error associated with assigning a given road to a specific TWRG. These two errors are considerably larger than the first error.

### Statewide Load Distribution Data

The last type of axle-load distribution, statewide, should be used only to provide load estimates when the state highway agency has little knowledge of the loads trucks will carry on the roadway being designed. This means that the agency has little confidence in its ability to predict the TWRG for the pavement section. The above-cited analyses indicate that use of contemporaneous statewide load data produces MAPEs of about 25 percent for combination trucks.[4]

Statewide load distributions are obtained (for each VC) by combining the data collected from all WIM sites in a state. These distributions (most likely moderate distributions) then serve to represent average conditions that can be used whenever something better is not available. Figure 2.2 illustrates a possible statewide distribution for tandem axles of Class 9 trucks. (This distribution was obtained by averaging the three load distributions shown in Figure 2.1.)

Statewide distributions are the least reliable load spectra for pavement design. Their use is an acknowledgment that the state has little idea about the vehicle weights being carried on the pavement in question. However, because these distributions represent average load conditions, they will be poor representations for pavements that experience very heavy or very light loading conditions. Thus, the pavement design will be reasonable if not optimal.

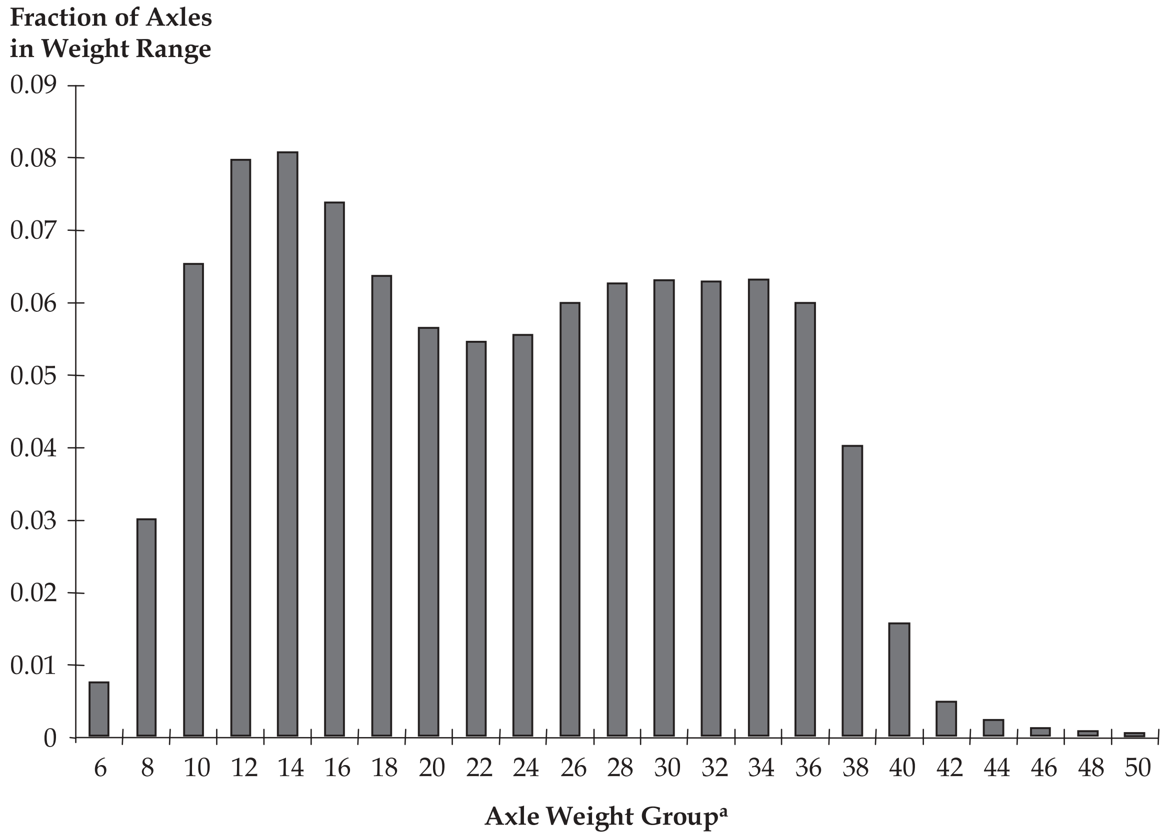
## 2.3 Level 1 WIM Sites

Level 1 WIM sites are sites at which design-lane WIM data have been collected for some period of time. These include sites at which WIM data have been collected continuously for a year or more, as well as sites at which data have only been collected for one or more short periods of time. Data collected at these sites are used by TrafLoad to produce one or more sets of load spectra for each site. All data should be quality checked and collected using accurately calibrated WIM equipment.

The following subsections describe the way in which TrafLoad uses WIM data and other information required by TrafLoad. The discussions include recommendations for developing a WIM data-collection system that will produce data that can be used effectively by TrafLoad.

[4] Ibid., Table 4.5.

**Figure 2.2 A Typical Statewide Load Distribution for FHWA Class 9 Trucks**




[a] Each group is identified by the maximum weight, in thousands of pounds, for the group.

## WIM Inputs to TrafLoad

For each Level 1 site, TrafLoad requires a current load spectra dataset. For some sites, TrafLoad should also be provided with a seasonal load spectra dataset. Each of these datasets consists of separate sets of load spectra by month and DOW, and there is a maximum of 84 sets of load spectra for each dataset. TrafLoad takes advantage of the resulting disaggregate sets of load spectra in two ways.

First, for any month for which all seven DOW sets of load spectra are available, the monthly load spectra are developed by averaging the seven sets of load spectra in a way that avoids overweighting or underweighting the load spectra collected on any particular day of the week.[5] For all months for which all seven DOW load spectra are available, this form of averaging

[5] For each VC, the averaging procedure uses the monthly average DOW traffic volumes for that class to obtain weighted averages of the seven DOW load spectra for the class. The procedure is described in Section 3.3 of Part 4, which is available online at http://trb.org/news/blurb_detail.asp?id=4403, and is based on the AASHTO procedure for summarizing traffic data (American Association of State Highway and Transportation Officials, *AASHTO Guidelines for Traffic Data Programs*, 1992, Chapter 5: Summarizing Traffic Data).

produces monthly load spectra that have no DOW bias. To improve the probability of obtaining complete sets of seven DOW load spectra, it is recommended that, if practical, WIM data from continuously monitored sites be collected and stored for at least 2 weeks of each month or, even better, for the entire month. (Collecting data for the entire month has the additional benefit of avoiding time-of-month bias, though this type of bias is usually much smaller than DOW bias.)

Secondly, for a site and month for which only a partial set of DOW load spectra are available (i.e., load spectra for 1 to 6 days of the week), TrafLoad uses information about how pavement damage factors for each VC vary by DOW to produce estimated load spectra for the month that combine the available DOW load spectra with information about the extent to which the load spectra for the other days of the week are likely to be more or less damaging than the available load spectra. (See Part 4, Section 3.3, available online at http://trb.org/news/blurb_detail.asp?id=4403.)

The seasonal and current load spectra datasets are discussed further in the following subsections.

## Continuous WIM Sites and Seasonal Load Spectra Datasets

Seasonal load spectra datasets are obtained from data collected at some or all of the continuous WIM sites in the states. The most significant use of data from these datasets is the development of monthly adjustment factors. These factors are used to adjust the load spectra obtained at other WIM sites for a given month so that they are reasonably representative of the load spectra for another month for which reliable WIM data are unavailable.

If load spectra are available by month and DOW, data from seasonal load spectra datasets are also used to produce DOW adjustment ratios that are used in developing a set of monthly load spectra from a set of DOW load spectra for a month for which one or more DOW load spectra are missing.

Each seasonal load spectra dataset must contain data for each month of the year, with a full week of data for at least one of these months (and preferably for all months). Ideally, this condition is met by defining a seasonal load spectra dataset to consist of 12 consecutive months of data. However, to allow for outages of WIM equipment, the data-collection period represented by a seasonal load spectra dataset may be extended to cover a period of up to 24 months. If, for any month of the year, the resulting dataset contains 2 months of data, only the data for the later month are used.

Seasonal load spectra datasets are developed using data collected from a single lane (or design lane) using WIM equipment that has been consistently calibrated over the entire collection period. Each such dataset should be collected over a period during which seasonal changes in axle weights are believed to be reasonably representative of those that currently occur at the site. Month-to-month variations in calibration should be minimized, as should any secular upward or downward drift in calibration. TrafLoad will interpret any such variations or drift as representing actual changes in axle weights, and, as a result, it will assume that similar variations in axle weights also occur at sites at which only 1 or 2 months of WIM data have been collected.

## Seasonal Load Spectra Factor Groups

To allow the application of seasonal adjustments to load spectra obtained from various WIM sites, each state must establish a set of seasonal load spectra factor groups and assign every WIM site in the state to one of these groups. Furthermore, each of these groups must contain at least one WIM site for which a seasonal load spectra dataset exists. For each of these groups, the software will use the seasonal load spectra datasets to develop a set of monthly adjustment factors.

The assignment of WIM sites to seasonal load spectra factor groups is based on how average pavement damage per vehicle varies over the course of a year. A convenient unidimensional measure of this last quantity (and one that is used by TrafLoad) is average 18,000-pound ESALs per vehicle (average ESALs per vehicle, or AEPV). The WIM sites that are assigned to a given load spectra factor group should have values of AEPV that exhibit similar seasonal variations; i.e., the peaks and valleys in the AEPV should occur at the same time of year, and the ratios between the maximum and minimum values of AEPV should be similar.

A reasonable starting point for the development of seasonal load spectra factor groups would be to distinguish three sets of functional systems: urban (U); rural Interstate (RI); and rural other (RO). In addition, any set of roads that has its own set of seasonally varying weight limits (such as spring-thaw restrictions or higher weights during winter freeze) should be assigned to a separate factor group or to separate factor groups. In establishing these factor groups, consideration might also be given to the way in which the month of the heaviest truck loadings varies regionally (e.g., as a result of differences in harvest season).

As observed above, each seasonal load spectra factor group must include at least one WIM site for which a seasonal load spectra dataset exists. When establishing seasonal load spectra factor groups, a state is likely to use its own WIM sites for this purpose. However, this is not a requirement. Any WIM site at which the seasonal variation in truck weights is believed to be typical of the seasonal load spectra factor group can be used.

## WIM VC Groups

The seasonal adjustments to the load spectra are performed separately for each of several user-defined VC groups. These VC groups are referred to as WIM VC groups to distinguish them from the VC groups (Type 1 VC groups) that are used for factoring classification counts. (See Section 3.3.)

The principal purpose of allowing the use of WIM VC groups is to make sure that, for any VC, the load spectra adjustments are based on a reasonable amount of data. For this purpose, any uncommon VC should be grouped with a more common class. In particular, any VC that is not commonly observed on a daily basis at all WIM sites that are used for seasonal load spectra datasets should be grouped with a more common class. However, because of a limitation in the current adjustment procedure, it is recommended that all common VCs be assigned to separate WIM VC groups.

## Current Load Spectra Datasets

Current load spectra datasets can be obtained from most or all WIM sites. There are two principal uses for a current load spectra dataset obtained for the design lane at a particular site:

- It can be used in designing pavement for that site; and
- It can be used in the development of a set of load spectra for a TWRG to which the site is assigned. (The development and use of load spectra for TWRGs is discussed in Section 2.4.)

Since the current load spectra dataset for a particular site may be used for designing pavement for that site, it is important that this dataset provide as good a set of estimates of the current load spectra at the site as practical. Accordingly, *a current load spectra dataset should contain data collected using calibrated WIM equipment* over a recent period when the axle loads are believed to be representative of the current axle loads observed at the site. The data-collection period may be up to 24 months long.

If a seasonal load spectra dataset exists for a particular site, it may also be used as the current load spectra dataset for the site. Alternatively, a separate dataset that is believed to better reflect current conditions may be used.

If a current load spectra dataset contains less than 12 months of data, the software uses monthly adjustment factors to impute load spectra for the missing month. For a particular site, the monthly adjustment factors that are used normally[6] are the ones developed for the seasonal load spectra factor group to which the site belongs.

In developing a current load spectra dataset for a particular site, it is important to minimize calibration error. To the extent practical, use of portable sensors should be minimized, since their effects on the road profile adversely affect data accuracy.

