Estimating Cumulative Traffic Loads, Final Report for Phase 1

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LTPP

FOREWORD

Pavement performance analysis encompasses a variety of applications, including the prediction of individual distresses, pavement design and rehabilitation, and pavement management. In all of these applications, knowledge of the cumulative traffic loads imposed on the pavement is a crucial element of the analysis process, especially in developing load-related distress prediction models. Because of the expensive and massive nature of the traffic data collection process in the field, it has been the responsibility of the participating agencies since the inception of the Long Term Pavement Performance (LTPP) program. The result has been considerable variation in the quality and quantity of the historical and monitoring traffic data, creating a need to estimate cumulative traffic loads for the entire pavement lifespan using the available fragmented data.

This report provides a methodology for obtaining cumulative traffic load spectra applicable for all LTPP sites, and demonstrates this methodology using 12 case studies. This report will be of interest to engineers involved in pavement design, pavement performance evaluation and prediction, and pavement maintenance and rehabilitation.

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16. Abstract

The knowledge of traffic loads is a prerequisite for the pavement analysis process, especially for the development of load-related distress prediction models. Furthermore, the emerging mechanistically based pavement performance models and pavement design methods (such as the anticipated *2002 Pavement Design Guide*) require the knowledge of the load spectra acting on the pavement during its lifespan.

This report describes a procedure for obtaining axle load spectra for Long Term Pavement Performance (LTPP) sections. The procedure has been demonstrated and evaluated by applying it to 12 LTPP sections for which different amounts of monitoring traffic data were available. Typically, for the majority of LTPP sections, there are only a few years for which the traffic load data were collected by automated equipment in the mid-1990s. To obtain axle load spectra for all in-service years, traffic loads must be projected: backcasted (for the years before the installation of traffic monitoring equipment) and forecasted (for the years after the automated equipment no longer provides data).

This report also contains a review of the evolution of motor carrier technology (in terms of economical and political changes, regulatory changes in vehicle weights and dimensions, and engineering changes) and its impact on traffic loads, and a proposal to develop and use new summary statistical measures and tools for the management of load spectra. Major findings and recommendations include:

1. Traffic load projections for the majority of LTPP sites are feasible.
2. The accuracy and reliability of the traffic projections for many of the LTPP sites may not be as high as originally anticipated.
3. The involvement of State highway agencies (SHAs) in the traffic projection process is crucial.
4. The traffic projection process is very challenging and labor-intensive. The main reason for the labor-intensive process is the need to carry out extensive quality assurance activities to resolve inconsistencies in the reported traffic data.
5. The quality assurance process would greatly benefit from developing a knowledge base or a catalog documenting a typical range of traffic load variables. The process would also benefit from the availability of summary measures for traffic loads that are independent of pavement variables.
6. Traffic modeling and forecasting is a highly cost-effective way to extend limited sampling data and compensate for the lack of data. To obtain payback on the large investment in the traffic data collection effort by SHAs, it is necessary to allocate sufficient resources to utilize fully the available traffic data through the traffic prediction process.
7. It is recommended to proceed with carrying out traffic load projections for the selected LTPP sites (Phase 2 study).
8. Phase 2 study, and any future projection of traffic loads, should include the input from the representatives of SHAs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

(Revised September 1993)

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CHAPTER 1. INTRODUCTION

BACKGROUND

Traffic data are recognized as a key data element or feature for the analysis of pavement performance. Pavement performance analysis can vary from short-term pavement evaluation to long-term pavement performance prediction, and it encompasses a variety of applications, including the prediction of individual distresses, pavement design and rehabilitation, and pavement management. In all these applications, knowledge of the cumulative traffic loads imposed on the pavement is a crucial part of the analysis process, especially in developing load-related distress prediction models.

At the inception of the Long Term Pavement Performance (LTPP) program, traffic information was recognized as the most difficult and complicated data item to be collected. This is because of the expensive and massive nature of the traffic data collection and analysis process, and because the collection of traffic data in the field has been the responsibility of the participating agencies, whereas other field data, such as roughness and deflections, have been collected directly by the Strategic Highway Research Program (SHRP). Over the years, the participating agencies received a series of guidelines on how traffic data should be collected and reported to LTPP. Examples of the most recent guidelines are given in references 1 and 2.

Most of the traffic data collection in the field is done automatically. Automatic Traffic Recorders (ATR) collect traffic volumes, Automatic Vehicle Classifiers (AVC) collect the vehicle volumes by vehicle category, and weigh-in-motion (WIM) scales collect axle weight data. The traffic data collected in the field are sent to LTPP, in the format specified in the *Traffic Monitoring Guide* [3], for processing and storage in the Central Traffic Database (CTDB). Selected aggregated traffic data are also stored in the LTPP Information Management System (IMS) [4].

There are three basic categories of traffic data stored in the CTDB: historical, monitoring, and supporting. Historical data were estimated by State highway agencies (SHAs) for the LTPP sections prior to the installation of traffic monitoring equipment. Historical data estimates include total Annual Average Daily Traffic (AADT) volumes, total AADT truck volumes, and total annual equivalent single-axle loads (ESALs) for each year from the time of roadway opening to traffic to the beginning of LTPP traffic monitoring. In some cases, very little supporting data were available, and the historical data are "best estimates." In all cases, the methodologies used by the SHAs to obtain the historical estimates have been recorded [4]. The years from the time the site was opened to traffic to the time the site was assumed by the LTPP experiment are referred to as *historical years.*

Monitoring data have been submitted by the SHAs for the years since the LTPP experiment began. Monitoring data fall into two categories: measured and estimated. Monitoring measured data are obtained by actual field measurements using ATR, AVC, and WIM equipment, whereas estimated monitoring data are estimated by SHAs for the years for which measured monitoring data are not available. The years from the time a site was assumed by the LTPP to present are referred to as *monitoring years.*

Supporting data describe conditions under which historical and monitoring data were collected. Supporting data may also include calibration results obtained for WIM scales.

NEED FOR PROJECTING TRAFFIC LOADS

The quality and quantity of historical and monitoring traffic data vary considerably. As a rule, historical data do not contain axle load data, and many LTPP sites have many years for which monitoring measured data—either WIM data or both AVC data and WIM data—are not available. Since the knowledge of cumulative axle loads is a crucial part of the pavement performance analysis process, the cumulative traffic loads for the entire pavement lifespan need to be estimated using the available fragmented historical and monitoring traffic data.

Furthermore, because emerging mechanistically based pavement performance models and pavement design methods (such as the anticipated *2002 Pavement Design Guide*) require knowledge of load spectra (rather than only ESALs), the cumulative traffic loads need to be estimated in terms of load spectra. A load spectrum is the distribution of the number of axles by load ranges for different axle configurations (single, tandem, tridem). In the CTDB, load spectra are also given separately for different vehicle classes.

The original name of this project, Traffic Backcasting Study, implies that traffic monitoring data are projected backwards. Closer examination of the available monitoring data revealed that, in order to obtain cumulative traffic loads for the entire in-service life of pavement sections, monitoring data have to be not only backcasted, but also interpolated (for the interim monitoring years without monitoring data) and forecasted (for years after the automated equipment no longer provides data). Consequently, rather than backcasting, the process of obtaining traffic loads for the entire lifespan of the pavement sites is referred to herein as *projecting.*

STUDY OBJECTIVES

To obtain load spectrum data for each year that an LTPP section has been in service, a study has been sponsored by the Federal Highway Administration (FHWA) to develop a procedure for projecting traffic loads and to apply the procedure to LTPP sections. The study has been divided into two phases. In Phase 1, a traffic projection methodology is to be developed. In Phase 2, based on FHWA's approval, the methodology is to be used to obtain cumulative annual load spectra for specific sections. The projected annual load spectra are to be stored in computed parameter tables.

The objectives of the Phase 1 study are to develop, document, demonstrate, and evaluate a methodology for obtaining cumulative traffic load spectra applicable for all LTPP sites. The demonstration and the evaluation of the methodology is to be documented by realistic case studies.

TRAFFIC DATA CONCERNS

Until now, historical trends in traffic data stored in CTDB have not been systematically evaluated. An example of such an evaluation, in terms of annual ESALs, is given in figure 1.

Figure 1 shows the relationship between historical ESALs (estimated by SHAs) and monitoring ESALs (measured by automated equipment) for three selected sites. The top part of the figure shows an example of a section (GPS test site 01-1021) with a consistent and expected trend between the historical estimates of ESALs and the ESALs calculated using measured monitored traffic data. The middle part of figure 1 is an example of a section (GPS site 05-3048) exhibiting significant differences between the historical ESALs and the monitoring ESALs. The bottom part of figure 1 is an example of a section (GPS test site 01-1019) with conflicting trends between historical and monitoring ESALs (growth versus decline). The alarming drop in ESALs reported for this section in 1996 invites further examination.

The trends in data presented in figure 1 are rather typical. A rough comparison of historical and monitoring trends in ESALs for all sites in the North Atlantic and North Central Regions, summarized in table 1, indicates that the historical and monitoring ESAL trends do not compare well and that the trends in the historical and monitoring ESALs vary considerably. It should also be noted that no annual historical or monitoring ESALs were available for 27 sites.

The subject of trends in ESALs was presented in this introductory chapter to indicate from the beginning that the process of projecting traffic volumes, relying on the available historical and monitoring data, is challenging and requires the judgment and involvement of the SHAs.

REPORT ORGANIZATION

This report documents the results of Phase 1 of the FHWA study. It builds on the Interim Report [5] and its three appendixes. This report contains a step-by-step methodology for projecting traffic load spectra suitable for all LTPP sections and demonstrates this methodology using 12 case studies.

Chapter 1 contains the introductory material. Chapter 2 describes basic characteristics of the LTPP traffic data base and its contents. The proposed traffic projection methodology is presented in chapter 3. A step-by-step procedure for conducting case studies, which is also essentially the procedure recommended for projecting traffic loads for the rest of the LTPP sections, is presented in chapter 4. Chapter 5 contains detailed description of the 12 case studies used to demonstrate and evaluate the proposed prediction methodology. Chapter 6 describes statistical measures and tools for managing traffic loads, including the proposed LTPP Pavement Loading Guide. The summary and recommendations are presented in chapter 7.

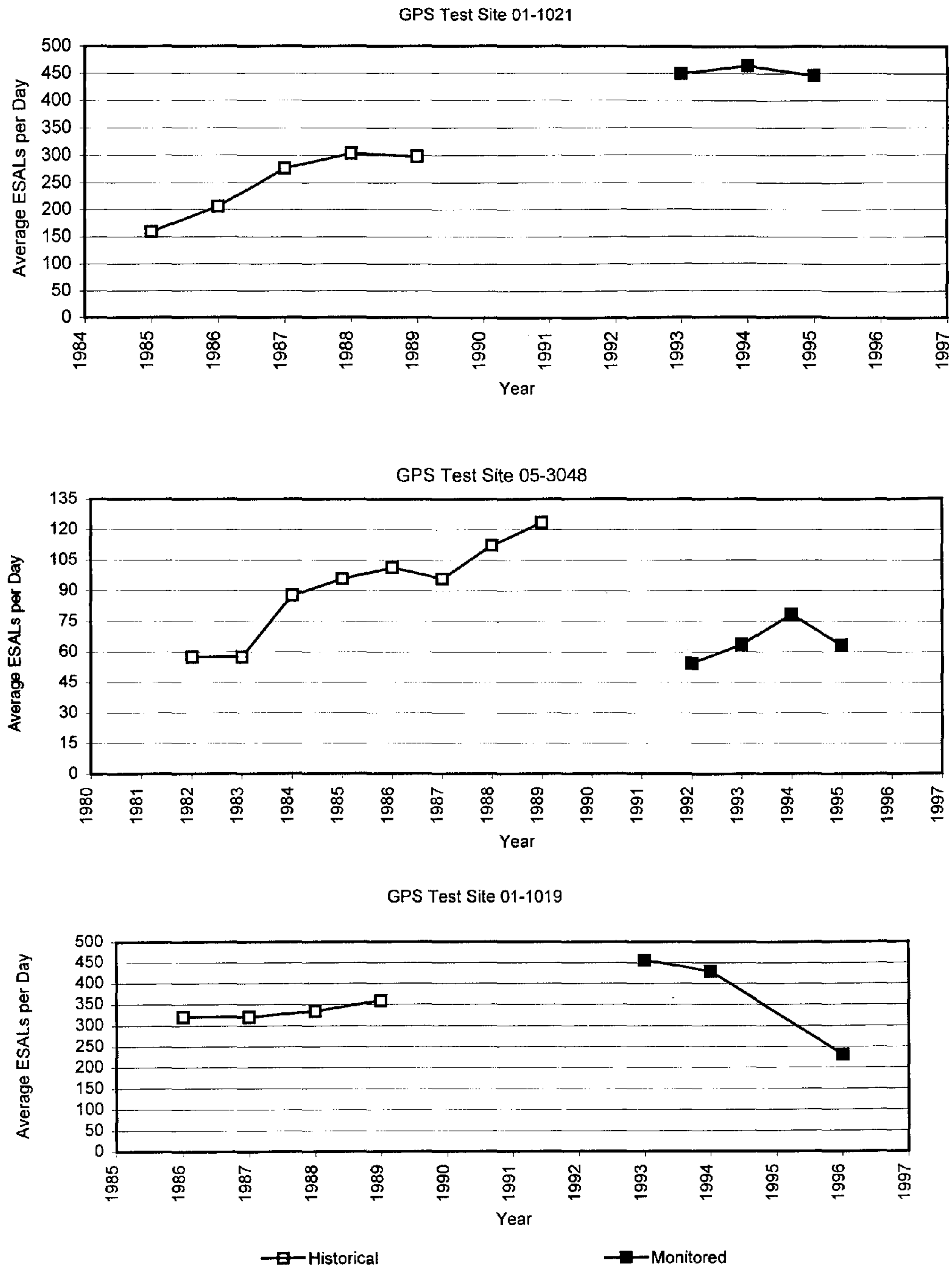


Figure 1. Comparison of trends for average historical and monitoring ESALs per day.