There is no minimum on the number of days of data incorporated into a current load spectra dataset. However, increasing the amount of data collected decreases the amount of imputation required to produce a complete set of monthly load spectra and increases the reliability of the resulting values. Imputation is unnecessary when data are collected continuously over the course of a year, and relatively little imputation is required when data are collected over 1-week periods in 3 or 4 months uniformly spread over the year. Using data that are collected in only 1 month places appreciably greater reliance on the imputation procedure. (However, even in this case, the software's imputation procedure is likely to produce a better representation of the seasonally varying pavement loads than would the simple alternative of using the load spectra that are observed in 1 month to represent the load spectra that occur in the other 11 months of the year.)

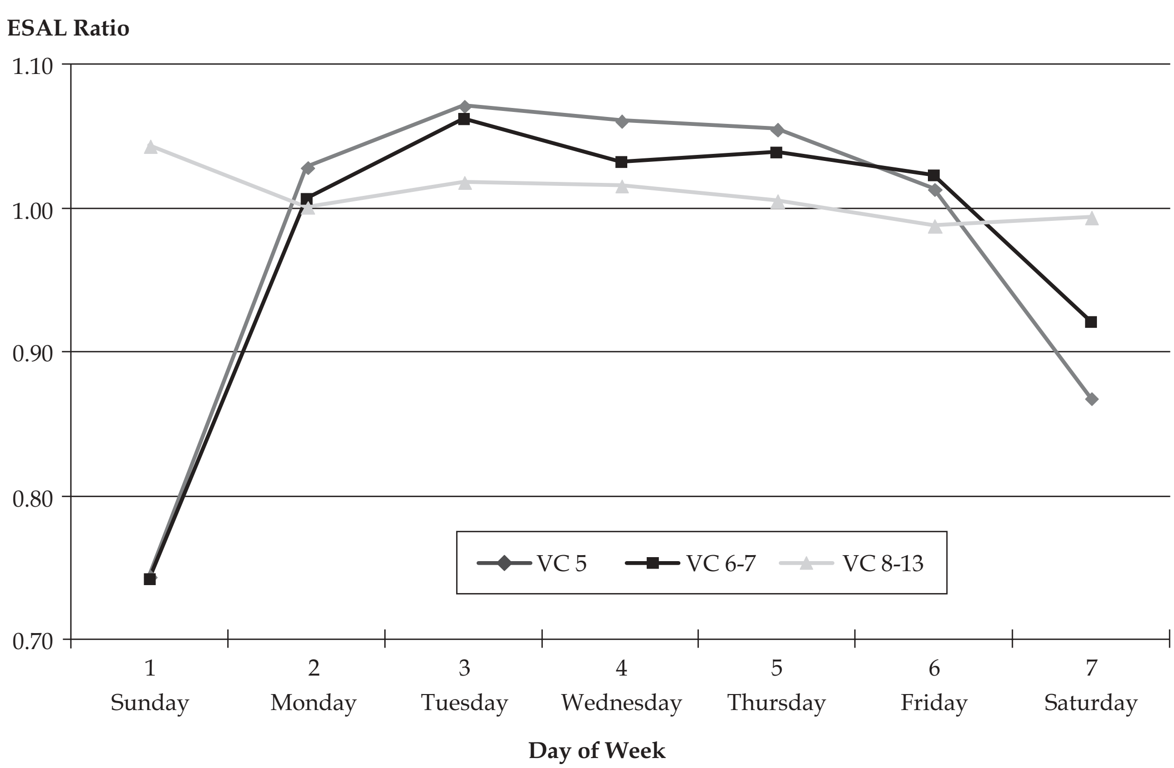
[6] In the special case of a site for which a separate seasonal load spectra dataset exists, the monthly adjustment factors used are the ones developed directly from that seasonal load spectra dataset. TrafLoad also allows the user to associate any site for which a seasonal load spectra dataset does *not* exist with a site for which such a dataset does exist and at which seasonal and DOW variations in load are believed to be very similar to those for the site in question. If such an association is made, daily and monthly adjustment factors developed using data from the associated site will be applied to data from the site in question in the absence of factors developed from a seasonal load spectra dataset for that site.

There is also the question of how much data to collect in a given month. The California data summarized in Figure 2.3 indicate that there is substantial variation in axle weights during weekends for single-unit trucks. Hence, monthly load spectra developed from a full week of data generally will be more accurate than load spectra developed from smaller amounts of data. However, this difference in accuracy is somewhat mitigated by TrafLoad's procedure (discussed earlier) for adjusting load spectra to account for the approximate effect of any missing days of the week.

## 2.4 Level 2 WIM Sites and TWRGs

Level 2 and 3 WIM sites are sites for which site-specific WIM data are not available. Pavement designs for such a site are developed using either a set of default load spectra developed on a statewide basis or a default set developed for a particular TWRG to which the site has been assigned. The goal of assigning sites to TWRGs is to permit the use of load spectra that better describe the axle loads at member sites than would a statewide set of load spectra. The following subsections provide guidance for developing TWRGs to be used for this purpose.

**Figure 2.3 Daily ESAL Ratios**




Source: Cambridge Systematics, Inc., *Accuracy of Traffic Load Monitoring and Projections*, Volume II: The Accuracy of ESALs Estimates, prepared for FHWA, February 2003, Figure 5.1.

## Background

The basic goals in forming TWRGs for default values are to group roads at which axle loads are likely to be reasonably similar (e.g., axle loads are likely to be higher than average) and to assign roads whose axle loads are not expected to be similar to different TWRGs. The TWRGs should be defined so that every road or road segment for which load spectra may be of interest is unambiguously assigned to a specific TWRG.

A key principle in forming TWRGs is that *all weight limits should be essentially the same on all roads in the group*. Thus, if some combinations are allowed to operate routinely at weights above 80,000 pounds on a set of designated roads, then the designated roads should be assigned to one or more TWRGs that are separate from the TWRGs to which other roads are assigned. Similarly, roads on which axle-weight limits vary seasonally (e.g., during spring thaw or during winter freeze) should be assigned to different TWRGs than roads on which axle-weight limits do not vary seasonally.

A corollary to the above principle is that the WIM sites whose data are used for deriving load spectra for a given TWRG need not all be in the same state, provided that they are all subject to the same weight limits and that the trucks operating at the out-of-state WIM site(s) are believed to carry loads that are similar to those carried at other sites in the TWRG.

One of the major influences on the load spectra for any site is the mix of empty, partial, and full loads of vehicles at the site. This influence is a significant factor affecting load spectra for combination trucks.

Combination trucks on long trips (i.e., trips of more than 200 miles) are likely to be fully loaded. Past studies have indicated that only about 15 percent of combination trucks operating on the rural Interstate system are empty. However, for short trips, most trucks operate loaded in one direction and empty in the other, while other trucks are used for pickup-and-delivery service, carrying partial loads for much of their trips. Since the percentage of combination trucks making short trips rises in urban areas (particularly in large urban areas), the percentage of fully loaded trucks usually declines, and so do axle weights. Similarly, non-Interstate roads in rural areas also carry a mix of long-haul and short-haul traffic, so axle loads for combination trucks are also likely to be lower on these roads than on the rural Interstate system.

The mix of empty and full loads can also result in significant differences in load spectra by direction. Directional differences are likely to be greatest on roads where most trucks are traveling to or from a particular site. For many such sites, nearly all these trucks are likely to operate empty in one direction and full in the opposite direction. On the other hand, trucks operating to or from a containerport usually operate loaded (and frequently very heavily loaded) in both directions. Roads that function primarily as access roads to a containerport are likely to warrant a TWRG of their own.

Another major influence on the load spectra on any road is the weight of fully loaded vehicles operating on the road. If most of the trucks that use a particular set of roads carry commodities that are likely to produce axle loads that are atypically high or low, that set of roads should be assigned to a separate TWRG. However, there is little reason to split a state into regional TWRGs if there are no regional variations in the commodities carried.

## Guidelines

The above discussion leads to the following guidelines for developing a set of TWRGs to be used for load spectra defaults:

1. If there are any significant differences in the size and weight limits applied to vehicles on different roads in the state, partition all roads into two or more sets, each with uniform size and weight limits.

2. For each of these sets of roads, develop a separate set of TWRGs, and assign the roads to these TWRGs on the basis of

   – Functional class,

   – Region, and/or

   – Direction.

The second step should be performed using judgment, local knowledge of the trucks operating in various parts of the state, and available WIM data.[7] Some observations that may be useful in carrying out this step are the following:

- There is almost certainly value in distinguishing roads by functional system: urban, rural Interstate system, and rural other.

- If there are significant regional differences in the density of commodities carried (particularly on rural other roads), these differences may warrant either using a combination of regions and functional systems or using regions instead of functional systems.

- Similarly, if, within any region, there are significant differences between the density of commodities carried on East-West roads and that carried on North-South roads, these differences may warrant using combinations of regions, functional systems, and road orientation.

- In the case of any TWRG that consists primarily or entirely of divided roads, if heavy (i.e., loaded) and light (i.e., empty) directions can be readily distinguished without using any WIM data,[8] it is likely to be desirable to divide the TWRG into heavy and light directions.

If practical, there should be between three and eight WIM sites in a TWRG. However, one or two WIM sites may be used for some small TWRGs. Three sites is the minimum number necessary to provide some confidence that all sites in the TWRG have reasonably similar load spectra. On the other hand, as the number of WIM sites in a TWRG grows, opportunities also grow for splitting the TWRG to produce smaller TWRGs, each with more uniform sets of load spectra.

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[7] Additional discussion of the formation of TWRGs is contained in FHWA's *Traffic Monitoring Guide* (May 2001, Section 5, Chapter 3).

[8] The heavy/light distinction can be useful only if, for any project site for which there are no WIM data, local knowledge can be used to distinguish the heavy direction from the light direction.

### Special Purpose TWRGs

Consider the case in which pavement is being designed for a site at which truck weights are believed to combine the weight characteristics of trucks operating at two Level 1 WIM sites but that is not itself a Level 1 site. One option is to assign such a site to one of the standard TWRGs (discussed above) and to use the load spectra developed for that TWRG as the load spectra for the site in question.

Another option is to develop a special-purpose TWRG that is used just for this pavement design. If the only Level 1 WIM sites assigned to this TWRG are the two sites mentioned above, the load spectra developed for this TWRG will be formed as unweighted averages of those developed for the two sites. (The current version of TrafLoad does not allow for using weighted averages in developing load spectra for TWRGs.) In general, development and use of such a special-purpose TWRG will require a separate run of TrafLoad, with the two Level 1 WIM sites assigned to the special-purpose TWRG instead of the TWRG(s) to which they are normally assigned. (The current version of TrafLoad allows sites to be assigned to only one TWRG.)

## 2.5 Level 3 WIM Sites

Level 3 design can be used when little is understood about the axle-weight distributions of the road segment being designed. Level 3 designs use the state's average axle-load distribution curves. They can be applied to any design project in the state, but their use entails a relatively high likelihood of at least modest load estimation error because few roads are truly average. Thus, the pavement design is likely to be either over- or under-designed.

Consequently, states are encouraged to use Level 2 load spectra whenever the combination of available data and engineering knowledge permits accurate assignment of a road to a TWRG with a reasonable degree of confidence.

Pavement designs for Level 3 sites are developed using a set of statewide load spectra defaults that are formed as a weighted average of the sets of load spectra developed for the TWRGs. The weights used in this process are user specified. For averaging, relatively high weights should be assigned to the more important TWRGs (in terms of size and/or degree of representativeness of conditions at Level 3 WIM sites) and lower weights to the less important TWRGs.

Because of the wide variety of loading conditions that occur from one road to another, the error associated with statewide load spectra defaults will be large. To allow for the possibility of large errors in the load spectra for Level 3 sites, the Pavement Design Guide software produces a very conservative pavement design. For roads with heavy loading conditions, such a design will result in a small probability of premature failure. However, for other roads, pavement will be over-designed (significantly so for roads with light loading conditions), causing state funds to be used inefficiently.

## ■ 2.6 Weight Data Collection

The truck weight data-collection program is somewhat different from the classification data-collection effort. Truck weight data are primarily collected using WIM technology, although a few state highway agencies also use weight data collected from static scales. In an ideal world, vehicle (and axle) weights would be collected continuously at a limited number of permanent locations as well as at a large number of sites where only short weighing sessions would be performed.

Unfortunately, both the cost of WIM data-collection and functional limitations in WIM sensor technology restrict the number and location of data-collection points at which state highway agencies can collect WIM data. WIM equipment only works accurately on flat, smooth pavements that are in good condition.[9] In addition, each time a WIM scale is placed in or on a pavement, the effects of road profile and roughness on vehicle dynamics mean that the scale must be recalibrated in order to collect data accurate enough to be used as input to the pavement design process.

Because calibration of a WIM scale is both time consuming and expensive, the cost of using accurate portable equipment is very high. Similarly, the cost of permanently installing WIM sensors is also high. The result is that state highway agencies generally operate relatively few WIM sites. The design of the WIM data-collection program is intended to obtain the best weight data for traffic load estimation, given these limitations.

The first recommendation of the *Traffic Monitoring Guide* is to make sure that the data being collected are accurate. This often means that the number of WIM sites must be reduced in order to ensure that the sites that are used are supplying accurate data. The NCHRP 139 project team fully endorses this recommendation. Use of weight data from poorly calibrated WIM scales can create significant biases in the pavement design process,[10] leading to unreliable pavement performance.

Given a limited number of WIM locations within each state, it is recommended that those sites be distributed across the state in such a way as to discover and measure truck weight patterns that differ by geographic region and/or by type of road. Thus, in a state such as Kentucky, some scales should be placed on roads that carry significant volumes of coal trucks, while other scales should be placed on roads that carry little or no coal traffic. Data from these different locations are then summarized to create regional load estimates that can be used within the TrafLoad and Pavement Design Guide design software.

When deteriorating pavement conditions at a WIM site cause the data to become unreliable, the WIM equipment should be moved to a new location where little is known about truck weights. This allows a state to slowly expand the geographic coverage of its weight data-collection effort. Slowly expanding the geographic coverage of the WIM program helps an agency learn about

[9] See the equipment descriptions in Cambridge Systematics, Inc., and Washington State Transportation Center, op. cit.

[10] *WIM Calibration, a Vital Activity*, FHWA Publication Number FHWA-RD-98-104, July 1998.

the variations in trucking characteristics that occur in the state, while staying within available data-collection budgets.

Where resources exist to collect and analyze the data collected, WIM sites should operate as permanent, continuous data-collection sites. (Note that these sites also provide continuous classification data as well as continuous volume data and thus take the place of ATRs and permanent vehicle classifiers.) Analyses of these continuous data sources allow states to learn if truck weights are changing over time or if they change by season of year or even by time of day. These data can also be used to direct the timing of enforcement actions intended to prevent overloaded trucks from using the roadway system.

Where resources for analyzing WIM data are extremely limited, discontinuous data may be collected, even from permanently mounted sensors. Limiting the data collected from permanently mounted sensors simply allows the state highway agency to focus its available resources on productive data-collection efforts. Where possible, even in cases of limited resources, sufficient data should be collected to measure possible changes in vehicle and axle weights over time.

# 3.0 Vehicle Classification Data

Chapter 2.0 discussed the collection of weigh-in-motion (WIM) data and the capabilities of the TrafLoad software for using these data to estimate the pavement loads produced by vehicles in various VCs. This chapter addresses the complementary topic of the data required by TrafLoad to estimate the number of vehicles in each class operating at a particular site. All data provided to TrafLoad are assumed to be quality checked.

As in the case of WIM sites, in this chapter different levels of classification-count sites are identified, reflecting the amount and quality of the counts collected at the sites. These levels are discussed in the first section of this chapter. The second section provides a brief summary of the traffic data produced by TrafLoad for use by the Pavement Design Guide software. Sections 3.3–3.5 discuss in some detail the classification data that are required by TrafLoad in order to produce these outputs. And the final section presents a recommended procedure for forecasting volumes of heavy vehicles over the design life of the pavement.

## ■ 3.1 Levels of Classification Site

TrafLoad provides the user with substantial flexibility in the amount of vehicle classification data to be collected for any site. The options have been grouped into three levels:

1. Sites for which continuous data from an automatic vehicle classifier (AVC) are available for periods of at least 1 week for at least 12 consecutive months. A distinction is made between

    1A. Data collected at the site in question and

    1B. Data collected at a reasonably nearby site on the same road.

2. All other sites for which vehicle classification counts are available. A distinction is made between

    2A. Sites for which at least one AVC count is available for a period of at least 48 weekday hours and

    2B. Sites for which only a manual classification count is available for a period of at least 6 weekday hours.

3. Sites for which volume counts are available but not classification counts. A distinction is made between

3A. Sites on the same road as a Level 1 or 2 site and

3B. Other sites.

The assignment of sites to classification levels is independent of their assignment on the basis of WIM data. Thus, it may be practical to collect Level 1 classification data at some sites for which only Level 2 weight data are available and vice versa.

## 3.2 Data Produced for the Pavement Design Guide Software

TrafLoad produces a moderate amount of traffic data for Level 1, 2, and 3A classification sites and a very limited amount of data for Level 3B classification sites. Brief summaries of the data produced for these two categories of sites are presented below, and more extensive discussions of the data required by TrafLoad for each of the levels are presented in subsequent sections of this chapter.

### Level 1, 2, and 3A Classification Sites

The most important data produced by TrafLoad's analyses of classification counts are estimates of annual average daily traffic by VC, or $AADT_i$, where the subscript $i$ denotes VC. The VCs may be the standard FHWA truck and bus classes (Classes 4–13) or any smaller set of user-defined classes into which the FHWA classes can be unambiguously mapped. (For example, the user may define "short," "long," and "very long" length classes, mapping FHWA Classes 4–7, 8–12, and 13 into the three length classes.)

For Level 2 and 3A sites, TrafLoad produces estimates of $AADT_i$ by direction. However, for Level 1 sites, at the user's option, TrafLoad will produce estimates of $AADT_i$ by lane or by direction. When provided with $AADT_i$ by direction, the Pavement Design Guide software applies a lane distribution factor (LDF), which is a function of the number of lanes, to estimate $AADT_i$ for the design lane. Users of the Pavement Design Guide software may either provide the LDFs or allow the software to use its own default values.

If the user requests estimates of $AADT_i$ by lane, the user must identify the design lane (or lanes) and pass the appropriate data to the Pavement Design Guide software. If the Pavement Design Guide software is told that it is receiving $AADT_i$ for a single lane, then it uses these values without further adjustment. This alternative will enable the Pavement Design Guide software to use better estimates of design lane $AADT_i$, provided that the user is able to readily recognize the design lane (as is frequently the case) and provided that the actual lane distribution of heavy vehicles is not expected to change as a result of the highway improvement. (Reasons for a change in lane distribution include adding lanes or eliminating badly deteriorated pavement that is affecting the pre-improvement lane distribution). When these conditions do not hold, the user should request that TrafLoad produce estimates of $AADT_i$ by direction.

In addition to the $AADT_i$, TrafLoad uses classification counts collected at Level 1A sites to derive or infer monthly traffic distribution factors to be used at all Level 1, 2, and 3A sites. Similarly, TrafLoad uses classification counts collected at Level 1A and 2A sites to derive hourly distribution factors (HDFs) for these sites and to infer HDFs for many other sites.[1] The monthly and hourly distribution factors provide the Pavement Design Guide software with the ability to estimate how the pavement load varies by time of day and time of year. This information, in turn, is used by the software in analyzing the effects of diurnal and seasonally varying environmental factors that affect the pavement's susceptibility to damage.

Since all estimates of $AADT_i$ for Level 1, 2, and 3A sites are developed by direction or lane, TrafLoad sets an accompanying set of directional distribution factors (DDFs) to 1.0, indicating to the Pavement Design Guide software that the $AADT_i$ represents traffic in one direction only. (If not provided with these DDFs, the Pavement Design Guide software would assume that the estimates represent two-way traffic, and an appropriate default DDF would be used.)

Additional information about the traffic data that TrafLoad produces for Level 1, 2, and 3A classification sites is presented in Sections 3.3–3.5.

### Level 3B Classification Sites

The Pavement Design Guide software requires, and TrafLoad produces, just two pieces of information for Level 3B sites:

- Total (two-way) annual average daily truck traffic and
- The "Truck Traffic Classification" group to which the site is assigned.

This information is discussed further in the second part of Section 3.5.

## 3.3 Level 1 Classification Sites

Level 1A sites are sites at which continuously operating AVCs have been used to collect a minimum of 1 week of classification counts for 12 consecutive months. The first two subsections below discuss these data and the several uses that are made of them. Level 1B sites are classification sites that are on the same road as a Level 1A site and reasonably near that site; these sites are discussed in the third subsection below.

### Continuous Classification Counts

The principal goal of the continuous classification-count program is the creation of factors needed to estimate annual average daily truck volumes from short-duration classification

[1] For sites for which HDFs are not provided to the Pavement Design Guide software, the software uses its own set of HDF default values.

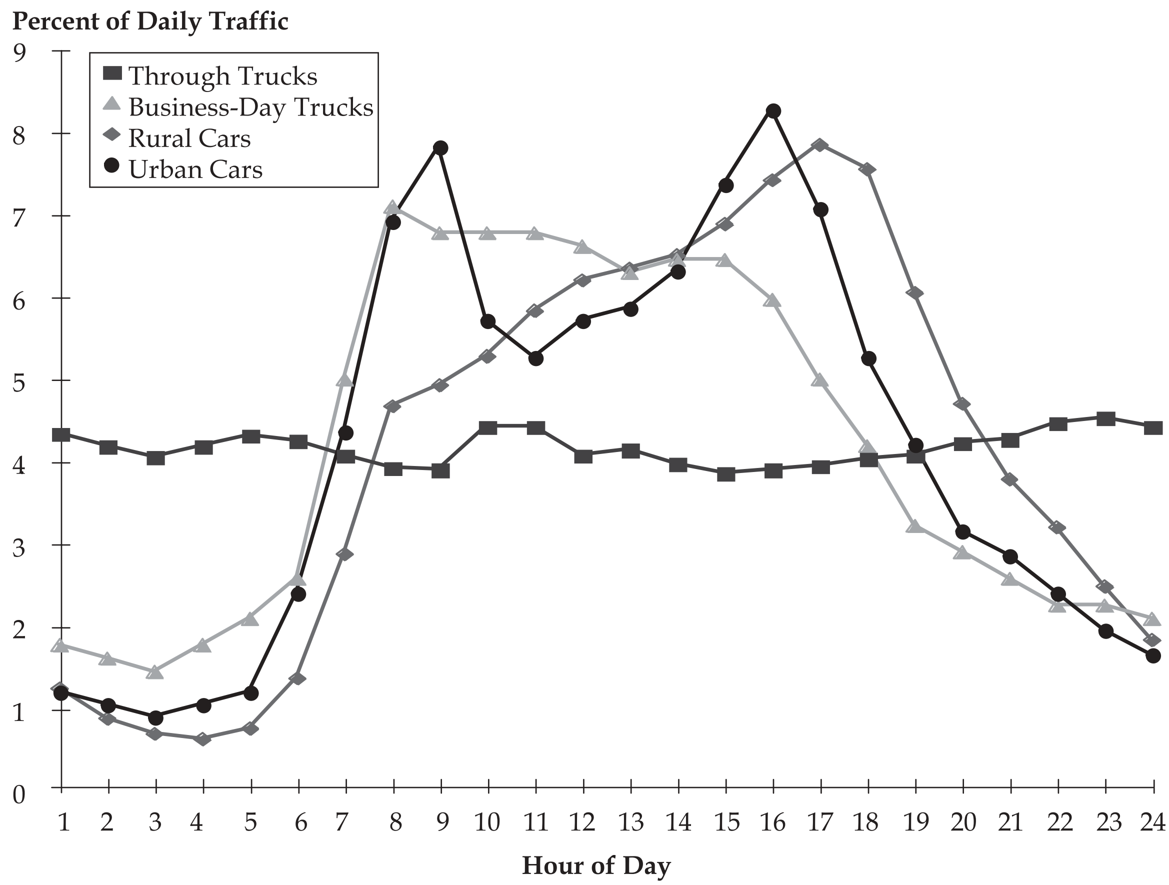
counts. The same information is also used to estimate seasonal fluctuations in truck volumes so that these changes can be accounted for in the design process.

To accomplish this goal, it is necessary to measure day-of-week and seasonal variation in truck traffic and to develop factors that can be applied to short-duration counts. As illustrated by Figures 3.1 and 3.2, truck volumes vary significantly by time of day (TOD) and day of week (DOW), and different patterns exist for local (predominantly business-day) trucks and for long-distance trucks.