Table 1. Comparison of historical and monitoring ESAL trends for North Atlantic and North Central Region sites.

Number of Sections	Monitoring Trend Type	Historical Trend Type	Comments
2	Decreasing	Fluctuating	Historical and Monitoring are on comparable scale
1	Decreasing	Increasing	Historical and Monitoring are on comparable scale
2	Decreasing	Increasing	Historical much higher than Monitoring
1	Decreasing	Increasing	Monitoring much higher than Historical
2	Fluctuating	Decreasing	Historical and Monitoring are on comparable scale
1	Fluctuating	Decreasing	Monitoring much higher than Historical
8	Fluctuating	Fluctuating	Historical and Monitoring are on comparable scale
2	Fluctuating	Fluctuating	Historical much higher than Monitoring
1	Fluctuating	Fluctuating	Monitoring much higher than Historical
11	Fluctuating	Increasing	Historical and Monitoring are on comparable scale
7	Fluctuating	Increasing	Historical much higher than Monitoring
2	Fluctuating	Stable	Historical and Monitoring are on comparable scale
1	Fluctuating	Stable	Monitoring much higher than Historical
2	Increasing	Fluctuating	Historical much higher than Monitoring
1	Increasing	Increasing	Historical and Monitoring are on comparable scale
5	Increasing	Increasing	Historical much higher than Monitoring
1	Increasing	Stable	Historical and Monitoring are on comparable scale
1	Stable	Increasing	Historical and Monitoring are on comparable scale
4	Stable	Increasing	Historical much higher than Monitoring
2	Stable	Stable	Historical much higher than Monitoring
1	One observation	Fluctuating	Historical much higher than Monitoring
1	One observation	Increasing	Historical much higher than Monitoring
27	No ESALs	No ESALs	No ESAL graph available

CHAPTER 2. CHARACTERISTICS OF LTPP TRAFFIC DATA

The traffic data collection and analysis effort has proven to be one of the most challenging aspects of the LTPP program. Reliable traffic data, and especially axle load spectrum data, are a necessity if the LTPP program is to provide useful products that will result in cost-effective durable pavements. Under SHRP, it was assumed that the participating highway agencies would be able to easily accomplish traffic data collection at each test section using the available technology. However, the high cost of installing, maintaining, and operating AVC and WIM equipment has resulted in a smaller amount of monitoring data, and at fewer sites, than perhaps originally anticipated.

LTPP data were used previously for a number of traffic studies, such as to evaluate the influence of the sampling rates on the precision of traffic estimates [6] or to study seasonal variation in traffic volumes [7]. However, no systematic utilization of traffic data involving the estimation of cumulative traffic loads has been attempted before. The estimation of cumulative loads utilizes trends in historical and monitoring data and is also a powerful quality assurance tool.

LTPP TRAFFIC DATA STRUCTURE

LTPP traffic data reside in two locations—the LTPP CTDB and the LTPP IMS.

The LTPP CTDB stores traffic data on five levels, as outlined in table 2 and shown in figure 2. Levels 1 through 4 store only measured monitoring data, whereas Level 5 stores historical and supporting data. Briefly, Level 1 data features annual axle load spectra for all vehicle classes combined. Level 2 data features annual axle load spectra for individual vehicle classes. (Vehicle classes used by LTPP are identical to the FHWA vehicle classes given in reference 3.) The annual axle load spectra on Level 2 are given separately for 10 vehicle classes, 4 through 13 inclusive. Level 3 data feature daily axle load spectra for individual vehicle classes. Up to 365 records for each vehicle class may appear on Level 3 for each LTPP test section and for each monitoring year. Thus, Level 3 data files can be very large and cannot be easily manipulated. Level 4 contains data in the form submitted by the SHAs. Level 5 contains supporting data.

The LTPP IMS contains Level 1 data, including the monitoring load spectra for all vehicle classes combined and segregated by axle type (single, tandem, tridem, and quads), as well as annual ESALs.

Monitoring traffic data collected by SHAs are sent to Regional Coordination Office Contractors (RCOC) in electronic format as individual vehicle records (raw data). After processing by RCOC, data are stored in the CTDB or in the IMS where they can be requested by the users. The flow of the traffic data between the SHAs and the users is illustrated in figure 3.

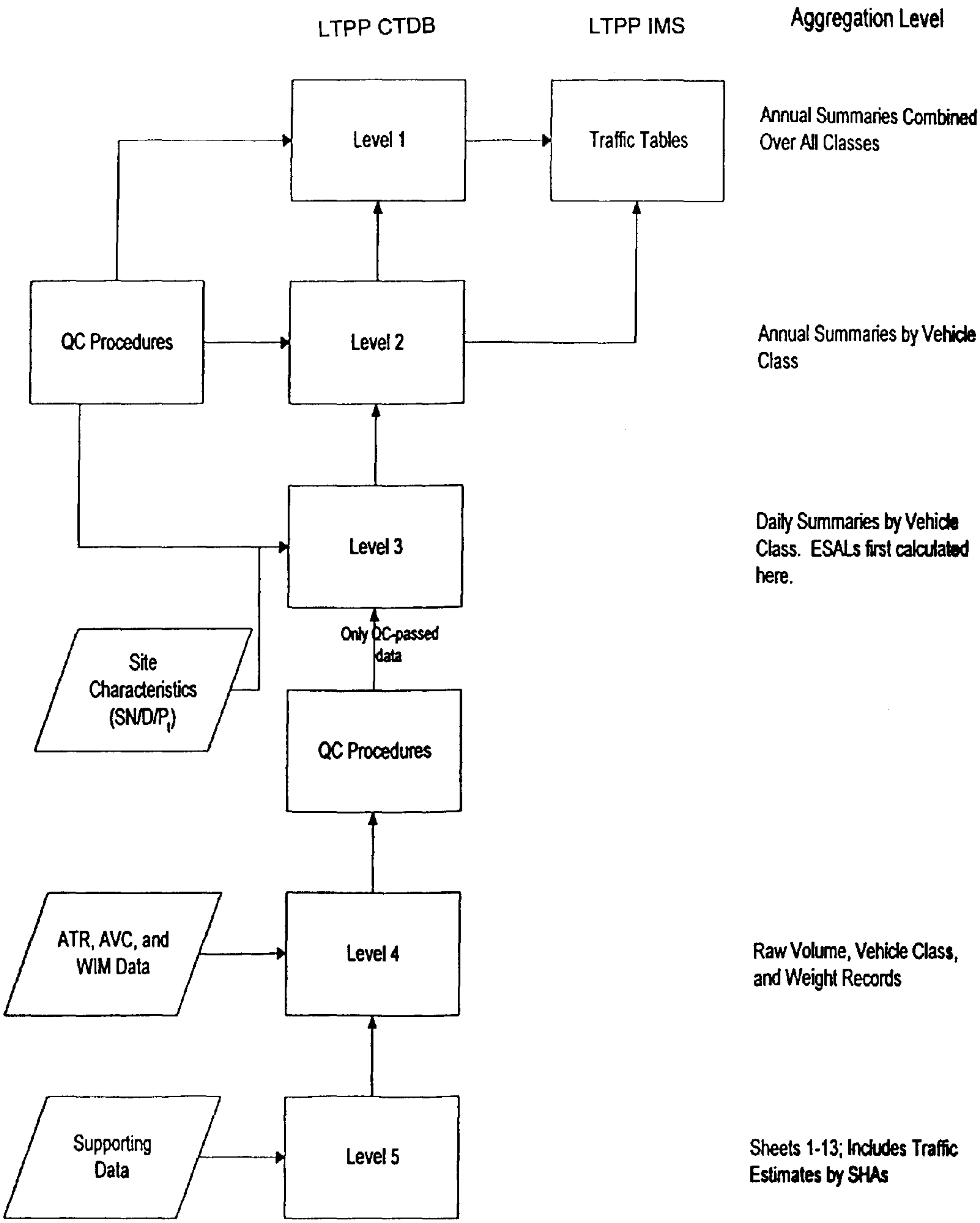


Figure 2. LTPP traffic data levels.

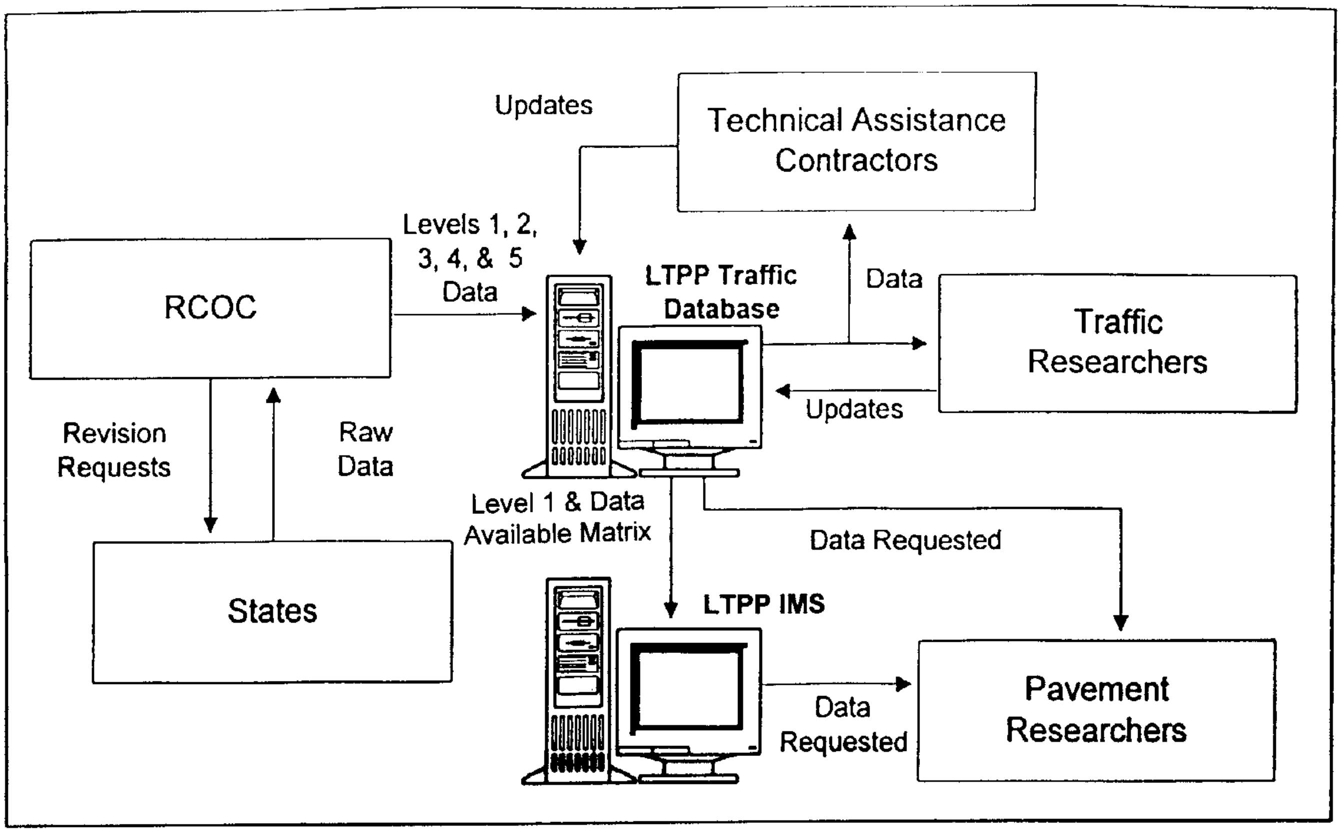


Figure 3. Flow of LTPP traffic data.

Table 2. LTPP CTDB data types.

Data Type	Description of Subtypes Available
Level 1	Annual axle loads, ESALs for all vehicles, and other summary statistics
Level 2	Annual axle loads, ESALs by vehicle class, and other summary statistics
Level 3	Volume (daily traffic volumes by vehicle class)
	Vehicle class (daily traffic volumes by vehicle class)
	Weight (ESALs and weight ranges by vehicle class)
Level 4	Volume (hourly traffic volumes by lane; "3-card")
	Vehicle class (hourly volumes by vehicle class; "4-card")
	Weight (individual truck weight records; "7-card")
Level 5	Vehicle class data submittal forms
	Weight data submittal forms
	Historical data sheets (Sheets 1-9) plus monitoring estimates (Sheet 10)

Note: Levels 3 and 4 have three distinct data types: volume, vehicle classification, and weight. Likewise, Level 5 is composed of three different types. Record layouts will therefore vary.

CHARACTERISTICS OF LTPP TEST SECTIONS

The distribution of LTPP test sections by highway functional classification is given in table 3, based on IMS data available as of fall 1998. LTPP sections located on rural Interstates and rural principal arterial highways comprise 32.2 percent and 42.7 percent of the sections, respectively. Altogether, 86.1 percent of all LTPP sites are located on rural highways. There are 9.3 percent of the sections located on urban principal arterial roadways (Interstate and other).

The vehicle distribution, by FHWA vehicle class and for each highway functional classification, is given in table 4. This table is based on limited data as of early 1997, but is considered representative. For truck traffic, vehicle class 9 (five-axle single trailer trucks) is the most frequent vehicle type for all highway classes, with the exception of urban major collectors and rural major collectors, where vehicle class 5 predominates. Class 5 (two-axle, six-tire single-unit trucks) is the second most frequent vehicle type. The FHWA vehicle truck classes are defined in table 5.

CHARACTERISTICS OF LTPP TRAFFIC DATA

LTPP traffic data have been used previously by several studies to characterize trends in the data [7], analyze the consequences of alternative sampling trends [6], and to assess their potential for developing models for predicting axle load distributions [8]. These studies were reviewed to obtain a better understanding of the LTPP data characteristics.

A study on seasonal patterns of vehicle volumes [7] concluded that, on a national level, both rural and urban sites exhibit a general pattern of lower volumes during the winter months and higher volumes from April through September. A similar pattern was reported by Sharma and Leng [9], who examined seasonal travel patterns for 52 sites in Minnesota. Hallenbeck [7] reported that on a national level, both rural and urban sites exhibit a general pattern of lower car and truck volumes during the winter months and higher volumes from April through September. Kim et al. [8] used LTPP data for 21 sites located on Interstate highways in the North Central Region (NCR) to develop axle load distributions for mechanistic pavement design. Data analysis showed that, for Interstate highways within the LTPP NCR, the distribution of axle load spectra was stable from 1991 through 1994.

The LTPP traffic data exhibit pronounced variations in truck volume, depending on the day of the week. For example, figure 4 shows the variation in the total number of tandem-axle loads (in the range of 0 to 142.4 kN [0 to 31,999 lb] for vehicle class 9 in 1996) for Site 26-1001. For the majority of the sections evaluated in this study, it was found that weekday truck traffic is significantly higher than weekend truck traffic. However, it is also possible that some sites exhibit the opposite patterns.

Table 3. Distribution of LTPP test sections by functional classification.

By General Pavement Studies (GPS) Section

LTPP Code	Description	GPS-1	GPS-2	GPS-3	GPS-4	GPS-5	GPS-6	GPS-7	GPS-9	Total	Total, %
1	Rural Interstate	54	27	59	21	41	60	41	17	320	32.2
2	Rural Principal Arterial	123	88	50	24	20	97	19	4	425	42.7
6	Rural Minor Arterial	34	23	6	4	1	16	8	0	92	9.2
7	Rural Major Collector	8	2	1	0	2	4	0	0	17	1.7
8	Rural Minor Collector	2	1	0	0	0	0	0	0	3	0.3
9	Rural Local Collector	0	0	0	0	0	0	0	0	0	0.0
11	Urban Interstate	5	0	11	15	19	4	9	4	67	6.7
12	Urban Principal Arterial	5	5	2	1	3	5	2	3	26	2.6
14	Urban Minor Arterial	15	4	7	5	0	5	0	1	37	3.7
16	Urban Major Collector	2	3	0	0	0	1	0	0	6	0.6
17	Urban Minor Collector	1	0	0	0	0	0	0	0	1	0.1
19	Urban Local Collector	0	0	0	0	0	0	0	0	0	0.0
	Unknown	0	0	0	0	0	0	0	1	1	0.1
	Total	249	153	136	70	86	192	79	30	995	100

By Specific Pavement Studies (SPS) Section

LTPP Code	Description	SPS-1	SPS-2	SPS-3	SPS-4	SPS-5	SPS-6	SPS-7	SPS-8	SPS-9	Total	Total, %
1	Rural Interstate	2	6	0	0	9	6	3	0	10	36	23.7
2	Rural Principal Arterial	14	4	0	0	8	5	0	1	15	47	30.9
6	Rural Minor Arterial	0	0	0	0	0	0	0	3	0	3	2.0
7	Rural Major Collector	0	0	0	0	0	0	0	1	0	1	0.7
8	Rural Minor Collector	0	0	0	0	0	0	0	6	0	6	3.9
9	Rural Local Collector	0	0	0	0	0	0	0	0	0	0	0.0
11	Urban Interstate	0	0	0	0	0	0	0	0	2	2	1.3
12	Urban Principal Arterial	0	2	0	0	0	0	0	0	0	2	1.3
14	Urban Minor Arterial	0	0	0	0	0	0	1	0	0	1	0.7
16	Urban Major Collector	0	0	0	0	0	0	0	0	0	0	0.0
17	Urban Minor Collector	0	0	0	0	0	0	0	1	0	1	0.7
19	Urban Local Collector	0	0	0	0	0	0	0	0	0	0	0.0
	Unknown	2	0	13	6	19	1	0	2	10	53	34.9
	Total	18	12	13	6	36	12	4	14	37	152	100

Table 4. Distribution by vehicle class at LTPP sites.

Functional Class	Vehicle Percentage						
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
Rural Interstate	0.2	63.1	12.3	0.3	2.3	0.8	0.1
Rural Principal Arterial	0.2	72.1	16.0	0.3	2.5	0.8	0.1
Rural Minor Arterial	0.1	72.3	19.1	0.3	2.2	0.7	0.1
Rural Major Collector	0.0	74.5	18.2	0.4	3.7	0.6	0.0
Urban Interstate	0.2	75.7	15.7	0.2	1.6	0.8	0.0
Urban Principal Arterial	0.2	71.3	17.4	0.2	2.5	0.6	0.3
Urban Minor Arterial	0.1	74.2	16.2	0.4	2.0	0.7	0.1
Urban Major Collector	0.0	74.5	19.9	0.1	1.9	0.4	0.0
Functional Class	Vehicle Percentage						
	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	
Rural Interstate	1.8	16.8	0.3	1.5	0.2	0.3	
Rural Principal Arterial	1.5	5.6	0.4	0.2	0.1	0.2	
Rural Minor Arterial	1.6	3.5	0.1	0.1	0.0	0.0	
Rural Major Collector	0.9	1.5	0.0	0.0	0.0	0.0	
Urban Interstate	1.1	3.9	0.2	0.2	0.1	0.6	
Urban Principal Arterial	1.4	3.9	0.6	0.3	0.4	0.8	
Urban Minor Arterial	1.1	4.5	0.2	0.3	0.1	0.2	
Urban Major Collector	1.2	1.3	0.3	0.0	0.1	0.2	

Note: FHWA vehicle class types are given in table 5.

Table 5. FHWA vehicle types.

Vehicle Class	Description
Class 1	Motorcycles
Class 2	Passenger cars
Class 3	Other 2-axle, 4-tire single-unit vehicles
Class 4	Buses
Class 5	2-axle, 6-tire single-unit trucks
Class 6	3-axle single-unit trucks
Class 7	4+-axle single-unit trucks
Class 8	4-axle or fewer single trailer trucks
Class 9	5-axle single trailer trucks
Class 10	6+-axle single trailer trucks
Class 11	5-axle or fewer multi-trailer trucks
Class 12	6-axle multi-trailer trucks
Class 13	7+-axle multi-trailer trucks

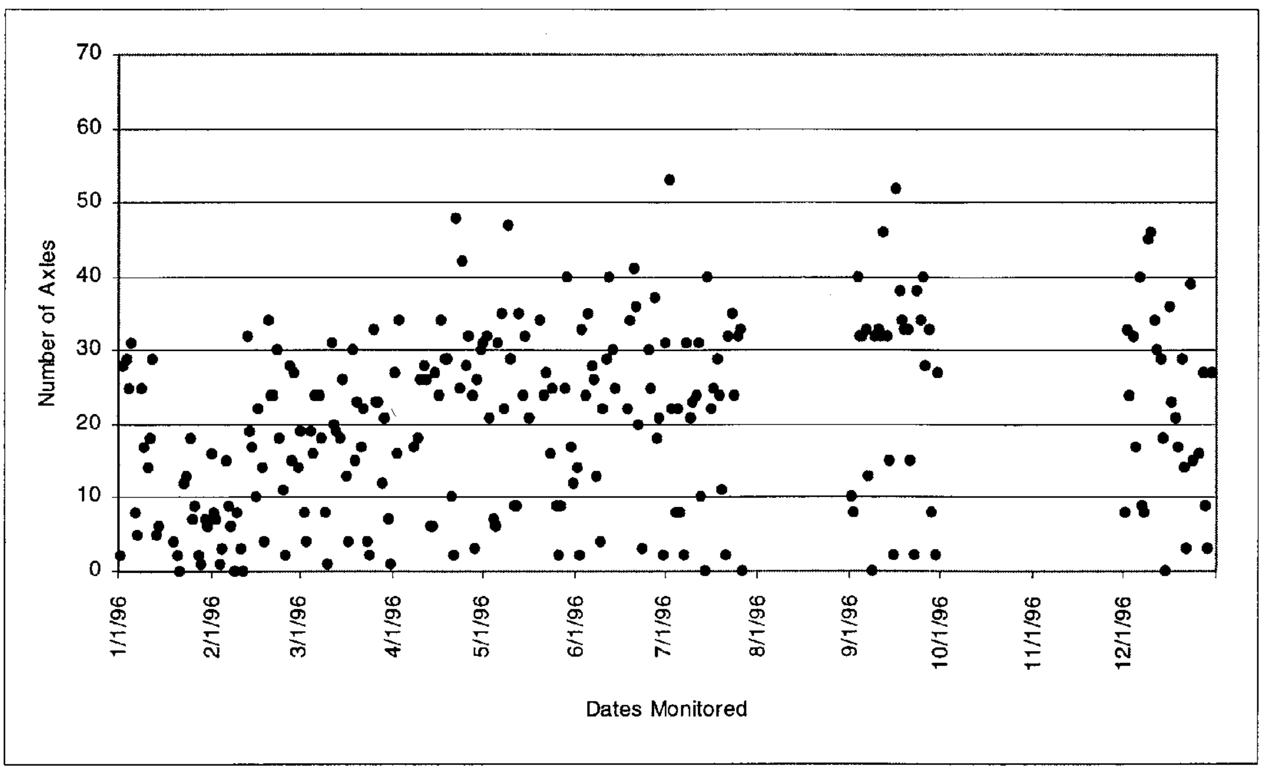


Figure 4. Daily traffic data for aggregate load levels for Class 9 vehicles for Site 26-1001 – tandem-axle loads, 0-142 kN (0-31,999 lb), 1996.

Considering the large variation in daily truck volumes, and the differences between weekday and weekend traffic, it was decided to aggregate by month all weekday and all weekend traffic to assess the potential of using aggregated data for traffic projection. As such, for each month, the average weekday and the average weekend aggregated axle load counts were determined. This is illustrated in figure 5, which shows separately the monthly variations in tandem-axle loads (in the range of 0 to 142.4 kN [0 to 31,999 lb] for vehicle class 9, between 91 and 96 for Site 12-4000), and in figure 6, which shows the monthly variations in single-axle loads (in the range of 0 to 75.6 kN [0 to 16,999 lb] for vehicle class 9, between 92 and 96 for Site 29-4036).

In addition to the review of the previous studies, we have also conducted an extensive evaluation of LTPP traffic data to obtain insights regarding data characteristics such as amount of data, trends and ranges, seasonal variation, variation between sites, potential of vehicle class 9 for prediction of axle load spectra, assessment of data inconsistencies, and so on. Most of the results of these exploratory analyses were presented in the interim report and the accompanying appendixes [5]. The assessment included evaluation of load distribution characteristics, including:

- Daily traffic variation between weekdays and weekends.
- Distribution by vehicle class and axle load ranges.
- Distribution by month and year.
- Axle load distribution for all vehicle classes.
- Trend analysis for Class 9 vehicles, including weekday and weekend traffic variation.

In the following, only selected characteristics of LTPP data are presented to illustrate the basic data characteristics.