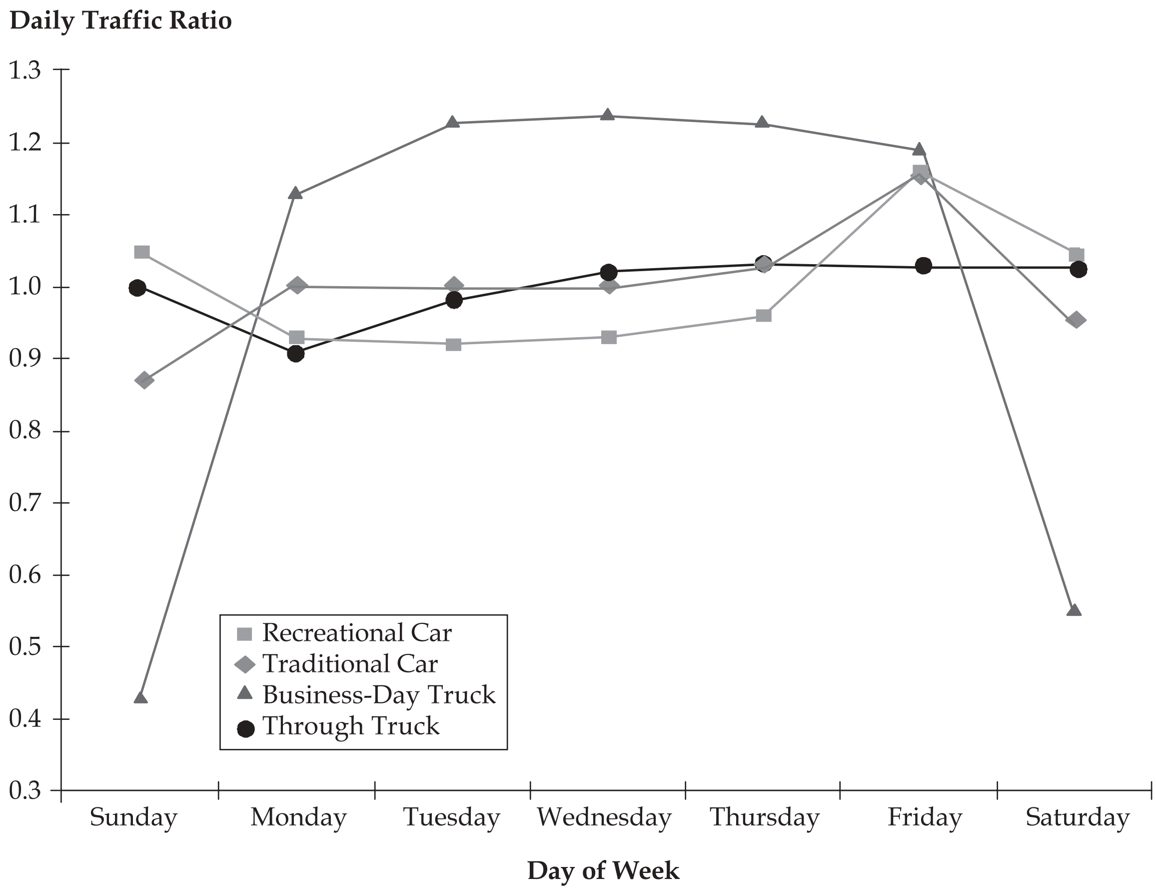
A sufficient number of continuous-count locations are needed to measure each of the different truck volume patterns found in a state or region. This means that continuous counters should be placed on different functional classes of roads and in different geographic locations within each state. It is especially important to be able to measure the differences in truck volume patterns between roads that carry primarily local truck traffic and those that serve through traffic.

A good rule of thumb is that the continuous classification-count program should be roughly the same size as the traditional continuous volume count program. (The latter program, conducted with automatic traffic recorders, is frequently called the ATR program.) In fact, the design of the continuous classification-count program is very similar to the design of the ATR

**Figure 3.1 Typical TOD Patterns**



## Figure 3.2 Typical DOW Patterns




program. While the recommended continuous-count program requires a significant number of count locations, it is important to note that continuous classifiers also serve as ATRs. Thus, it is possible to use the classification counters in place of ATRs at the same time as they are used to supply continuous classification data. Such a step significantly reduces the number of continuous counters an agency needs and reduces unnecessary duplication of the data-collection effort.

Permanent, continuous counts also provide an excellent source of information on truck volume trends. In particular, all highway agencies should monitor the total volume of heavy trucks. The trend in truck volume should be examined both for each individual roadway on which a permanent data-collection device is located and for each of the geographic areas in the state. (Truck traffic tends to vary with both the economic activity taking place in a geographic region and the amount of through traffic passing through the area.) Also of interest are changes in the mix of trucks. Changes in truck size and weight laws can have significant effects on the total number (and percentage of) large trucks of specific designs.

FHWA's *Traffic Monitoring Guide* provides wide latitude in the selection of locations where permanent classifiers are placed. For the purposes of both general monitoring and pavement design, permanent classifiers should be placed on a variety of roads throughout the state. Thus, some classifiers should be on Interstate highways and other major routes that carry heavy through-traffic volumes. Others should be placed so that trucking patterns specific to within-state movements of freight can be monitored. Lastly, where possible, urban locations should also be monitored, so that urban truck volumes can be measured.

## Uses of Data from Continuous Classification-Count Sites

The highest quality estimates of $AADT_i$ are those that are developed using 12 months of data from a continuous classification-count site. Such a site is referred to as a Level 1A classification site. For such a site, estimates of $AADT_i$, monthly traffic distribution factors by VC, and hourly distribution factors are developed entirely from the classification counts obtained for the site.

In addition, classification counts obtained at these sites are used for developing several types of traffic ratio.[2] Two of these types of traffic ratio are monthly and DOW traffic ratios that are used for seasonal and DOW factoring of short-duration classification counts obtained at Level 2 classification sites. The use of separate sets of monthly and DOW traffic ratios for this purpose makes it possible to adopt independent definitions of the seasonal and DOW factor groups that are used for this purpose. The development and use of the seasonal and DOW factor groups are discussed in the first and third subsections below, and a related concept, VC groups, is discussed in the second subsection.

*Monthly traffic ratios that are used for adjusting any short-duration classification count should (if possible) be current year traffic ratios*; that is, they should be developed from data that are collected over a 12-month period that includes the months during which the short-duration counts are collected. The resulting estimates of $AADT_i$ generally will be better estimates of $AADT_i$ for that 12-month period than estimates developed using traffic ratios developed using data from earlier 12-month periods. In particular, current-year traffic ratios will provide a better adjustment for any unusual conditions affecting truck volumes at the time that a short-duration count is collected. (Such conditions include unusual weather, a poor harvest, or the beginning of a sharp recession or of an economic recovery.)

A third type of traffic ratio developed from classification counts obtained at Level 1A classification sites is TOD traffic ratios. These traffic ratios are combined with partial-day classification counts obtained at manual-count sites to estimate 24-hour traffic volumes, by VC, at these sites. The development of TOD factor groups is discussed in the fourth subsection below.

A fourth type of traffic ratio developed from classification counts obtained at Level 1A classification sites is applied to data from Level 1B classification sites and is described in a subsequent section discussing such sites.

[2] TrafLoad users should think of the "traffic ratios" used by TrafLoad as "factors." The technical distinction between "traffic ratios" and "factors" is presented in Section 4.1 of Part 1, along with an explanation of the advantage of using traffic ratios.

### *DOW Factor Groups*

As observed earlier (see Figure 3.2), "through trucks" and "business-day trucks" have very different DOW volume patterns. The volume of through trucks varies only slightly from day to day, while the volume of business-day trucks drops substantially on Saturdays and Sundays. For purposes of the present discussion, we shall replace the term "business-day" with "business-week" to emphasize that our interest is in the drop-off in activity during the weekend (and not the drop-off at night).

The volume pattern shown in Figure 3.2 for business-week trucks provides a good example of the importance of DOW factoring. For a site where nearly all trucks are business-week trucks, estimates of $AADT_i$ derived from weekday classification counts *without* DOW factoring will tend to be overestimates. (The plot in Figure 3.2 indicates that, on average, the overestimates will be in the 15- to 25-percent range.) DOW factoring is designed to correct for the overestimates that are reflected in weekday classification counts.

In order to use DOW factoring effectively, it is necessary to distinguish VCs and sites where business-week trucking predominates from VCs and sites where through trucking predominates. Since nearly all single-unit trucks are used primarily for local service, business-week trucking is likely to be dominant for FHWA Classes 5–7 at nearly all sites.

In the case of buses and combination trucks (Classes 4 and 8–13), the situation is more complex. At sites on the Interstate system that are more than 200 miles from a major urban area, most vehicles in these classes are likely to be through vehicles. On the other hand, in major urban areas, vehicles in these classes are more likely to be providing service of a more local nature, especially on roads that carry little or no through traffic. In these areas, the volume of vehicles in these classes is likely to be appreciably lower on weekends than on weekdays.

A schematic summary of the above observations is presented in Table 3.1. The table indicates that Class 5–7 vehicles are likely to exhibit a business-week volume pattern at nearly all sites at which significant numbers of these vehicles operate, while other truck and bus classes are likely to exhibit a business-week pattern at some sites and a through pattern at other sites. For this

**Table 3.1 Commonly Observed DOW Volume Patterns, by VC**

| | VCs | |
|---|---|---|
| **DOW Volume Pattern** | **5 - 7** | **4 and 8 - 13** |
| Business-Week Pattern | X | X |
| Through Pattern | - | X |

Key: X Pattern is likely to exist at many sites.
– Pattern occurs only under unusual circumstances.

reason, when developing DOW factor groups, attention should be focused on the bus and combination-truck classes, particularly on the most important of these classes (usually Class 9).

The general approach to developing DOW factor groups is to start by distinguishing two or three such groups:

- One consisting of sites at which buses and combination trucks exhibit a business-week pattern;
- One consisting of sites at which they exhibit a through pattern; and
- Perhaps, one consisting of sites at which they exhibit an intermediate pattern.

For the purpose of developing DOW traffic ratios for each of these factor groups, there should be a minimum of three continuous classification-count sites in each group, with a larger number (five to eight) used wherever possible.

For many states, the two or three DOW factor groups described above will suffice. However, states with large numbers of continuous classification-count sites may wish to consider establishing additional DOW factor groups. One possibility that might be considered is increasing the number of groups corresponding to intermediate "through"/"business-week" patterns.

Another possibility for increasing the number of factor groups involves identifying and distinguishing different DOW patterns for through trucks. In particular, the dip in through-truck volume that, in Figure 3.2, is shown as occurring on Monday is actually affected by distance from the trucks' origins and destinations. As a result, these DOW patterns may vary by road orientation (North-South versus East-West) or by direction of travel. These differences are likely to be most significant in the mountain and western plains states, where many trucks are traveling to and from relatively distant origins and destinations.

### *VC Groups*

In concept, it would be desirable to develop separate sets of DOW traffic ratios for each VC. However, attempting to do so may produce zero values for some DOW traffic ratios for uncommon classes, resulting in division by zero when traffic counts are subsequently divided by these ratios. To avoid this problem, a set of user-defined vehicle-class (VC) groups are established.

In TrafLoad, VC groups used in the factoring of classification counts are called "Type 1 VC groups" to distinguish them from the WIM VC groups discussed in the preceding chapter. The Type 1 VC groups are also used in the development and application of seasonal and TOD traffic ratios.

When defining Type 1 VC groups, a general rule is that VCs that have appreciably different DOW or seasonal volume patterns should be assigned to separate VC groups. If TOD factoring is to be used, this rule also applies to TOD volume patterns. As observed previously, FHWA VCs 5–7 tend to exhibit business-week and business-day volume patterns that are stronger than those exhibited by the other VCs, suggesting that these three VCs generally should be assigned to a separate Type 1 VC group from the other VCs.

When first setting up Type 1 VC groups, two VC groups may be found to be sufficient. However, TrafLoad allows users to define a larger number of VC groups, and some users may wish to take advantage of this capability to divide the VC groups further. The one limitation in this process is that VCs that are rarely used should be assigned to VC groups that include one or more VCs that are frequently used. If this is not done, there is a small possibility that the TrafLoad factoring procedure will be forced to terminate abnormally in order to avoid dividing by zero.[3]

### *Seasonal Factor Groups*

As discussed above, the DOW factor groups should be designed to group sites with similar DOW patterns of truck volume. Similarly, the seasonal factor groups should be designed to group sites with similar seasonal (or month-of-year) patterns of truck volume. Toward this end, the research team makes several observations about seasonal variations in truck volumes:

- As in the case of automobiles, seasonal variations in truck volumes tend to be weaker in urban areas than in rural areas.
- In many areas, the highest truck volumes occur during the May–October period, and the lowest volumes occur in January.
- Local influences (commodities carried, harvest season, etc.) can produce substantial site-to-site variation in the timing and intensity of the seasonal peak in truck volumes on rural non-Interstate roads.
- The greater diversity of trucks using the Interstate system mutes the effects of local influences on seasonal variations in truck volumes, producing more consistent seasonal patterns.