The average normalized distribution of monitored axle loads for 18 States and Provinces of the North Atlantic (NAR) and North Central Regions (NCR) is given in figures 7 through 9. These data are averages for all years from 1991 to 1997 for which the data were available. Corresponding plots in terms of cumulative percentage of load applications are given in figures 10 through 12. Both single- and tandem-axle load distributions typically exhibit bi-modal shapes. Also, both single- and tandem-axle loads exhibit a similar pattern, with the exception of data obtained for Rhode Island. The loading pattern for tridem axles is much more diverse than that obtained for single and tandem axles. This can be best seen by comparing the variation in plots presented in figure 12 with the plots in figures 10 and 11. Overall, even though the results presented in figures 7 through 12 are State or Provincial averages for all available years (1991 through 1997), the differences between the States appear to be significant.

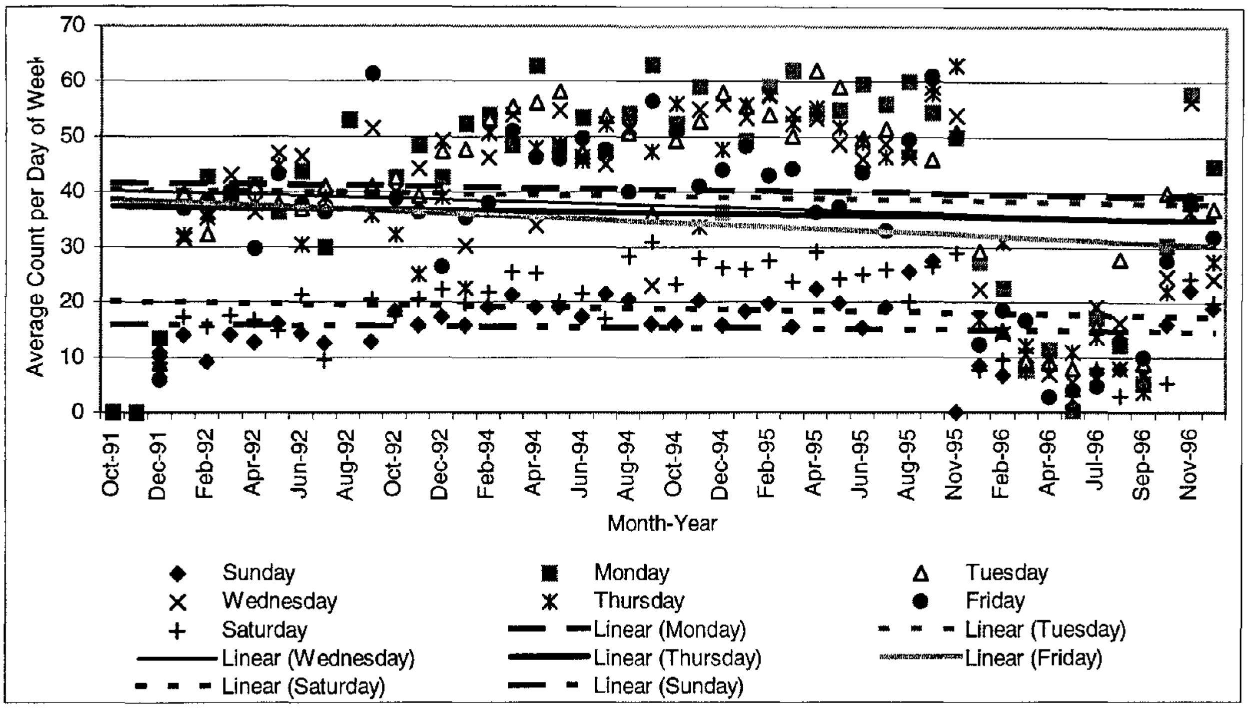


Figure 5. Axle load distributions by day of the week for Class 9 vehicles for Site 12-4000 – tandem-axle loads, 0-142.4 kN (0-31,999 lb), 1991 to 1996.

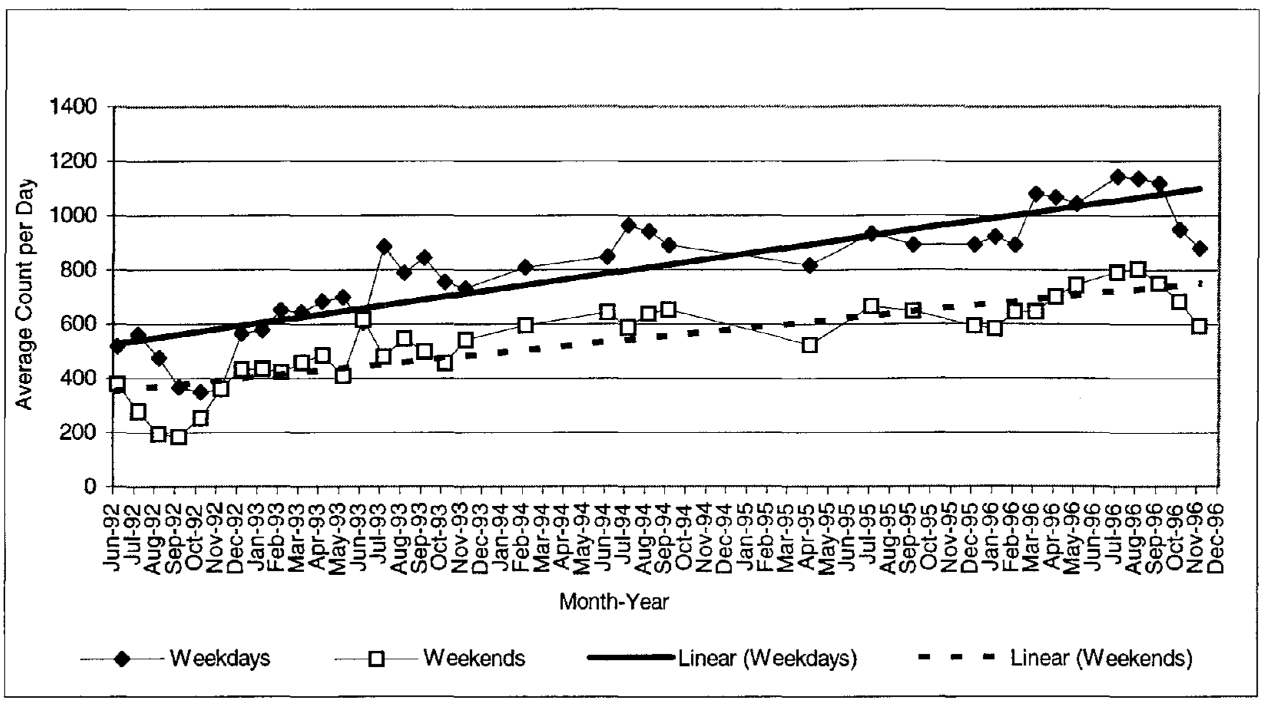


Figure 6. Weekday/weekend axle load counts for Class 9 vehicles for Site 29-4036 – single-axle loads, 0-75.6 kN (0-16,999 lb), 1992 to 1996.

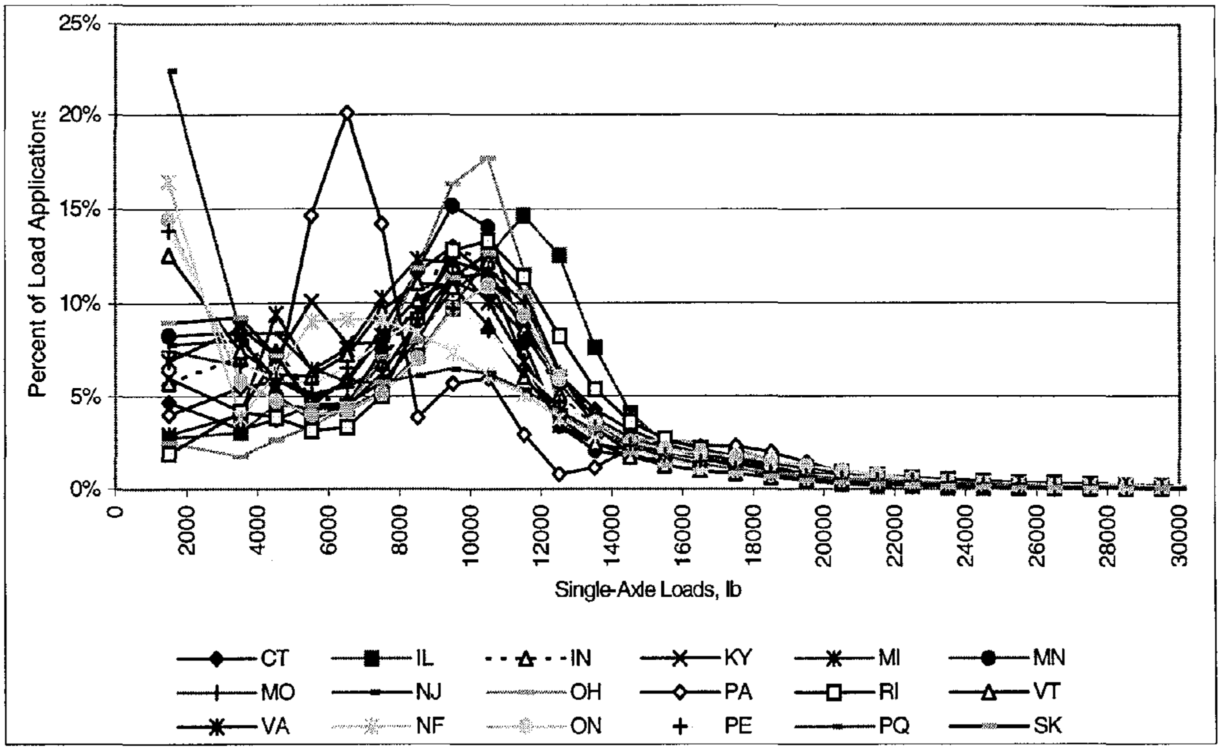


Figure 7. Distribution of single-axle loads for the NAR and NCR States/Provinces.

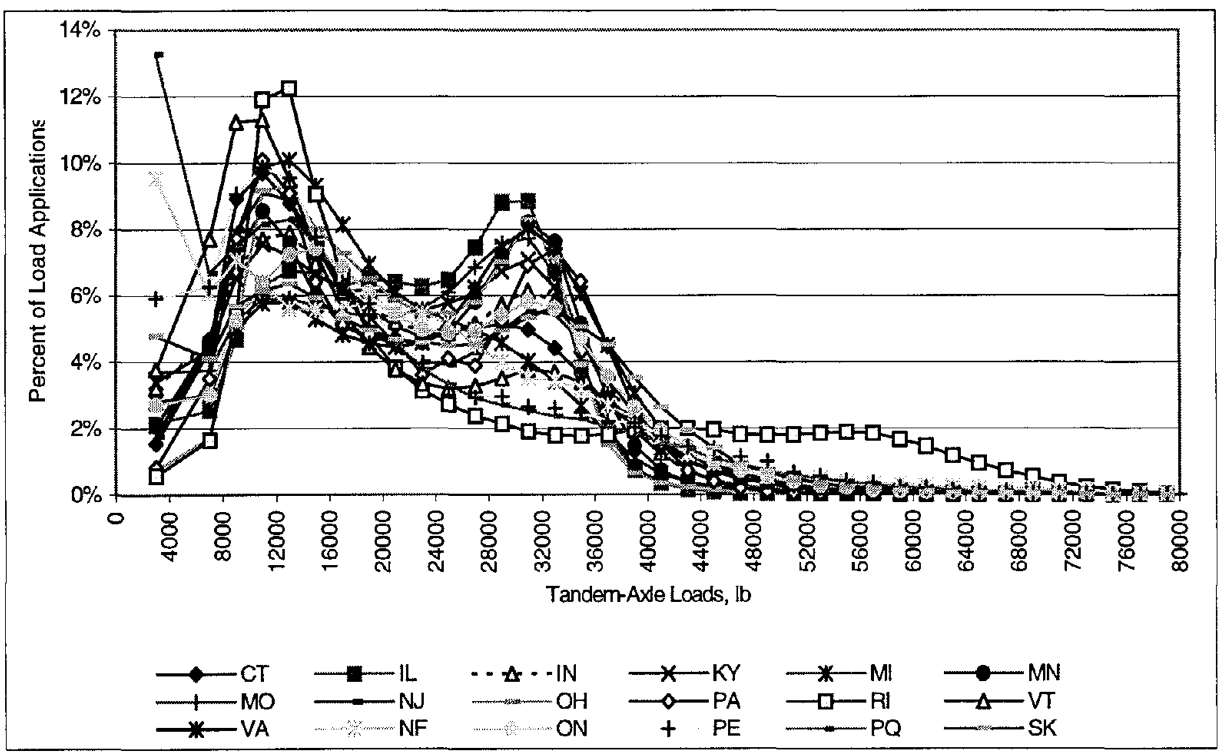


Figure 8. Distribution of tandem-axle loads for the NAR and NCR States/Provinces.

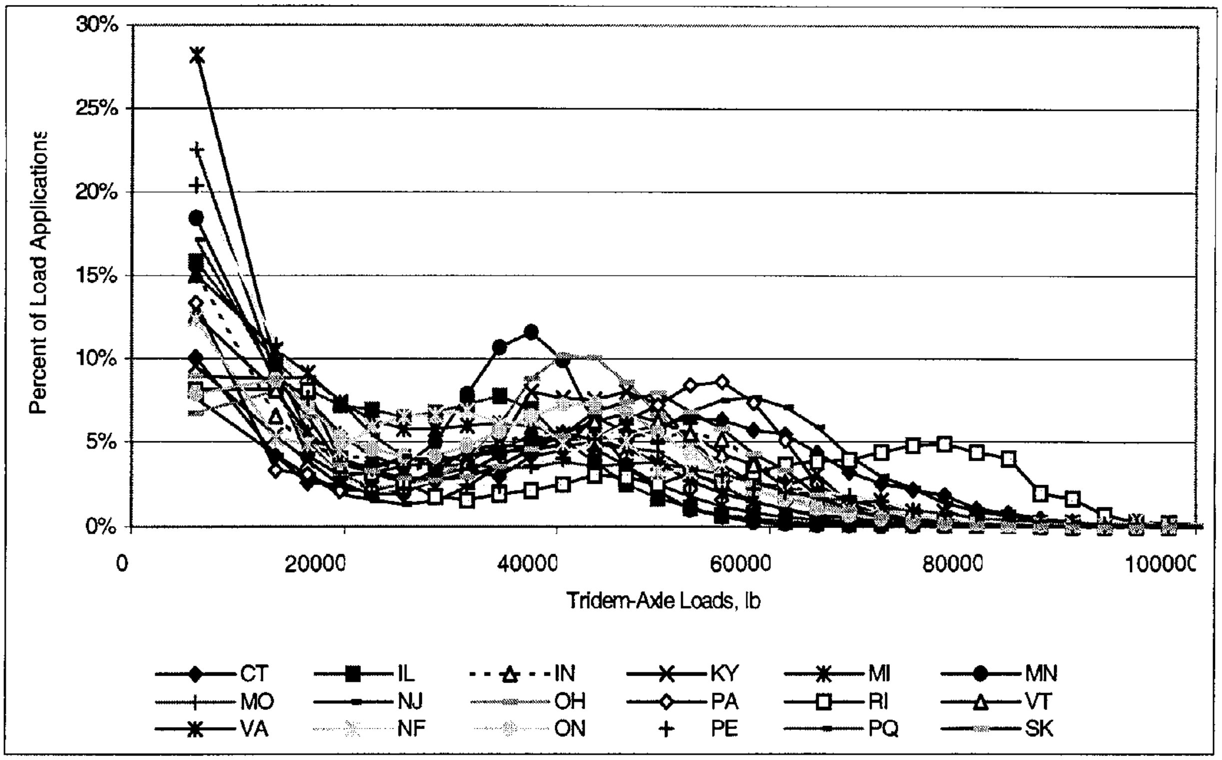


Figure 9. Distribution of tridem-axle loads for the NAR and NCR States/Provinces.

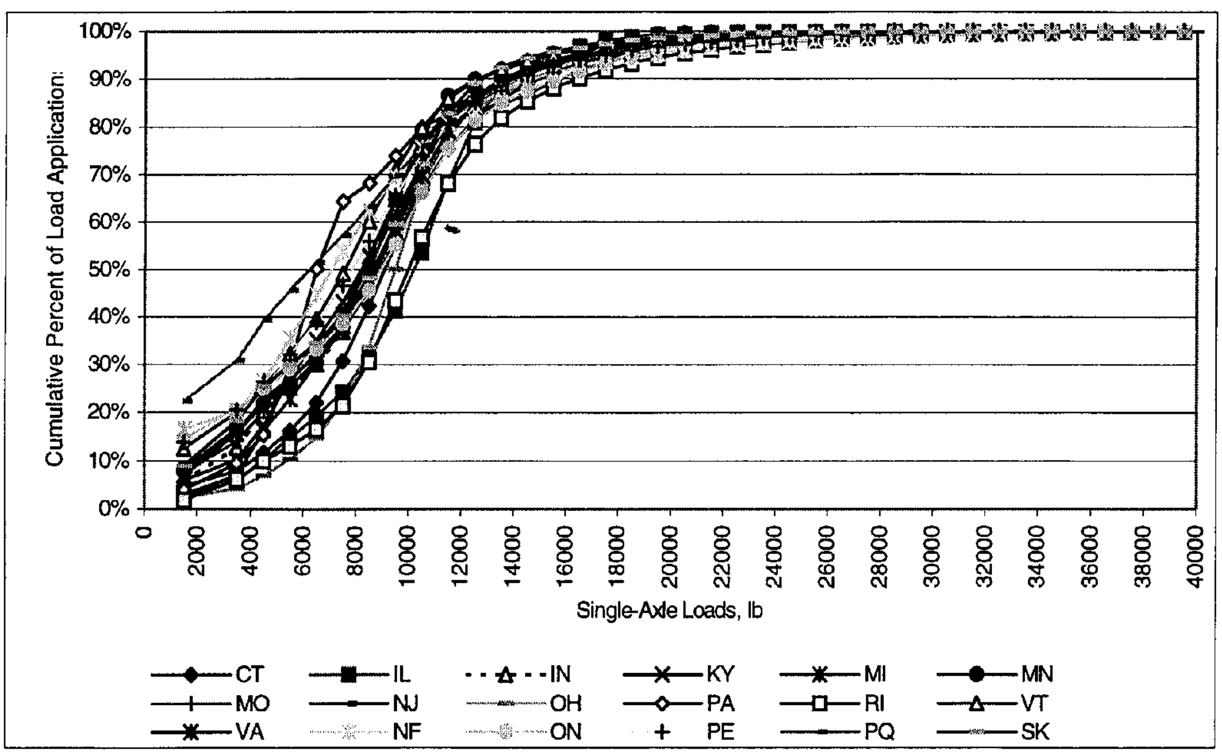


Figure 10. Cumulative distribution of single-axle loads for the NAR and NCR States/Provinces.

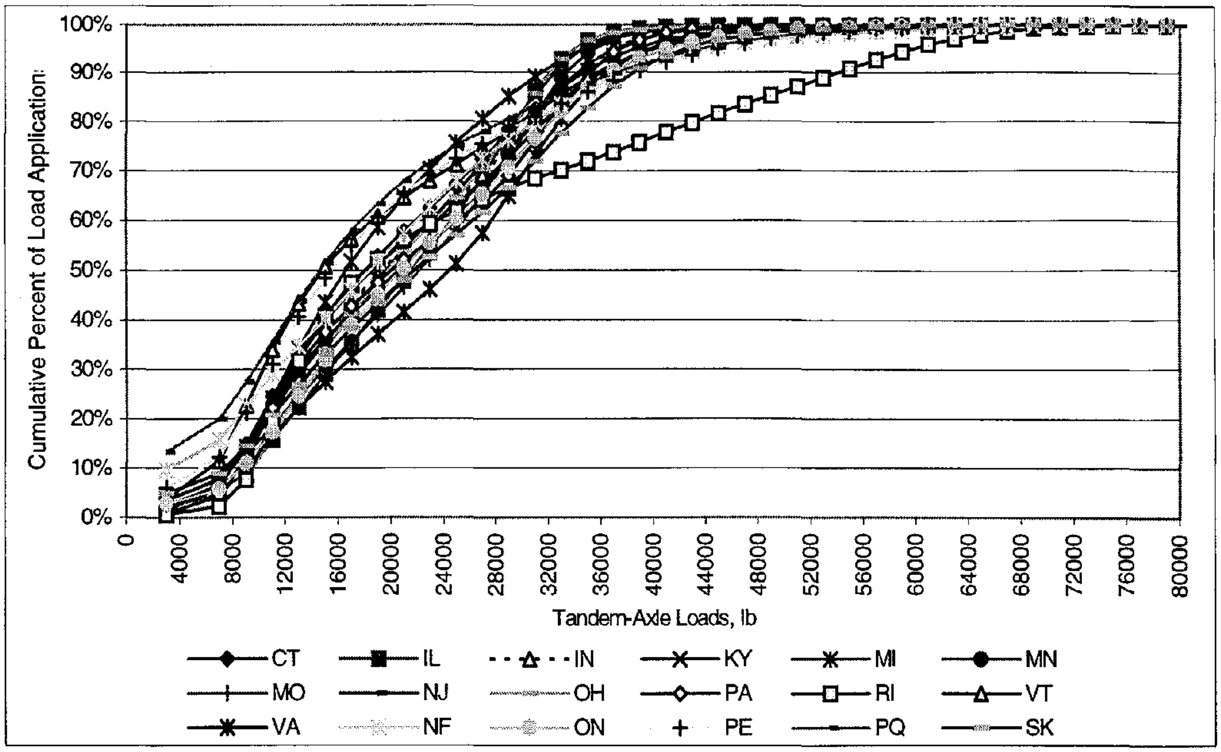


Figure 11. Cumulative distribution of tandem-axle loads for the NAR and NCR States/Provinces.

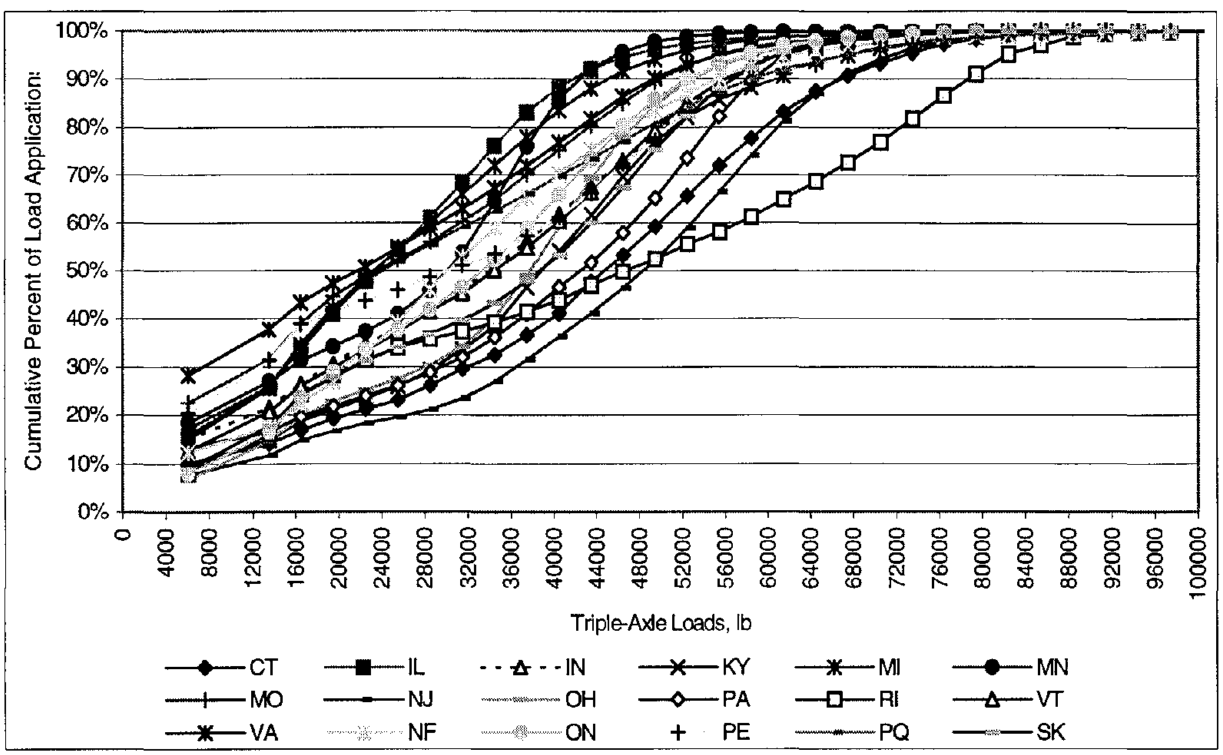


Figure 12. Cumulative distribution of tridem-axle loads for the NAR and NCR States/Provinces.

COMPARISON OF TRENDS IN HISTORICAL AND MONITORING DATA

Historical data provided by SHAs are annual data: AADT volumes, annual truck volumes, and annual ESALs. Thus, to compare historical and measured monitoring data, the monitoring data must also be in terms of annual data. To facilitate this comparison, the research team developed a set of Annual Traffic Data Projection Sheets. These sheets summarize, in one place, all applicable historical and monitoring data for a given section, including:

- AADT volumes.
- AADT truck volumes (for FHWA vehicle classes 4 through 13 inclusive).
- Annual average daily number of ESALs.
- Average number of ESALs per truck, "truck factor" (third item in this list divided by the second item).

The bottom part of the sheet shows annual percent change since the section was open to traffic. Step-by-step instructions for developing the Annual Traffic Data Projection Sheet are given in chapter 4, step 4. Figure 13 show an example of the Annual Traffic Data Projection Sheet for Site 05-3059.

CONCERNS REGARDING QUALITY OF TRAFFIC DATA

The following concerns regarding quality of traffic data are based on the review of available LTPP traffic data documentation and on the results of data analysis conducted during the course of this study.