The above observations suggest that, for many states, the development of seasonal factor groups might begin with the creation of an urban group and a rural Interstate group. Some consideration might also be given to creating a third group consisting of sites whose seasonal variations are in between those of the first two groups. This group might include urban IS sites with relatively high volumes of through trucks.

[3] As an example, consider a DOW factor group that contains no Level 1A site at which any vehicle in a specific VC group was observed on a Sunday. In this case, the Sunday traffic ratio for this DOW factor group and this VC group will be zero. Assume that a 7-day classification count is obtained for a Level 2 site that has been assigned to this DOW factor group and that one or more vehicles in that VC group are observed on Sunday at this site. Then TrafLoad will be unable to factor the Sunday count for this VC group at this site.

Similar problems can also be constructed for seasonal and TOD factoring, and they are even more likely to occur if combined monthly/DOW traffic ratios are used for factoring counts obtained at Level 1B sites.

The remaining issue is how to develop seasonal factors to be applied to classification counts obtained at rural Level 2 sites that are not on the Interstate system. A simple alternative is to create a single rural non-Interstate factor group for this purpose.[4] Issues relating to the development of seasonal factor groups for classification counting are discussed further in the *Traffic Monitoring Guide* (pp. 4-22 through 4-32).

As in the case of DOW factors, TrafLoad develops separate sets of seasonal factors for each seasonal factor group and each Type 1 VC group.

### *TOD Factor Groups*

TrafLoad uses TOD factoring to convert partial-day classification counts (collected at Level 2B sites) to estimates of 24-hour traffic volumes by VC. As in the case of seasonal and DOW traffic ratios, TrafLoad uses classification counts from Level 1A sites to develop several sets of TOD traffic ratios. In particular, for each of the user-defined Type 1 VC groups, TrafLoad develops a separate set of 24 TOD traffic ratios (or “hourly fractions”) for each user-defined TOD factor group. Since partial-day classification counts are almost always collected on a weekday, only weekday classification counts are used in developing TOD traffic ratios.

At a minimum, the TOD factor groups should be designed to distinguish sites at which business-day trucking predominates from sites at which through trucking predominates. Additional TOD factor groups may also be created to represent intermediate situations and/or more extreme cases of business-day or through-trucking patterns. It is likely that the TOD factor groups frequently will be identical to the DOW factor groups (discussed earlier), but the software allows the user to identify differences where appropriate. (For example, sites on a road that is used primarily to access a truck terminal or warehouse that operate 24 hours per day, 5 days per week, might be treated as “through-trucking” sites for the purpose of TOD factoring but not for the purpose of DOW factoring.)

FHWA VCs 5–7 almost always exhibit a business-day volume pattern (just as they almost always exhibit a business-week volume pattern). For this reason, when developing TOD factor groups, attention should be focused on the bus and combination-truck classes, just as in the case of DOW factor groups.

TOD factoring is performed only if there are sites at which partial-day classification counts are collected. If no such sites exist, it is not necessary to define TOD factor groups.

## Level 1B Sites

Consider a classification site that is not a Level 1A site but that is on the same road as a Level 1A site. If it is believed that the two sites are sufficiently close that most trucks that pass

[4] A more ambitious alternative would be to examine the seasonal patterns of all Level 1A rural non-Interstate sites, and, on the basis of this review, create two or more separate rural non-Interstate factor groups. If this alternative is adopted, it will then be necessary to determine how to assign rural non-Interstate Level 2 sites to factor groups. However, if this assignment is performed well, the resulting estimates of $AADT_i$ for these sites are likely to be better than those that would result from using a single rural non-Interstate factor group.

one of the sites pass both sites, then the site in question qualifies as a Level 1B site that is "associated" with the Level 1A site, and this information should be provided to the TrafLoad software. TrafLoad is capable of producing high-quality $AADT_i$ estimates for Level 1B sites, with the quality of these estimates depending on the similarity of the truck traffic at the two sites.

TrafLoad has two procedures for producing $AADT_i$ estimates for Level 1B sites. The choice as to which procedure to use for a particular site is made automatically by TrafLoad. Brief, somewhat technical descriptions of the two procedures and how the choice is made are presented below.

The monthly traffic distribution factors and hourly distribution factors for any Level 1B site are assumed to be the same as those for the associated Level 1A site.

### *Direct Scaling*

The simpler of the two procedures for estimating $AADT_i$ at a Level 1B site is "direct scaling." TrafLoad uses direct scaling whenever

a) Classification counts at a Level 1A site associated with a Level 1B site have been obtained for the same hours and dates as the classification counts that were obtained at the Level 1B site and

b) Both sites have no more than one lane in each direction.

Under these circumstances, the ratios of the counts at the two sites are used to scale the $AADT_i$ at the Level 1A site to produce estimates of the $AADT_i$ at the Level 1B site.[5] Separate scale factors are used for each Type 1 VC group.

### *Factored Counts*

The second procedure for estimating $AADT_i$ at a Level 1B site is a factoring procedure. For this purpose, for each Level 1A site, a set of combined monthly/DOW traffic ratios is developed. For each Level 1A site, each direction, and each Type 1 VC group, 84 such ratios are developed, corresponding to all combinations of the 12 months and 7 days of the week.[6] Each of these ratios is developed by TrafLoad by obtaining monthly average day-of-week traffic (MADW) for a given direction and VC group and dividing by AADT for that direction and VC

[5] If the user has requested that $AADT_i$ be estimated by direction (rather than by lane), then direct scaling would be appropriate even if Condition (b) does not hold. However, the current version of TrafLoad does not perform direct scaling in this case.

[6] The use of 84 combined monthly/DOW traffic ratios allows the factoring procedure to reflect the combination of monthly and DOW variations in volume better than can be done with separate monthly and DOW traffic ratios (12 monthly ratios and 7 DOW ratios). However, combined traffic ratios cannot be used in conjunction with monthly and DOW factor groups that are developed independently of each other. Hence, TrafLoad uses combined traffic ratios for factoring counts from Level 1B sites and separate monthly and DOW traffic ratios, developed using data from groups of Level 1A sites, for factoring counts from Level 2 sites.

group. TrafLoad uses the traffic ratios obtained at a Level 1A site to convert short-duration classification counts obtained at any associated Level 1B site to estimates of $AADT_i$ by lane. (See Part 4, Step CF, available online at http://trb.org/news/blurb_detail.asp?id=4403.)

As in the case of monthly traffic ratios, the monthly/DOW traffic ratios applied to short-duration counts obtained at any Level 1B site should be "current year" traffic ratios; i.e., they should be developed from data that are collected over a 12-month period that includes the month during which the short-duration count is collected.

The research team makes two observations about this factoring procedure. The first is that the conversion process involves dividing by the MADW for each Type 1 VC group. Hence, the accuracy of the resulting estimates of $AADT_i$ is affected by the similarity of the seasonal and DOW volume patterns for the VCs within each VC group but not by the similarity (or dissimilarity) of these patterns between VC groups. The second observation is that the adjustment procedure uses traffic ratios obtained from a single Level 1A site, a site that should have seasonal and DOW volume patterns that are very similar to those at the corresponding Level 1B site(s). For this reason, the resulting estimates of $AADT_i$ should be substantially better than those that can be produced at Level 2 sites.

## ■ 3.4 Level 2 Classification Sites

Level 2 classification sites are classification sites that do not qualify as Level 1 classification sites. That is, less than 12 months of current data are available for these sites, and they are not associated with another site on the same road for which 12 months of current data are available. A few of these sites are continuous classification sites at which data are missing for one or more months. However, most of these sites are ones at which classification counts are collected as part of a state's short-duration classification-count program. Counts collected as part of this program fall into three categories:

1. *Coverage counts* that are collected periodically (e.g., once every third year) at a relatively fixed set of sites to provide general information about truck volumes and how these volumes are changing over time;

2. *Expected project counts*, collected at sites at which highway projects are anticipated, to provide data for use in the planning and design process; and

3. *Project-specific counts*, collected either to provide additional information about sites at which expected project counts have already been collected or to provide data to be used for projects that had not been anticipated.

Most short-duration counts collected for pavement design projects are likely to fall into the second of these categories. That is, they are likely to be collected to support pavement design projects that are anticipated to occur in the near future. These potential projects should be identified by highway planners as soon as practical. Planning and programming tools available for this purpose include pavement management systems.

The early identification of pavement projects and scheduling of classification counts requires coordination among the data-collection staff, the pavement design staff, and other agency staff involved in the programming and prioritization process. While this level of communication is not easy, it has several advantages. It allows the traffic engineering office to schedule needed counts so that they can be collected efficiently. It ensures that data are available to designers when needed, thus speeding up the design process. And finally, it provides an opportunity to collect extra counts to be used in the design of major projects. As discussed below, estimates of $AADT_i$ developed from three or four 7-day counts collected over the course of a year are likely to produce appreciably better estimates of $AADT_i$ than similar estimates developed from a single 48-hour classification count.

A key to this approach is to be generous when estimating possible pavement design locations. Traffic volume and classification counts at most locations are considered to be reliable for at least 2 years. Thus, even if an expected pavement design project does not make this year's design list, it will likely make next year's list, and traffic data will already be collected and available for that location.

Even with good communication between pavement and traffic engineering staff, it may not be possible to collect all the traffic data required as part of the routine data-collection effort. Accordingly, allowance should always be made for a possible need for project-specific counts to supplement the expected project counts.

Short-duration classification counts are usually collected using automatic vehicle classifiers (AVCs). However, at some urban sites, manual classification may be preferred. Because manual counts usually cover only part of a day, estimates of $AADT_i$ derived from manual counts are not likely to be as good as estimates derived from accurate classification counts obtained with AVCs for periods of 48 hours or more. Accordingly, these two types of short-duration counts are distinguished from each other by calling AVC sites Level 2A sites and calling manual classification sites Level 2B sites. The two following subsections contain brief discussions of the collection and analysis of counts at these two types of classification sites.

## AVC Sites (Level 2A)

Level 2A classification sites are sites at which automatic vehicle classifiers (AVCs) are used to obtain one or more classification counts over the course of a year. Accurate AVC counts usually require that vehicles are traveling at constant speed with adequate spacing between vehicles, conditions that may be difficult to meet in urban areas. Each AVC count should cover a period of at least 48 weekday hours (though TrafLoad's Level 2A procedure is capable of estimating $AADT_i$ from 24-hour classification counts). Improved estimates of $AADT_i$ will be produced if count duration is extended or if multiple classification counts are collected over the course of a year.

Section 3.3 included a discussion of TrafLoad's use of data from continuous classification-count sites (Level 1A sites) to develop sets of monthly and DOW traffic ratios. These traffic ratios are used by TrafLoad to convert the short-duration counts collected at Level 2A sites to estimates of $AADT_i$. For any Level 2A site, the traffic ratios used are those developed for the seasonal and DOW factor groups to which the site belongs.

As observed in Section 3.3, monthly traffic ratios that are derived from current year data work better for this purpose than monthly traffic ratios derived from historic data. For this reason, when providing TrafLoad with a set of Level 2 classification counts to be factored, the user should (if possible) also provide TrafLoad with Level 1A counts for a 12-month period that includes the month(s) during which the Level 2 counts were collected.

The quality of the estimates of $AADT_i$ that are produced will tend to vary with the degree to which the seasonal and DOW patterns in truck volumes at the Level 2A site match the volume patterns in the seasonal and DOW factor groups to which the site has been assigned. Use of 7-day counts reduces or eliminates the need for DOW factoring, and use of multiple counts over the course of a year reduces the need for seasonal factoring. Thus, 7-day counts and multiple counts are strategies for increasing the amount of data collected in order to improve the quality of $AADT_i$ estimates.

Hourly distribution factors for each Level 2A site are developed by TrafLoad from the counts collected at the site. TrafLoad sets the monthly traffic distribution factors for each Level 2A site equal to the monthly traffic ratios for the seasonal factor group to which the site has been assigned.