Sampling Errors - Annual load spectra given in Level 1 are reported even if they are based on only 1 day of measured monitoring data. In this case, to obtain annual estimates from 1 day of WIM data, the measured data are adjusted by volume and class distribution estimates. The sampling errors can be estimated based on work reported by Hallenbeck [6].

Calibration of AVC and WIM Equipment - WIM scale calibration concerns have not yet been studied in sufficient detail. It has been shown that even a relatively small drift in the response of scale sensors or relatively small calibration errors can result in significant changes in the axle weights. The research team had no opportunity to examine WIM or AVC calibration results, and it appears that these results are generally not available. It is disturbing that the CTDB contains only data related to single, tandem, and tridem axles. No quadruple axles have been reported, even though such axles regularly occur, for example, in Michigan and Ontario. This indicates that AVC equipment may not be functioning properly.

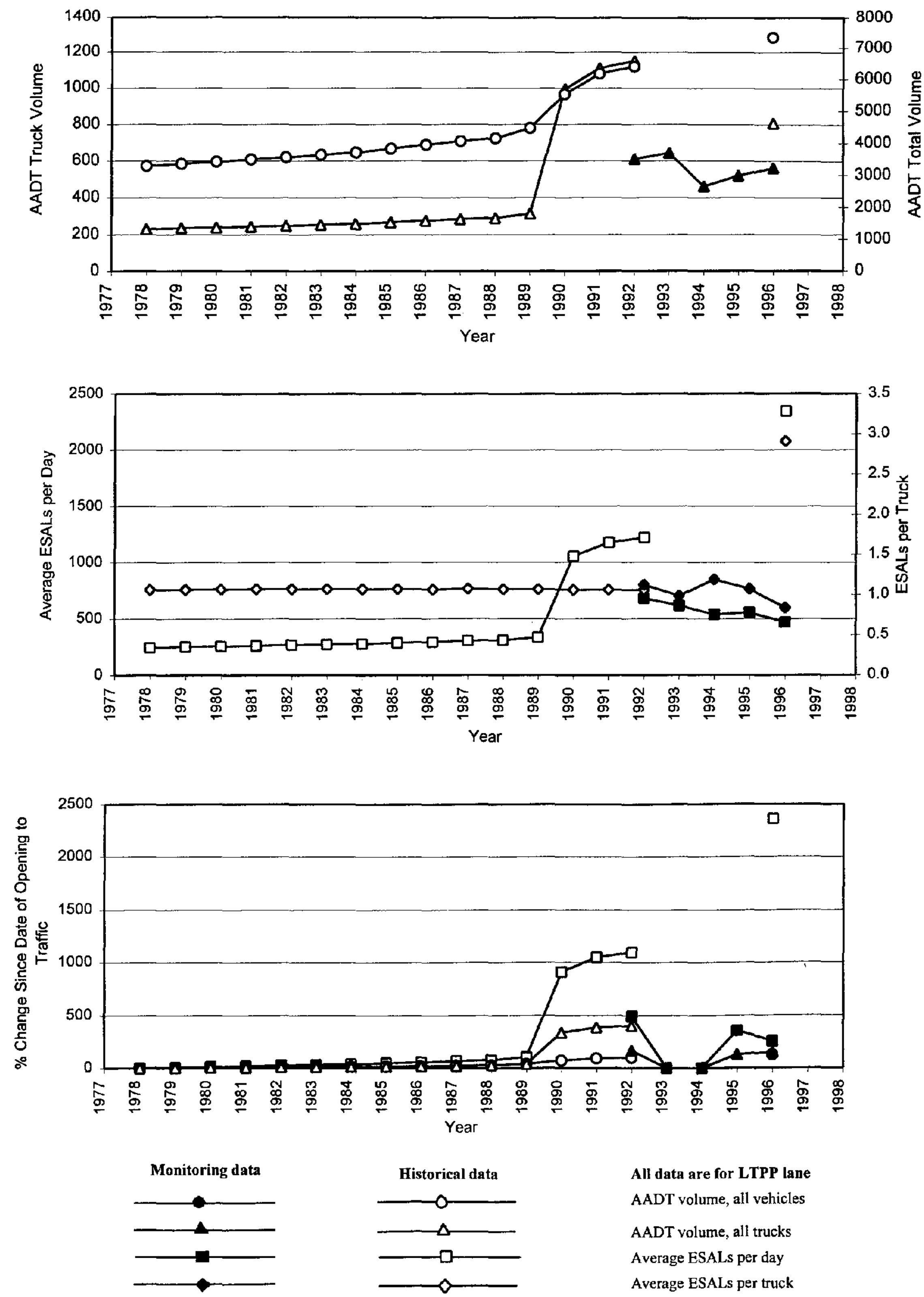


Figure 13. Annual Projection Data Sheet for Site 05-3059.

Unavailability of Measured Monitoring Data - Typically, only 2 or 3 years of measured monitoring data are available for the majority of LTPP sites. Several sites are missing WIM data and some sites are missing both WIM and AVC data.

Compatibility Between Historical and Monitoring Data - The compatibility between historical and monitoring data was discussed in terms of ESALs in chapter 1. Overall, there are many perceived discrepancies between historical and monitoring data, and also within both the historical and the monitoring data.

CHAPTER 3. METHODOLOGY FOR PROJECTING TRAFFIC LOADS

Forecasting of traffic loads for pavement design is a common pavement engineering activity, and most SHAs have developed practices and procedures to do so in terms of the traditional ESALs [10-13]. However, producing traffic load projections (backcasting, interpolating, and extrapolating) for LTPP sections is difficult because of the large number of sites involved, the location of the sites across the United States and Canada, and the need to project axle load spectra (not only the traditional ESALs).

Generally, forecasting of traffic loads for pavement design involves two types of projections:

- Forecasting of traffic volumes and loads.
- Forecasting of truck technology through which the projected traffic volumes and loads are applied to the pavement. For example, at present, the predominant application of truck loads is through air suspension and wheels equipped with radial tires.

Projection of traffic loads and volumes can be accomplished using network assignment models or corridor assignment models. The network assignment models utilize a variety of procedures, such as origin-and-destination studies; economic input-output models; and the traditional transportation planning process consisting of trip generation, distribution, and assignment. These procedures can provide balanced forecasts over a large area based on macro-economic trends.

The corridor assignment models for projecting traffic volumes and loads utilize a set of projection factors, usually called growth factors, which are applied to the specific traffic characteristics that need to be projected, such as traffic volumes or truck factors (ESALs per truck). Different growth factors can be used for different vehicle classes. For long-term projection, usually only one global growth factor is used, and this factor is applied to the total truck volume. Growth factors can be based on region-wide or corridor-specific trends, on the combination of regional and corridor-specific trends, and, if available data exist, on historical trends in vehicle volumes and loads.

Because there are relatively few and disconnected LTPP sections in any specific region, the corridor assignment models are more suitable for projecting traffic loads for LTPP sites than the area-wide network assignment models.

The examination of data shows that for the majority of sections, some historical and monitoring data trends exist. Even though these trends are often conflicting, they provide some guidance. The historically based trends can be verified or supported by region-wide trends. For example, FHWA maintains a web site, www.fhwa.dot.gov/ohim/ohinstat.htm, which provides vehicle travel statistics (e.g., miles of travel) segregated by State, year, FHWA highway functional class, and vehicle type (e.g., passenger cars, heavy single-unit trucks, and combination trucks). Data from this site were used to produce figure 14, which compares the growth in vehicle-miles for passenger cars with that for combination trucks on rural Interstates. Some observations based on figure 14 include the following:

- Between 1982 and 1994, the growth in passenger car and combination-truck travel was similar and averaged about 5 percent per year.
- After 1994, the rate of growth for combination trucks increased to more than 10 percent per year, whereas the rate of growth for passenger cars remained at 5 percent.
- For the 32.3 percent of the LTPP sites located on rural Interstates, we can expect a substantial growth in truck traffic during the period of 1981 to 1997.

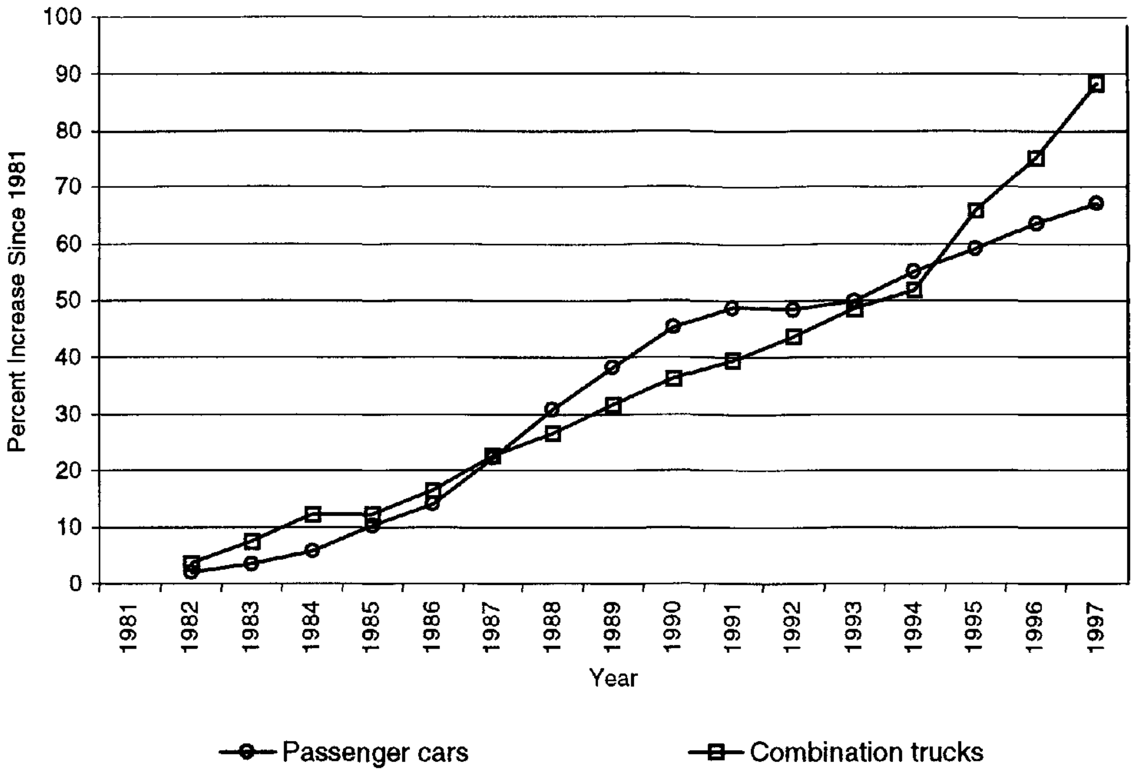


Figure 14. Percent increase in vehicle-miles traveled on rural Interstates.

A number of indicators have been used to establish a growth rate for truck traffic, such as ton-miles of transported freight, total shipment value, diesel fuel usage, truck production volume, and truck registration numbers. On the macro level, long-term growth in gross domestic product (GDP) was also used. However, each of these indicators has flaws as an overall indicator of truck traffic growth. For example, there are several reasons for truck traffic to be increasing at a greater rate than the economy as a whole. Manufacturing industries have been restructured so that a typical manufacturing plant no longer makes the finished product from the raw materials. Many small plants now take in the raw materials and make components, which may then be assembled into larger components at another plant before ultimately becoming a part of the finished product. The prime example of this type of restructuring is the automobile industry. This process requires just-in-time delivery that is supported by truck transportation.

The projection of truck technology will be described at the end of this chapter, after discussing the evolution of motor carrier technology and the proposed traffic-prediction procedure for LTPP sections.

EVOLUTION OF MOTOR CARRIER TECHNOLOGY

This section reviews the salient changes in motor carrier technology, referred to as "truck technology," that occurred during the LTPP traffic data projection period. This review is important for several reasons. First, the review underscores the difference between projecting traffic volumes and loads and projecting truck technology. It is through truck technology that the projected traffic volumes and loads are applied to the pavement. Second, some changes in truck technology may affect pavement performance, and their existence should be understood. Third, the review should provide insight into possible errors in traffic load projections intended for pavement performance modeling, if the ongoing changes in truck technology are ignored. And finally, the review should provide insight for interpreting observed historical changes in vehicle class volume and axle load.

During the lifespan of LTPP sections, truck technology in the United States and Canada underwent extensive changes in three areas:

- Economical and political changes.
- Regulatory changes in vehicle weights and dimensions.
- Engineering changes.

The main changes in these three areas and their connection to the prediction of traffic loads and, ultimately, to pavement performance modeling are briefly discussed below.

Economical and Political Changes

Economical and political changes include changes in taxation, insurance requirements, and, most significantly, deregulation. Deregulation can alter two fundamental aspects of operation in the motor carrier industry—who can compete and what prices can be charged. The deregulation process started in the late 1970's, and the last vestige of trucking regulation—that maintained by the States over transportation wholly within their boundaries—was overturned by a Federal preemption in 1994, becoming effective in 1995 [13]. The result of these changes is more intensive competition between motor carriers (and between transportation modes), leading to the increase of truck traffic and better utilization of vehicle plants. Deregulation may have contributed to the accelerated growth in vehicle-miles of travel on rural Interstates after 1994, as shown in figure 14.