## Manual Classification-Count Sites (Level 2B)

In order to classify vehicles reliably on the basis of axle-spacing criteria, AVCs must be located where vehicles are neither accelerating nor decelerating and where the spacing between vehicles is sufficient to allow consecutive vehicles to be readily distinguished. Because these conditions are difficult to meet in urban areas, urban classification counts frequently are collected manually. (Alternatively, classification on urban streets and roads may be limited to length classification.) Manual classification counts are usually collected only during daylight hours, usually for a period of 6 to 12 consecutive hours. Conversion of these partial-day counts to estimates of $AADT_i$ is a two-step process:

1. Each set of partial-day classification counts is converted to a set of estimates of volume by VC for the day on which the counts were collected.

2. The procedures discussed in the preceding section are used to convert these estimates of 24-hour volume by VC to estimates of $AADT_i$.

Procedures for performing the first of these two steps are discussed below. This step adds some additional error to the resulting estimates of $AADT_i$ (over and above the error introduced by the factoring procedures discussed above). Accordingly, sites at which classification counts are obtained manually are described as Level 2B sites.

TrafLoad uses TOD traffic ratios to convert partial-day classification counts to estimates of volume by VC for the day on which the count is collected. These traffic ratios generally are developed from hourly classification counts obtained for weekdays at Level 1A sites, as discussed in Section 3.3. For this purpose, each Level 2B site must be assigned to a TOD factor group that is believed to have a TOD pattern for truck volume (particularly for combination trucks) that is similar to the pattern that is believed to exist at the site in question. A separate set of TOD traffic ratios is used for each Type 1 VC group.

For Level 2B sites, TrafLoad also produces a set of monthly traffic distribution factors and, at user option, it may produce a set of hourly distribution factors. As in the case of Level 2A sites, the monthly traffic distribution factors for each Level 2B site are equal to the monthly traffic ratios for the seasonal factor group to which the site has been assigned.

For sites identified by the user as ones at which a business-day truck pattern exists, TrafLoad produces a set of hourly distribution factors that have the values shown in Table 3.2. For all other Level 2B sites, TrafLoad does not produce any hourly distribution factors. Instead, the Pavement Design Guide software provides its default TOD distribution.[7]

## 3.5 Level 3 Classification Sites

Level 3 classification sites are sites for which volume counts exist but classification counts do not exist. There are two types of Level 3 classification site:

- Level 3A sites are sites on the same road as an associated Level 1 or Level 2 site and sufficiently close to that site to carry a traffic mix that is similar to the mix at the associated site.

- Level 3B sites are all other sites.

For both types of Level 3 site, TrafLoad requires either an estimate of overall (two-way) annual average daily truck traffic (AADTT) or estimates of overall AADT and overall percent trucks from which AADTT can be derived.

### Level 3A Sites

Level 3A classification sites are sites that are on the same road as an associated Level 1 or Level 2 site and sufficiently close to that site to carry a traffic mix that is similar to the mix at the associated site. For such sites, TrafLoad uses the estimates of $AADT_i$ by direction at the associated site to distribute the user-supplied estimate of AADTT over the various truck

[7] There is a relationship between the hourly distribution factors (HDFs) required by the Pavement Design Guide software and the TOD traffic ratios (TODTRs) developed and used by TrafLoad. However, the Pavement Design Guide software requires a single set of HDFs for all VCs combined, while TrafLoad generates separate sets of TODTRs for each VC group. The current version of TrafLoad does not contain a procedure for converting the TODTRs into HDFs.

**Table 3.2 Hourly Distribution Factors Used by TrafLoad 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% |

Derived from data for urban other principal arterials (Functional System 14) in Mark Hallenbeck, et al., *Vehicle Volume Distributions by Classification,* Chaparral Systems Corporation and Washington State Transportation Center, June 1997, for FHWA, FHWA-PL-97-025, pp. 79-80.

classes and over the two directions of travel.[8] TrafLoad sets the monthly distribution factors for the Level 3A site equal to the corresponding factors for the associated site. Similarly, the hourly distribution factors for the Level 3A site are set equal to the ones for the associated site, if they exist.[9]

### Level 3B Sites

Level 3B sites are similar to Level 3A sites except that they have no associated Level 1 or Level 2 site. Instead, users are required to assign each Level 3B site to one of 17 Truck Traffic Classification (TTC) groups that have been defined by the Pavement Design Guide team.[10] Table 3.3 lists the 17 TTCs along with the criteria used to distinguish among them. The Pavement Design Guide software uses the TTCs as the basis for disaggregating estimated AADTT into the standard FHWA VCs.

Pavement designs developed by the Pavement Design Guide software for Level 3B classification sites require the use of load spectra for the standard FHWA VCs. These load spectra normally will be developed by TrafLoad. If these are not supplied by TrafLoad, the Pavement Design Guide software will use a set of default load spectra that have been developed from national data.

## 3.6 Forecasts

The Pavement Design Guide software requires forecasts of linear or exponential rates of change in the $AADT_i$ over the design life of the pavement. A simple procedure for estimating

[8] There are two potential improvements to the current TrafLoad procedure for handling Level 3A sites. One improvement would require TrafLoad to be modified to produce estimates of overall AADT for Level 1 and Level 2 sites (instead of just $AADT_i$ for truck classes). If TrafLoad has an overall AADT value for each associated site, then, for Level 3A sites, TrafLoad would require estimates only of AADT (but not percent trucks), since the percentage of trucks could be assumed to be the same as at the associated site.

An alternative improvement would entail implementing a somewhat more sophisticated (and more demanding) algorithm for analyzing Level 3A sites. This algorithm would require that total traffic be counted at the 3A site at the same time as it is being counted at the associated site, with the counts at the 3A site being obtained by direction and, if practical, for a period of at least 48 hours. TrafLoad would then estimate $AADT_i$ for the Level 3A site, by direction, by using the volume counts at the two sites as the basis for scaling the corresponding estimates of $AADT_i$ for the associated site.

[9] As discussed above, TrafLoad does not create hourly distribution factors for all Level 2B sites. Accordingly, TrafLoad does not create hourly distribution factors for some Level 3A sites that are associated with Level 2B sites.

[10] ERES Consultants and FUGRO-BRE, *Determination of Traffic Information and Data for Pavement Structural Design and Evaluation,* NCHRP Project 1-37A, Interim Report, December 1999, pp. 39–53.

**Table 3.3 Truck Traffic Classification Groups**

| | | Percentage of AADTT in Key VCs | | | |
|---|---|---|---|---|---|
| TTC Description | | VC 9 | VC 5 | VC 13 | VC 4 |
| 1 | Major single-trailer truck route (type I) | > 70 | < 15 | < 3 | - |
| 2 | Major single-trailer truck route (type II) | 60 - 70 | < 25 | < 3 | - |
| 3 | Major single- and multi-trailer truck route (type I) | 60 - 70 | 5- 30 | 3 - 12 | - |
| 4 | Major single-trailer truck route (type III) | 50 - 60 | 8- 30 | 0 - 7.5 | - |
| 5 | Major single- and multi-trailer truck route (type II) | 50 - 60 | 8 - 30 | > 7.5 | - |
| 6 | Intermediate light and single-trailer truck route (type I) | 40 - 50 | 15 - 40 | < 6 | - |
| 7 | Major mixed truck route (type I) | 40 - 50 | 15 - 35 | 6 - 11 | - |
| 8 | Major multi-trailer truck route (type I) | 40 - 50 | 9 - 25 | > 11 | - |
| 9 | Intermediate light and single-trailer truck route (type II) | 30 - 40 | 20 - 45 | < 3 | - |
| 10 | Major mixed truck route (type II) | 30 - 40 | 25 - 40 | 3 - 8 | - |
| 11 | Major multi-trailer truck route (type II) | 30 - 40 | 20 - 45 | > 8 | - |
| 12 | Intermediate light and single-trailer truck route (type III) | 20 - 30 | 25 - 50 | 0 - 8 | - |
| 13 | Major mixed truck route (type III) | 20 - 30 | 30 - 40 | > 8 | - |
| 14 | Major light truck route (type I) | < 20 | 40 - 70 | < 3 | - |
| 15 | Major light truck route (type II) | < 20 | 45 - 65 | 3 - 7 | - |
| 16 | Major light and multi-trailer truck route | < 20 | 50 - 55 | > 7 | - |
| 17 | Major bus route | - | - | - | > 35% |

Source: ERES Consultants and FUGRO-BRE, *Determination of Traffic Information and Data for Pavement Structural Design and Evaluation*, NCHRP Project 1-37A, Interim Report, December 1999, pp. 40 and 42.

these rates of change is presented below. Some more sophisticated forecasting procedures are discussed in Part 1, Appendix A.

## A Simple Procedure

A simple procedure for forecasting the rates of change in traffic volumes for the design lane or design direction at any particular project site is presented below. In the procedure, the rates of change are referred to as "growth rates" to emphasize that, for the purpose of pavement design, traffic growth is of primary interest. However, the procedure may also be applied to sites at which traffic is expected to decline.

The procedure consists of six steps:

1. *Distinguish two groups of VCs: single-unit trucks and buses (FHWA Classes 4–7); and combinations (Classes 8–13).*[11] The distinction between the two VC groups permits the development of separate growth rates for single-unit trucks (which are used almost exclusively to serve the local economy) and combinations (whose usage responds to a much wider range of influences).

2. *Identify all Level 1A sites for which estimates of* $AADT_i$ *have been developed for at least 4 years and that are believed to have historic rates of growth in the volume of heavy vehicles that are similar to those at the project site.*

3. *Associate the project site with one or more Level 1A sites identified in Step 2.* Only Level 1A sites are used for this purpose because the $AADT_i$ estimates developed for these sites are likely to achieve a much greater level of consistency over time than estimates developed for other sites.

4. *Use regression to estimate either linear growth rates or exponential growth rates for each Level 1A site for each VC group.*[12] In choosing between the two types of growth, a simple option is to choose the type that is believed to best describe expected future growth in truck traffic at the project site—linear growth if it is believed that the annual increase in this traffic is not likely to grow and exponential growth if this annual increase is expected to grow. (The Pavement Design Guide software has no provision for sites at which the annual increase is expected to decline over time. For such sites, linear growth should be assumed.) If this option is used, the same type of growth should be assumed for both VC groups (single-unit trucks and combinations).

   A slightly more complex option is to choose the type of growth that best fits the historic data at the Level 1A sites and then to modify the type of growth in Step 6. This option is discussed further in the latter part of the next subsection. If this option is used, the type of growth used in the regressions need not be limited to linear or exponential, and the regressions for single-unit trucks can be one type of growth and those for combinations can use a different type of growth.

5. *For each VC group, average the growth rates obtained in Step 4 for the associated Level 1A sites.*

6. *Judgmentally adjust the growth rates on the basis of a review of macroeconomic and site-specific factors.*

The Step 6 review should consider any identifiable factors suggesting that future growth in heavy-vehicle traffic at the target site is likely to differ from past growth at the Level 1A sites. Factors to be considered include

- Expected changes in macroeconomic trends,

[11] The vehicle-class groupings recommended here are the only ones handled by the current version of TrafLoad.

[12] Regression capabilities are available in most computer spreadsheets as well as in many other types of software.

- Planned and recently completed facilities that may affect the generation of truck trips, and
- Planned and recently completed highway projects that may affect truck routings.

This last category includes both new and upgraded feeder routes and new and upgraded parallel facilities. An interesting example of the effect of upgrading is the recent conversion of New Mexico SR-44 from two lanes to a four-lane divided highway (and its redesignation as US-550). The upgraded facility has attracted a significant amount of truck traffic heading northwest from Albuquerque that formerly used several other Interstate and U.S. highways. The facility is now feeding an increased number of trucks onto roads heading north and west from the Farmington area.

Procedures that may be used for making the required adjustments are discussed in the next subsection.

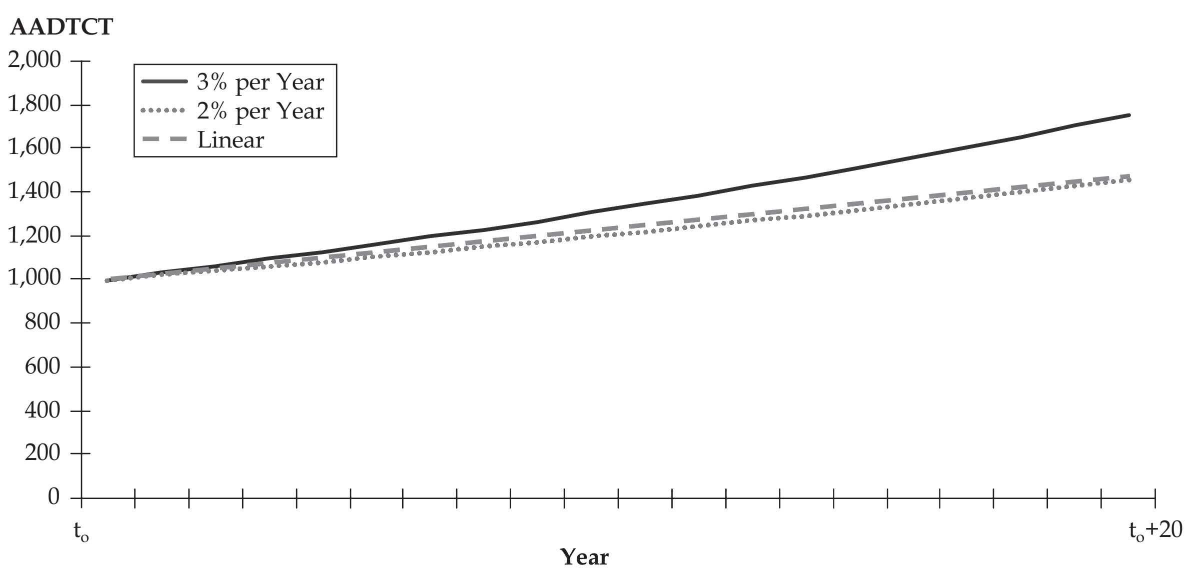
## Adjusting the Forecast

The adjustments made in Step 6 may be made directly to the (linear or exponential) growth rates developed in Step 5. Alternatively, it may be helpful to plot the Step 5 results in a spreadsheet and to use the plot as an aid in making the adjustments.

As an example, assume that, for a site of interest, AADT of combination trucks in the base year is estimated to be 1,000 and the forecast growth rate is estimated to be 3 percent per year. The solid line in Figure 3.3 represents this forecast over a 20-year period. Forecast AADT for combination trucks at the end of this period is 1,754.

Assume that the analyst believes that some downward adjustment of this forecast to a 2-percent annual growth rate may be appropriate. The dotted line in Figure 3.3 shows this alternative fore-

**Figure 3.3 Three Alternative Forecasts**



cast, producing a forecast-year value of AADT for combination trucks of 1,457. The forecast-year volume is 17 percent lower, but the total volume over the entire 20-year design period has only been reduced by 9.6 percent (from 9.81 million to 8.87 million).

A third forecast assumes the same truck volumes in the base year and in the forecast year as those of the second forecast, but the third forecast assumes linear growth. This third forecast is also shown in Figure 3.3. This forecast assumes somewhat larger increases in traffic volumes than does the second forecast in the early years but smaller increases in the later years. The total volume over the 20-year design period is 8.97 million, slightly higher than the total volume produced by the second forecast.

In the above example, the initial forecast (Steps 4 and 5) was developed under the assumption of exponential growth, but consideration was given to substituting linear growth. Such a possible substitution is always an option, subject to two restrictions on the selected form for the forecast:

- It must be either linear or exponential and
- It must be the same for both VC groups.[13]

For the purpose of pavement design, the most important traffic volume estimates are the total numbers of trucks and buses, by VC, expected over the design period. For the three forecasts discussed above, these estimates are represented graphically by the areas under the three curves in Figure 3.3. In developing these estimates, it should be recognized that the most important information consists of the base-year estimates of existing $AADT_i$. Forecasts of overall growth in traffic volume (which are necessarily more speculative) are less significant—in the example, a 65-percent increase in overall growth (from an increase of 457 combinations per day for the two lower curves to an increase of 754 for the highest curve) increases the total number of combinations over 20 years by only about 10 percent.

## Using TrafLoad

Although TrafLoad does not develop traffic forecasts, it does provide the user with substantial flexibility for entering forecasts. These options are summarized in Table 3.4. It allows the user to provide a linear or exponential growth rate developed in Step 5 of the above procedure. Alternatively, modified forecasts produced in Step 6 can be described in terms of the overall change in traffic volume over the forecast period or in terms of the volume forecast for the end of the period.

For Level 1, 2, and 3A sites, TrafLoad allows separate specification of forecasts for two VC groups: single-unit vehicles and combinations. However, it does not currently allow separate forecasts for individual VCs. Exponential growth rates specified for one of the two VC groups are applied to each VC in the group. Linear growth rates specified for one of the VC groups are distributed among the corresponding VCs in proportion to their base-year volumes ($AADT_i$). For Level 1, 2, and 3A sites, if TrafLoad has been requested to estimate $AADT_i$ for

[13] The second restriction applies only if forecasts are entered into the system via TrafLoad. See the next subsection.

## Table 3.4 TrafLoad Input Options for Forecasts

| | User Inputs | |
|---|---|---|
| **Input Option** | **Linear Growth** | **Exponential Growth** |
| Annual | Annual change | Annual percentage change |
| Overall change | Total change over period* | Percentage change over period* |
| Forecast AADT | Forecast AADT for VC group* | Forecast AADT for VC group* |

* Also requires specification of the base year and forecast year.

the design lane, then linear forecasts of growth are interpreted as being for this lane; if TrafLoad has been requested to estimate $AADT_i$ for a given direction, then linear forecasts of growth are interpreted as being growth in traffic for that direction. For Level 1, 2, and 3A sites, TrafLoad also requires that the same input option and the same type of growth (linear or exponential) be used for both VC groups.

For Level 3B sites, TrafLoad accepts only a single forecast of growth. This forecast is applied to total two-way truck volume, with no distinctions by lane, direction, or VC.

# 4.0 Data Handling

This chapter discusses the data collection and handling needed to create the datasets used by TrafLoad and the relationship of this data handling to a state's traffic data-collection program.

Highway agencies currently collect, manipulate, store, and report traffic data. No fundamental change in this existing data flow is required to meet the traffic data requirements of the Pavement Design Guide.

- Data must still be collected from the field, preferably using modern, calibrated, automated data-collection equipment.
- Data are downloaded from the devices used to collect data from the field and analyzed in the office. This analysis process includes checks for data quality, a summarization step, and a storage process that allows for later use.
- These summaries are then extracted and manipulated as needed to produce the traffic load estimates required by the Pavement Design Guide.

These activities are discussed in the first two sections of this chapter, and related administrative and institutional issues are discussed in Section 4.3. Extensive information on data-collection equipment is presented in a companion volume.[1]

## ■ 4.1 Data Collection

The Pavement Design Guide mechanistic design software does not require collection of new types of traffic load data. The TrafLoad data analysis system that feeds the Pavement Design Guide software uses the traditional measures of volume, vehicle classification, and truck axle weights to compute the traffic loading inputs needed. All of these measures are currently collected to one degree or another by every state highway agency and are discussed in FHWA's *Traffic Monitoring Guide*.

While all state highway agencies already collect data, it is likely that the number, timing, and location of counts that highway agencies perform will change in order to produce better traffic loading estimates. In addition, some state highway agencies may have to create new summary

[1] Cambridge Systematics, Inc., and Washington State Transportation Center, *Equipment for Collecting Traffic Load Data*, prepared under NCHRP Project 1-39, June 2003 available online at http://trb.org/news/blurb_detail.asp?id=4403.

output reports and data files from the data they are already collecting in order to input traffic loading estimates into the new pavement design software.

These changes in count location and duration are purely voluntary. However, the availability and quality of data collected by each state will have a direct impact on the accuracy of traffic load inputs to the pavement design process and consequently on the reliability of the pavement designs developed with the new software.

The basic data-collection design for providing traffic load data fits within the general traffic data-collection guidance provided by the FHWA in the 2001 *Traffic Monitoring Guide*. A key point is that a large portion of the traffic data collection required for estimating traffic loads should be collected as part of the routine traffic data-collection program. Thus, pavement design engineers need to work closely with those engineers who select, schedule, perform, and analyze the traffic data being collected. This increased level of communication will ensure that traffic load estimates can be collected cost effectively and that the summary statistics needed by the pavement designers are readily available and easily loaded into the pavement design software.

Each state highway agency should have a traffic count program that, at a minimum, collects

- Short-duration volume counts,
- Continuous volume counts,
- Short-duration classification counts,
- Continuous classification counts, and
- Weigh-in-motion (WIM) measurements (i.e., truck weighing).

Because pavement depth is not significantly impacted by the volume of light-duty vehicles, mechanistic design is primarily concerned with the number and weight of trucks and buses using the roadway in question. Volume data collection is not discussed in this report. Uses of classification and weight data are discussed in earlier chapters, and the collection and handling of these data are discussed in this chapter.

Short-duration classification count program elements are designed to provide site-specific volume (by VC) measurements that determine the total number of axle loads on a given roadway segment. Continuous-count elements provide measures of temporal variation needed to convert short-duration counts into unbiased measures of average annual conditions. WIM measurements provide data on the weights of each axle group.

These data-collection program elements provide all of the information needed for producing the traffic loading estimates required by TrafLoad. Table 4.1 summarizes the data requirements of TrafLoad and identifies the traffic data-collection elements that provide the raw data needed to meet these requirements. Table 4.2 describes the data that each of these elements contributes to the pavement design process. Both tables identify distinctions between the three levels of classification data discussed in Chapter 3.0 and between the three levels of weight data discussed in Chapter 2.0.

**Table 4.1 Data Required by the Pavement Design Guide Software**

| Required Data | Source for Data |
|---|---|
| AADT$_i^a$ for up to 13 VCs (1, 2, and 3A)[b] | ▪ Continuous classification counts, or<br>▪ Short-duration classification counts adjusted for day of week and season |
| AADT and Percent Trucks (3B) | ▪ Short-duration volume counts, adjusted for day of week and season and<br>▪ State estimates of truck percentages (from a combination of short and continuous classification counts) |
| Truck Traffic Classification Group (3B) | Judgment |
| Monthly Traffic Distribution Factors by VC | Continuous classification counts |
| Axle-Load Distribution Factors–Site Specific (1) | Weigh-in-motion data collection |
| Axle-Load Distribution Factors–Regional (2) | Weigh-in-motion data collection–statewide program |
| Axle-Load Distribution Factors–Statewide (3) | Weigh-in-motion data collection–statewide program |
| Linear or Exponential Growth Rate | Various sources |
| Directional Distribution Factor | Set to 1.0, except for Level 3B analyses |
| Axle Groups per Vehicle (for each VC) | Weigh-in-motion data collection |
| Hourly Distribution Factors | ▪ Continuous classification counts or<br>▪ Short-duration classification counts |

[a] $AADT_i$ is AADT by VC.

[b] Numbers in parentheses identify the input levels for which the data are used.

## ■ 4.2 Data Analysis

Once data are collected from the field, the data must be analyzed. This process consists of

- Quality control review of the collected data (to ensure that the equipment operated correctly),
- Summarization of the data into statistics and record formats that can be readily used by others inside and outside the state highway department, and

## Table 4.2 Data-Collection Elements for TrafLoad

| Type of Traffic Data Collection | Data Produced for TrafLoad |
|---|---|
| Short-Duration Volume Counts | Provides a "counted" measure of average daily traffic (ADT), which serves as an input to the computation of AADT (Class Level 3) |
| Continuous Traffic Counts | Used to compute the seasonal and day-of-week adjustment factors necessary to compute AADT from ADT values |
| Short-Duration Vehicle Classification Counts | Actual truck volumes (by type of truck) on the road for which the measurement was made (Level 1 or 2 class data)<br>TOD distribution factors by VC |
| Continuous Vehicle Classification Counts | Day-of-week and seasonal adjustment factors for trucks<br>Actual truck volumes for Level 1 (class) sites<br>Monthly traffic distribution factors by VC<br>Trend measurements used when forecasting future truck volumes |
| Short-Duration WIM Measurements | Current load spectra datasets (Weight Level 1) (if a well-calibrated site)<br>Used in the computation of Level 2 (weight) regional axle-load spectra by Truck Weight Road Group (TWRG) and Level 3 statewide axle load spectra<br>Used to correctly assign a specific roadway to a specific TWRG |
| Continuous WIM Measurements | Seasonal and current load spectra datasets (Weight Level 1)<br>Day-of-week and seasonal adjustments for load spectra datasets developed from short-duration WIM measurements<br>Used in the computation of Level 2 (weight) regional axle-load spectra by Truck Weight Road Group (TWRG) and Level 3 statewide average axle load spectra<br>Also used for continuous classification data |

- Storage of summary statistics in a form that permits ready retrieval and use by other analysis tools.