Better utilization of vehicle plants leads to the use of customized truck configurations for "full-load" trucks (these trucks usually transport one commodity, such as portland cement or logs, and operate either fully loaded or unloaded) and to better utilization of "less-than-full-load" trucks (trucks used for pick-up and delivery of general cargo). The consequence of these changes, together with the widespread use of wireless communication technology, has been a trend toward increased payload, truck axle weights, and ESALs per truck.

Regulatory Changes in Vehicle Weights and Dimensions

The changes in vehicle weights and regulations have been occurring on both the Federal and the State levels.

Changes on the Federal Level

The maximum gross vehicle weight (GVW) of 356 kN (80,000 lb), together with the single-axle weight limit of 89 kN (20,000 lb) and tandem-axle weight limit of 151 kN (34,000 lb), was instituted on the Interstate system by provisions of the Surface Transportation Assistance Act (STAA) of 1982. However, from the viewpoint of the States, these were "minimum/maximum" weights they were expected to be accommodated throughout the Interstate system. In practice, the STAA only resulted in a weight increase on the Interstate system in a few States.

The introduction of double trailers to the Interstate system was significant in the eastern States, but these now represent only about 3 percent of all large trucks. Voluntary extension by States of the Federal weight and dimension limits for State roads probably had a much more significant effect. The States were free to increase the weights, particularly the GVW of vehicles operating on highways in their jurisdiction, and to maintain higher pre-existing loads allowed by regulation or permit (the so-called "grandfather" rights).

With time, about 25 States permitted the operation of a variety of vehicles, including a combination of truck tractor and two or more trailers or semitrailers with a GVW exceeding 356 kN (80,000 lb). This type of vehicle was defined as a longer combination vehicle (LCV) in the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). In 1992, under the authority of ISTEA, Federal regulation §23 CFR 658.5 "froze" the values of weights and dimensions of LCVs at the values that were in effect on June 1, 1991 (July 6, 1991 for Alaska). The frozen values became the new maximum vehicle weights and dimensions applicable to the Interstate system for this class of vehicle. ISTEA froze States' rights to change their regulations and permits for LCVs, and the 1998 Transportation Efficiency Act for the 21st Century (TEA-21) maintained the LCV freeze. States continue to be able to interpret grandfather rights for straight trucks and tractor-semitrailers, but generally have been reluctant to do so without some kind of Federal agreement.

Changes on the State Level

The vehicle weight and dimension regulations on the State level have been evolving for many years. Consequently, State laws covering vehicle weights and dimensions are complex and differ from State to State, or even from county to county (e.g., in New York State) or between roads within a State (Interstate, toll, and State highways). States also use a permit system that allows permanent or semi-permanent exemptions from the regulations. Thus, there are eight axle group combinations in Michigan, four axle group combinations in Washington State, and liftable axles in these States and many others.

In terms of grandfather rights on Interstates, nine States allow single-axle loads greater than 89 kN (20,000 lb), eight allow tandem-axle loads greater than 151 kN (34,000 lb), and three allow GVW greater than 356 kN (80,000 lb). At least 19 States also allow some kind of other vehicles and loads at gross weights greater than 356 kN (80,000 lb), some on Interstates under permit or regulation, and some only on other roads. Sometimes the allowance depends on the cargo.

Some specific examples of State regulations include:

- Maine allows 445 kN (100,000 lb) on six axles for raw forest products and constructions materials.
- New Hampshire allows 441 kN (99,000 lb) on six axles, plus 5 percent tolerance, and other conditions that are not known.
- New York has several permit systems. One for dump and garbage trucks allows weights well over the bridge formula (New York's "R permits" for dump trucks and garbage vehicles are restricted to some State roads), another allows six- and seven-axle tractor-semitrailers up to about 467 kN (105,000 lb), and a local system in six down-State counties allows up to 552 kN (124,000 lb) on six axles.
- Massachusetts, Rhode Island, New Jersey, North Carolina, South Carolina, and perhaps others allow weights well over the bridge formula (up to 50 percent) for special hauling vehicles (SHVs) such as dump trucks and garbage trucks.
- Kentucky has special rules on some roads for coal haulers.
- Michigan allows up to 730 kN (164,000 lb) on 11 axles, either a tractor-semitrailer or a double trailer (less weight for fewer axles).
- Ohio allows Michigan trucks at Michigan weights by permit on State roads for access to the Ohio and Indiana Turnpikes.
- Montana allows B-trains (longer combination vehicles) at Canadian weights (about 614 kN [138,000 lb]) on some routes.
- Washington allows B-trains at 467 kN (105,000 lb).
- Eastern seaboard States (at least some of Maryland, Delaware, Rhode Island, Pennsylvania, New Jersey, New York, Massachusetts, and New Hampshire) have made international containers eligible for overweight permits by declaring the container to be an indivisible load. The vehicle may still have to conform to Bridge Formula B, but the permit system has required and popularized use of tridems on container chassis in the last 2 to 3 years.
- Weights may go up by 10 percent in winter in Minnesota.

The evolution of truck weights and dimensions is likely to continue, with most of the changes happening on State roads off the national network. The changes are prompted by competition (within the industry and by other modes), increasing international trade and greater use of containers (many International Standards Organization [ISO] containers cannot be legally carried by trucks limited to 356 kN [80,000 lb] GVW), and the increasing impact of the North American Free Trade Agreement (NAFTA) truck traffic (trucks coming to the United States from

Canada have a high proportion of tridem axles). Under NAFTA, the United States' borders are to open January 1, 2000 to Canadian and Mexican trucks (and vice versa). The situation in Canada is analogous: Provinces agreed to allow operation of trucks meeting common requirements in all Provinces, but are free to allow vehicle weights and dimensions above the minimum requirements as they wish.

Obviously, the changes in regulations over time will differ between LTPP sites in different States. They are also likely to differ over time between the sites in the same State because of route-specific permits, or because certain commodities that are given preferential treatment primarily use certain routes. For example, log trucks are typically seen only on roads leading to mills. In summary, because of the diversity in the vehicle weight and dimension regulations, LTPP sites have been exposed to a variety of different and changing vehicle streams.

Engineering Changes

The following engineering changes in truck technology have occurred over the lifespan of the LTPP experiment in essentially a uniform manner at all LTPP sites.

- *Nearly exclusive use of radial tires.* While it was reported in 1988 that 74 percent of all truck tires were radials [10], today that number is 100 percent. Radial tires, compared to bias ply tires, operate at a higher tire pressures, and their imprint is more sharply defined.

- *Increased use of air suspension.* Presently, about 80 percent of all new truck tractors and about 60 to 70 percent of all new semitrailers are equipped with air suspension. A well-maintained air suspension is believed to result in lower dynamic pavement loads compared to the traditional spring-leaf suspension. However, air suspensions result in a common trailer heave frequency regardless of load. Thus, the switch to air suspension may result in high pavement loads always occurring at the same point past a crack or pothole when vehicles travel at the same speed (the phenomenon of spatial repeatability). The spatial concentration of loads may lead to accelerated localized pavement damage.

- *Increase in the width of trailers.* STAA of 1982 increased the allowable width of trailers from 2.44 to 2.59 m (96 to 102 in). (This is a regulatory change, but it was included among the engineering changes because of its direct influence on pavement performance.) The increased track width for trailers (the track width for tractors stayed at 2.44 m [96 in]) means that the trailer tires run partly on the pavement surface not used by the tractor, and vice versa. Because the lifespan of trailers is about 20 years, the full impact of this change is just now coming into force.

- *A limited trend to use wide single tires (super singles).* After their initial appearance in the mid-1980s, the trend toward the use of wide single tires in North America fizzled.

- *Changes in axle groups.* In several jurisdictions, the appearance of multiple-axle groups (tridem and higher) occurred after the mid-1970s.

REQUIREMENTS FOR TRAFFIC LOAD PROJECTION METHODOLOGY

The proposed methodology was developed to satisfy the following basic requirements.

Capability to Produce Required Traffic Load Projections – The basic requirement of the projection methodology is to produce, for each in-service year of LTPP sections, an annual axle load distribution spectrum. The annual axle load distribution spectrum combines the annual contribution of all vehicles in classes 4 through 13, and is reported separately for single, tandem, and tridem axles. Where warranted by available monitoring data, monthly distribution factors are also required. It should be noted that some sites already have monitoring annual spectra in IMS for at least some monitoring years. For these years, traffic projections may not be required.

Capability of Predicting Traffic Loadings for the Majority of LTPP Sites – Despite the variability in the quantity and quality of available historical and monitoring data, it is important to have a traffic projection procedure that can accommodate virtually all sites.

Full Utilization and Compatibility With Available Data – The guiding principle of traffic projections is the need to utilize fully all available monitoring data for pavement performance prediction. The selection of the projection method must fit the available monitoring data and achieve the best utilization. The methodology must be compatible with the amount and the accuracy of available traffic data.

Transparency and Modularity – The procedure should be understandable and well documented. If more data become available, or if certain steps in the prediction process are improved in the future, it should be easy to incorporate these changes into the procedure.

Utilization of Knowledge of Sampling Procedures and Trends in Data – For example, previous LTPP traffic studies assessed the relative importance of the classified truck volumes and WIM data for the precision of ESAL estimates, and they quantified the importance of site-specific WIM data for estimating traffic loads [6].

Capability of Predicting Seasonality – The term *seasonality* refers to temporal variations in traffic loading data on an hourly, daily, weekly, monthly, yearly, or other periodic basis. Any requirements for predicting seasonal changes in traffic loads should be dictated by the pavement performance modeling needs. For the purposes of supporting the development of pavement performance prediction models for the *2002 Pavement Design Guide*, it appears that only two seasonality periods need to be considered for LTPP pavement performance modeling: day-night variation and monthly variation. Day-night variation (or hourly variation) was not addressed by the current prediction procedure; however, the projection of monthly variation was addressed. In addition to the current requirements stemming from the ongoing work on the *2002 Pavement Design*

Guide, other seasonal changes in the traffic loads may need to be projected in the future (for example, weekly traffic load variation associated with the spring thaw period). To provide projections of hourly or weekly variation in traffic loads would require extensive processing of Level 4 CTDB data, raw data submitted by SHAs, and the development of specific projection procedures.

PROJECTION CATEGORIES

Because of the large differences in the quantity of traffic monitoring data available for the LTPP sections, different traffic load projection methods need to be developed for different sections. Based on the assessment of available measured monitoring data, four categories of traffic projections were established:

Category 1 is intended to capture all LTPP sections that have sufficient AVC and WIM data to enable projection of monthly variation in traffic loadings. The definition of Category 1 was established in the interim report [5] by consensus between FHWA and the Data Analysis Technical Support (DATS) contractor as follows: at least 210 days of AVC data for at least 2 years, a minimum of 1 weekday and 1 weekend of WIM data per quarter, and the availability of AVC and WIM data for at least 2 years in a 5-year period.

Category 2 is intended to represent sections with both AVC and WIM data; however, compared with Category 1, the amount of data is insufficient for projection of monthly variation in traffic loadings. It is expected that the majority of sites in this category will meet the recommended minimum data collection requirements for General Pavement Studies (GPS) sites (continuous AVC data plus 2 days of WIM data per year) [1].

Category 3 represents LTPP sections with solid AVC monitoring data, but virtually no site-specific WIM monitoring data.

Category 4 represents LTPP sections with virtually no reliable AVC and WIM measured monitoring data.

The following distribution of the LTPP sites into the four projection categories is tentative and is given only to provide a preliminary indication of the projection needs. The reason for the crude estimate is that: (1) the mere presence of AVC and WIM monitoring data (as shown in an IMS summary table) does not guarantee the actual availability of monitoring data for projection; and (2) the existence of other factors that influence the selection of the projection category, such as site-specificity of monitoring data and the availability of regional vehicle classification and weight data, was not evaluated.

Number of Sections per Category				**Total Number of Sections**
1	**2**	**3**	**4**	
100	550	200	100	950

DESCRIPTION OF TRAFFIC LOAD PROJECTION METHODOLOGY

The traffic load projection methodology was established by taking into account the requirements for the methodology discussed in the previous section, particularly the quantity and quality of available historical and monitoring data. A corridor assignment model using a global growth factor was selected as the main projection tool. The growth factors are used as multipliers to project a representative annual load spectrum (called *base annual load spectrum*) where necessary. Monthly spectra are obtained by dividing the annual load spectra into 12 parts using monthly distribution factors.

The following description of the traffic load projection methodology is intended to provide an overview of the methodology. A detailed, step-by-step description of the traffic load projection methodology, including examples, is provided in chapter 4.

1. *Development of Annual Traffic Data Projection Sheet and Establishment of Annual Traffic Growth Factors.* The growth factors are based on the historical and monitoring traffic data, and on the quantity and quality of AVC and WIM measurements used to obtain the data. Site-specific annual growth factors are determined for each in-service year of LTPP sections.