Data that are not reviewed, summarized, and stored for easy use simply waste the available data-collection resources.

Mechanistic pavement design does not require that state highway agencies perform these tasks in a particular manner. It does require that specific output reports be made available from the collected data. It also requires that effective quality assurance procedures be adopted and followed in order to maintain the quality of the data being used as input to the design process. The key components of this process are discussed below.

## Quality Control

Data-collection equipment does not always work as intended. Sensors fail, come loose, or are improperly installed. Settings can be inappropriate. The equipment may not be properly calibrated, or the calibration may drift over time as environmental conditions change. In some cases, operating conditions may not allow the equipment to function as designed.

Data from equipment that is not operating correctly yield inaccurate measurements of traffic loads that in turn result in poor design of pavement depths. Quality control programs are intended to identify malfunctioning or poorly calibrated equipment and to remove data collected by that equipment from the analysis process. In some cases, this means that additional data must be collected to replace the invalid data. In other cases, alternative data may be available (e.g., loss of 2 weeks of data from a continuous-count location is not serious). Performing quality checks quickly allows repair or recalibration efforts to be undertaken quickly, which in turn prevents loss of a large volume of data.

Quality control is particularly important for weigh-in-motion data, as many WIM scales are subject to calibration drift. Calibration drift of as little as 10 percent can result in errors of up to 40 percent in the estimates of pavement damage.[2]

For these reasons, each data-collection agency should have a quality assurance process that checks incoming data for errors. This can be a significant task, depending on the type of data collection being performed, the volume of data being collected, and the amount of automation present in the traffic data processing system operated by the state highway agency.

A pooled-fund study led by the Minnesota DOT developed a knowledge-based system for performing data quality checks for volume, classification, and weight data.[3] Other projects, such as FHWA's Long-Term Pavement Performance project, have also developed and published basic quality assurance procedures.[4] A summary of the most common data quality checks is provided in Section 5.5 of a companion report.[5]

All quality check procedures compare measured traffic characteristics with a set of known values. Known values are drawn either from previous data-collection experience for that location

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[2] *WIM Calibration, a Vital Activity*, FHWA Publication Number FHWA-RD-98-104, July 1998.

[3] Intelligent Decision Technologies, Ltd., Traffic Data Quality Procedures, Pooled-Fund Study, Expert Knowledge Base, Interim Task A3 Report, prepared for Minnesota DOT, November 1997.

[4] FHWA, LTPP Division, *Data Collection Guide for Long-Term Pavement Performance Studies*, Operational Guide No. SHRP-LTPP-OG-001, Revised October 1993.

[5] Cambridge Systematics, Inc., and Washington State Transportation Center, *Equipment for Collecting Traffic Load Data*, prepared under NCHRP Project 1-39, June 2003, available online at http://trb.org/news/blurb_detail.asp?id=4403.

or from independently measured sources. (For example, to determine if the clock on a data-collection device correctly distinguishes daytime from nighttime, 1:00 a.m. and 1:00 p.m. volumes might be compared using the known fact that 1:00 p.m. volumes normally exceed 1:00 a.m. volumes.)

A key to the quality assurance effort is to make sure the known values against which collected data are compared are accurate measures of the expected traffic patterns. For example, traffic volume on the freeway connecting Los Angeles and Las Vegas often has 1:00 a.m. traffic volumes that are large enough to exceed 1:00 p.m. volumes. Thus, the check described above is not an appropriate quality control check for this location, even though it is quite applicable to most other roadways in the nation.

This same key point is important when known values are used for automatically adjusting the calibration of data-collection equipment such as WIM scales. Such algorithms can work, but only when the known values are correct and when a sufficient number of vehicles cross the scale in the time period observed. If any of the key assumptions used for auto-calibration are incorrect, the auto-calibration system will not work effectively and can actually decrease the accuracy of the data collected. Auto-calibration problems may exist if the average axle weights of either passenger cars or Class 9 truck steering axles are not known, if either of these averages varies over time, or if adequate samples of these two vehicle types are not observed during any calibration period.

Periodic collection of independent data is required to confirm that the values used for quality assurance checks are correct. These independent tests include (1) the calibration of WIM and classifier systems when they are first installed and used at a site and (2) visual confirmation that portable classifiers are correctly functioning when they are placed on a roadway. Once the initial equipment operation can be verified, datasets can be collected and used for determining the known traffic patterns against which new data are compared.

This type of quality control procedure is designed to identify suspect data (i.e., data that do not fit expected patterns). If unexpected patterns are observed, additional forensic work is required. In some cases, it is readily apparent that equipment or sensors have failed. For permanent data-collection sites, such failures indicate that repairs are needed as quickly as practical. In the case of short-duration data collection, the affected data must be discarded and, usually, replaced by new data.

In other cases, the unusual data are plausible but unexpected (for example the Los Angeles/Las Vegas TOD patterns mentioned above). In these cases, additional data should be collected to confirm or invalidate the unusual data. For these second-chance data-collection efforts, particular attention should be paid to setting up and calibrating the equipment to ensure that the confirmation dataset is accurate. If the new data support the unexpected traffic pattern, then the known value for this site must be updated to reflect the new information.

## Data Summarization

Once the collected traffic data have successfully passed through the quality assurance process, an efficient mechanism is needed for storing and summarizing the data so that they can be used when needed for pavement design. Most states have existing programs that collect and store both volume and classification data on a section-by-section or count-by-count basis. In many states, these data can be retrieved by section through the state highway agency's geographic information system.

Changes in existing data summarization procedures that may be required to support mechanistic pavement design include the creation of some additional summary statistics that not all states currently compute and store. These statistics are intended to provide better site-specific traffic loading estimates and thus provide for better pavement designs.

Among the statistics that are computed by TrafLoad for use by the pavement design software are

- Seasonal (monthly) patterns of truck volumes;
- TOD distributions for truck volumes;
- Load spectra for different roads and roadway groups; and
- Numbers of axles, by type of axle, for each class of trucks.

The last two statistics have been discussed in some detail in Chapter 2.0, and other needed statistics (including the first two) have been discussed in Chapter 3.0.

## Use of TrafLoad

If TrafLoad is used to process traffic data and generate traffic data inputs for the Pavement Design Guide software, then the required data must be loaded into the system. There are two primary forms of data to be entered:

- Hourly vehicle classification records from specific count locations and
- Axle-load data by vehicle for specific sites.

Hourly vehicle classification records are assumed to be available in the FHWA C-card (or four-card) record format. Data from both short-duration and continuous sites should be supplied in this format. While all state highway agencies can currently create C-card records easily, considerable change may be needed within current data processing systems in order to make hourly classification data available to pavement designers. Many states only provide access to summary statistics such as average daily traffic and overall percent trucks. Making hourly records available to TrafLoad may require modification to current systems or changes in administrative procedures used to store, request, and report traffic data.

Axle-load data for individual vehicles are assumed to be available in the FHWA W-card (or seven-card) record format. As in the case of C-card records, making the W-card records available to TrafLoad may require modification to current systems.

It is expected that some software development work will be required at most state highway agencies to simplify the extraction of data items from existing traffic databases and to make the appropriate files accessible to TrafLoad. In most cases, these development efforts should be modest.

## ■ 4.3 Administrative and Institutional Changes

In preparing to use the new procedures for pavement design, one of the biggest hurdles for most states is likely not to be technical but institutional. In most highway agencies, pavement design and traffic data collection and analysis are in separate areas. This separation limits interaction between these two groups and reduces the ability of the traffic data-collection group to adopt procedures that satisfy the changing input requirements of pavement design and that meet other needs of pavement designers.

Most state highway agencies already collect the data needed for estimating traffic loads for mechanistic design. However, few agencies currently summarize this information and effectively report it to their pavement designers. As a consequence, few pavement design groups actually use much of the load data being collected. If the mechanistic design practices are to be implemented effectively, these failings must be remedied.

The key to improving the collection of load data and its conversion into effective inputs for the mechanistic design procedures is a substantial increase in the interaction between pavement designers and the traffic data-collection and analysis staff. This interaction should include the following:

- Training for pavement designers on
  - What traffic data are needed,
  - Why those data are important,
  - What effect the data have on the resulting pavement designs,
  - Where to get the data that are collected,
  - How to request more data when the available data do not meet design requirements, and
  - How to review the traffic estimates being provided.
- Training for data-collection and analysis staff on
  - What data are important for pavement design and what data have the largest effect on pavement design,
  - How the data collected are used in the design process, and
  - What the flow of traffic load data is in the pavement design process.
- Increased communication that
  - Allows data-collection staff to correctly anticipate (and schedule) the data needs of the designers,

  - Ensures that the data and summary statistics produced by the data-collection staff meet the needs of the pavement designers,

  - Ensures that the data required are transmitted to the pavement design staff in a timely fashion and in a format that can be easily loaded into the mechanistic design software, and

  - Involves both pavement design and data-collection staff in the review and refinement of the data-collection and summarization process used to feed the design process. (For example, are the Truck Weight Road Groups correctly defined? If not, how should they be revised? Where should additional truck weight data be collected? What other holes in the available traffic data should be remedied?)

- Reviews of

  - The resources that are spent collecting traffic data,

  - The relative value to the pavement designers of the various resources, and

  - The potential value to the pavement program of addition expenditures on data collection.

Although state highway agencies are already doing much of what is needed to meet the traffic data requirements of mechanistic pavement design, considerable work is still required to refine the existing procedures and software. Although data are collected, they often are not adequately summarized and reported. Resources will be needed to address these deficiencies.

Resources are traditionally in very short supply for traffic data collection and analysis, and it will be necessary for the pavement design group to lend political support to the data-collection group if those resources are to be obtained. This will only happen if the pavement design group understands the importance of the traffic load data and if the traffic data-collection group can be relied on to provide those load estimates in a responsive and efficient manner. Neither of these conditions is currently met in very many highway agencies.

The recommended increases in both communication and training should result in many improvements in both data-collection and pavement design processes. Fostering effective communication between the data-collection team and the pavement design group should result in traffic data-collection decisions that consider the needs of the pavement designers more effectively. Similarly, improved communication will enable pavement designers to use traffic data more effectively, thus allowing the development of more reliable designs.

# Glossary

| | |
|---|---|
| AADT | Annual average daily traffic. |
| $AADT_i$ | Annual average daily traffic for vehicle class *i*. |
| AADTT | Annual average daily truck traffic (all classes, combined). |
| AEPV | Average ESALs per vehicle. |
| ATR | Automatic traffic recorder. |
| AVC | Automatic vehicle classifier. |
| DDF | Directional distribution factor. |
| DOW | Day-of-week. |
| ESALs | (18,000-pound) equivalent single-axle loads. |
| HDF | Hourly distribution factor. |
| LDF | Lane distribution factor. |
| MADW | Monthly average days of the week. |
| TOD | Time-of-day. |
| TTC | Truck traffic classification. |
| TWRG | Truck weight road group. |
| VC | Vehicle class. |
| WIM | Weigh-in-motion. |

# Levels of Classification Site

| | |
|---|---|
| 1A | Site for which AVC data are available for periods of at least 1 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 6 weekday 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. |

Abbreviations used without definitions in TRB publications:

| | |
|---|---|
| AASHO | American Association of State Highway Officials |
| AASHTO | American Association of State Highway and Transportation Officials |
| APTA | American Public Transportation Association |
| ASCE | American Society of Civil Engineers |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| ATA | American Trucking Associations |
| CTAA | Community Transportation Association of America |
| CTBSSP | Commercial Truck and Bus Safety Synthesis Program |
| DHS | Department of Homeland Security |
| FAA | Federal Aviation Administration |
| FHWA | Federal Highway Administration |
| FMCSA | Federal Motor Carrier Safety Administration |
| FRA | Federal Railroad Administration |
| FTA | Federal Transit Administration |
| IEEE | Institute of Electrical and Electronics Engineers |
| ITE | Institute of Transportation Engineers |
| NCHRP | National Cooperative Highway Research Program |
| NCTRP | National Cooperative Transit Research and Development Program |
| NHTSA | National Highway Traffic Safety Administration |
| NTSB | National Transportation Safety Board |
| SAE | Society of Automotive Engineers |
| TCRP | Transit Cooperative Research Program |
| TRB | Transportation Research Board |
| TSA | Transportation Security Administration |
| U.S.DOT | United States Department of Transportation |