2. *Selection of the Base Annual Load Spectrum.* The base annual spectrum is a representative spectrum used to calculate annual load spectra for years without the annual monitoring spectra.
   - For Categories 1 and 2, the available annual monitoring spectra are used to determine and select the base annual load spectrum.
   - For Category 3, the base annual load spectrum is obtained by combining the available site-specific vehicle class distribution with the best available (or typical) axle load spectra for individual vehicle classes.
   - For Category 4, the base annual load spectrum is obtained by combining the typical vehicle distributions with the typical axle load spectra for individual vehicle classes.

3. *Calculation of Load Spectra for All In-Service Years.* The base annual load spectrum is calculated for all in-service years. This is done by multiplying the base annual load spectrum by the appropriate annual traffic growth factors.

4. *Calculation of Monthly Load Spectra.* For Category 1, it is necessary to produce monthly monitoring vehicle volumes and load spectra. At present, traffic data stored in CTDB are available only on a daily or an annual basis. To aggregate the data on a monthly basis requires extensive programming and data processing, and this work is now carried out elsewhere by LTPP. The traffic projection methodology assumes that the required monthly axle load spectra will be produced as part of future CTDB activities. Nevertheless, to illustrate and assess the feasibility of projecting monthly load spectra, we have developed monthly load spectra (based on monthly AVC and WIM data) for three sections in Category 1. The development of the monthly monitoring load spectra was a

significant and labor-intensive undertaking requiring extensive programming and processing of Level 3 data. The procedure developed and used to obtain monthly spectra is documented in appendix A.

Note: Following the principle of full utilization of available traffic data, the projection of monthly variation of classified truck volumes should also be considered for Category 2 sites, and perhaps even for Category 3 sites, with extensive AVC data spanning several years.

5. *Development of Monthly Traffic Data Projection Sheet.* The monthly projection sheet and its accompanying monthly distribution factors use a concept similar to the one that was used for the development of the Annual Traffic Data Projection Sheet and its annual growth factors. However, there are two changes: the traffic data are presented on a monthly basis, and only measured monitoring data are used to establish the monthly distribution factors (annual growth factors are based on both historical and monitoring data).

6. *Development of Monthly Distribution Factors.* The Monthly Distribution Factors are used to distribute the annual axle load spectrum into 12 monthly spectra. The monthly factors are developed only if a visible and logical pattern in the monthly vehicle load distribution is present for 2 or more years.

PROJECTION OF TRUCK TECHNOLOGY

Evolution of truck technology resulted in the economical, political, regulatory, and engineering changes described previously. In this section, the option of projecting these changes, as part of traffic load projections, is discussed.

Economical and Political Changes

Changes in the economical and political sphere can be accommodated within the framework of annual growth factors.

Regulatory Changes in Vehicle Weights and Dimensions

When projecting load spectra by multiplying the base annual load spectra by an annual growth factor, it is implied that only traffic volumes are changing, while the technical characteristics of trucks remain unchanged. However, during the lifespan of LTPP sites, truck characteristics may have also changed because the vehicle weights and dimension regulations have changed, and because of the engineering changes described previously. Consequently, for example, when backcasting annual load spectra from 1995 to 1978 (by multiplying the 1995 load spectrum by an annual growth factor), the 1995 spectrum will contain load spectra for vehicles, axle groups, or loads that did not exist at some earlier time. For example, a portion of the 1995 spectrum that includes tridem axles will be projected to 1978 and will be assumed to exist in that year. However, it is possible that no tridem axles existed in 1978 on that particular section, and if they did exist, they probably were not equipped with air suspension and radial tires.

Appropriate procedures and methods exist to project (backcast or forecast) traffic streams resulting from regulatory changes. These procedures have been developed to quantify the impact of proposed regulatory changes in truck weights and dimensions on the highway infrastructure. Typically, they are based on iterative estimations of the change in the truck fleet from one year to the next, considering one-for-one vehicle replacement, replacement of one configuration by others due to regulatory changes, and the growth rate [15].

However, when pondering the option of projecting regulatory changes, consideration must be given to the accuracy of the underlying traffic monitoring data and the amount of work involved in developing models for projecting regulatory changes. The regulatory changes may differ even between LTPP sites in the same jurisdiction (e.g., Interstates versus State highways). Consequently, many specific models would be needed, and the development of these models would require close cooperation with local regulatory agencies. Given the requirement for site-specific models and the uncertainties in projecting traffic volumes, the projection of regulatory changes for LTPP sites is not recommended at present.

Engineering Changes

Projecting engineering changes in truck technology is relatively simple because the engineering changes have occurred essentially uniformly at all LTPP sites. The need for projecting engineering changes should be dictated by pavement performance modeling requirements, particularly when it comes to modeling specific pavement distresses. In the absence of specific directions, engineering changes were not projected.

CHAPTER 4. PROCEDURE FOR CONDUCTING CASE STUDIES AND TRAFFIC PROJECTIONS

ORGANIZATION OF THE PROCEDURE

The description of the method for conducting case studies is organized as a step-by-step procedure and covers the projections in all four projection categories. Typically, each step is first described in terms of its objectives and the procedures involved, and the description is followed by an example. To distinguish the description of the step from its example, the examples are typed in italics.

With the exception of steps 7 and 12, all steps are common, with slight variations, to all four categories.

Even though the step-by-step procedure presented herein was developed for case studies, it is expected that a similar procedure will be used for the subsequent work involving routine projection of traffic loads for all LTPP sites. The present procedure is labor-intensive, particularly the steps dealing with quality assurance issues.

QUALITY ASSURANCE ISSUES AND TRAFFIC PROJECTIONS

Previous quality assurance activities conducted by LTPP on traffic data were constrained in several ways.

- Because of the large quantities of traffic data, it was necessary to automate the quality assurance of data being collected by WIM and AVC equipment.
- The quality assurance employed previously can be characterized as an automated review to detect common equipment problems, rather than a comprehensive and detailed quality assurance process [16].
- Quality assurance did not consider trends in monitoring data. Data obtained for each day, or year, were evaluated independently. Thus, for example, ESALs obtained for 1992 were not compared with ESALs obtained for the previous or subsequent years.
- The relationships and trends between historical and monitoring traffic data were not systematically evaluated. Thus, for example, historical total truck volume reported for 1992 was not compared with monitored total truck volume obtained for 1993.

Quality control and assurance activities conducted by the participating States and Provinces responsible for collection of traffic data are believed to vary considerably, and are usually not documented in the CTDB.

In summary, to ensure the basic integrity of the data used for projections, it is also necessary to carry out the basic quality assurance review of traffic data. Consequently, quality assurance review is an integral part of conducting case studies. Furthermore, because of many traffic data problems and inconsistencies encountered during the completion of the case studies, the largest part of the procedure for conducting case studies deals with quality assurance issues.

IMPORTANCE OF LOCAL INVOLVEMENT

It is highly desirable and recommended to carry out quality assurance reviews, as well as traffic projections, in cooperation with representatives from the participating States and Provinces. These representatives know local traffic patterns and are usually in the best position to estimate past growth rates; historical, current, and expected traffic volumes; composition; and loads. However, this was not done for the case studies presented herein.

STEP-BY-STEP PROCEDURE FOR CARRYING OUT CASE STUDIES

STEPS 1 THROUGH 6 - APPLICABLE TO ALL CATEGORIES

Step 1. Describe Site Characteristics.

The description of site characteristics related to the transportation function of the highway can enable the analyst to form an opinion about the expected traffic volumes, composition, and loads. The description should include highway number; number of lanes; functional type of the highway using FHWA/LTPP classification; specific description of the highway function (e.g., farm to market route, recreational, or commuter route), if known; and general location of the highway. Background characteristics of sites are also available on Data Sheet 1, CTDB Level 5. However, access to Level 5 data is very time-consuming. The location of the site can be obtained from IMS. It is also advisable to note the location of other LTPP sites in the vicinity that can serve as surrogates for projections using site-related monitoring data.

Example for Site 05-3095:
Site 05-3095 is located on Interstate 540, a four-lane urban principal arterial highway in Arkansas, connecting Fort Smith, population 40,000, with Interstate 40. Fort Smith is roughly equidistant between Little Rock and Oklahoma City and is about 16 km (10 miles) from Interstate 40.

Step 2. Outline Vehicle Weight and Dimension Regulations Applicable to the Site.

The objective of the outline is to provide the analyst with insight regarding possible causes for atypical vehicle weights and load spectra. The outline should address vehicle weight and dimension regulations (Federal and State, including special permit regulations) that represent a significant departure from Federal Regulation §23 CFR 658.

Very few, if any, LTPP sites are located on highways subjected to heavy atypical truck traffic, such as log-haul roads in Mississippi, coal-haul roads in Kentucky and West Virginia, or the New York State Thruway. Also, there are probably very few, if any, LTPP sites subjected to light atypical truck traffic, such as the Garden State Parkway (New Jersey). However, many sites are located on highways where trucks with gross vehicle weights exceeding 356 kN (80,000 lb) are allowed without a permit. These sites are in the jurisdictions that allow longer combination vehicles (LCV); in the States and Provinces with tailor-made vehicle weight and dimension regulations (such as Michigan, Rhode Island, and Ontario); and on roads often subjected to special permit vehicles, such as routes near northeastern ports used to haul ISO containers rated at 30 metric tons. LCV were grandfathered in June 1991 under the provisions of the Surface Transportation Assistance Act of 1982 in approximately 25 States, including Arizona, New York, Ohio, and Utah. An overview of developments in truck technology is outlined in chapter 3.

For traffic loading projections in Categories 1 and 2, the outline of vehicle weight and dimension regulations provides useful insight for quality assurance purposes. For projections in Categories 3 and 4, the outline is particularly important because these categories rely on regional or site-related vehicle class distributions and on regional load spectra, respectively. Consequently, when choosing a representative vehicle class distribution, or a representative set of load spectra distributions, it is advisable to ascertain the expected truck regulatory environment.

Example:
LCV are not allowed at Site 05-3095. State and special permit regulations are unknown and are difficult to establish without contacting local representatives.

Step 3. Describe Quality and Quantity of Available Monitoring Data.

The following sources should be assessed to obtain information on the quality and quantity of the available monitoring data.

- *Equipment location codes in the IMS [4].* These codes indicate the location of the AVC and WIM equipment in relation to the test site. The locations of the AVC and WIM equipment are coded separately as:

  - Site-specific (S) – The equipment is located at or nearby the test section and accurately measures the traffic that crosses the test section.
  - Site-related (R) – The equipment is located on the same roadway as the test section, but a major truck traffic generator is located between the test section and the equipment.
  - Other (O) – The equipment is located on another roadway.

  Additional information on location identification codes can be found in reference 4. Limited review of the equipment location codes in IMS indicates that these codes are consistently reported.

- *Data availability codes in IMS.* These codes indicate the amount and basic characteristics of monitoring data. Data availability codes are shown in table 6 [4].

Table 6. Data availability codes.

Data Code	Interpretation
9	Continuous WIM meeting the American Society for Testing and Materials (ASTM) standard.
8	Continuous WIM not meeting the ASTM standard.
7	Continuous AVC with portable WIM for all seasons.
6	Continuous AVC with some seasonal WIM.
5	Continuous AVC with limited WIM.
4	Continuous AVC with no WIM.
3	Continuous Automatic Traffic Recorders (ATR) with limited – but seasonal – vehicle classification and WIM data.
2	Limited – but seasonal – vehicle classification and WIM data.
1	Limited vehicle classification and truck weight data (short counts).
0	Data collected on different roadway.

  A review of the data availability codes in the IMS indicates that these codes are consistently reported.

- *Assessment of the amount and monthly distribution of days with available site-specific AVC and WIM data.* Several IMS tables need to be examined to obtain this information because the main IMS table, which provides a summary of annual data (TRF_MONITOR_BASIC_INFO), does not consistently contain data for all monitoring years.

- *AVC and WIM calibration data.* The records pertaining to the results of the calibration of AVC and WIM equipment are stored in CTDB Level 5. These records can be valuable in interpreting data with perceived idiosyncrasies. However, information on AVC and WIM equipment calibration is often unavailable, and it is very labor-intensive to obtain and analyze calibration data.

Example for Site 05-3095:
Data availability code is 6. No information on calibration of AVC and WIM equipment is available. The extent of monitoring data is summarized in table 7.

Table 7. Extent of monitoring data for Site 05-3095.

Data Type		Monitoring Year					
		1992	1993	1994	1995	1996	Total
AVC	Days	19	81	201	32	172	505
	Month	3	3	9	3	?	18+
WIM	Days	20	37	20	11	17	105
	Month	3	5	3	1	?	12+

Notes: Month = Number of months for which some of the AVC and WIM data are available.
? = Data could not be obtained.

- *Availability of site-related data.* If there are no (or limited) site-specific AVC and WIM data, it is necessary to investigate the availability of site-related AVC and WIM data. The location of the nearby LTPP sites, obtained in step 1, can be a starting point.

Example:
Refer to figure 15, prepared as part of the case study for Site 04-1002, which provides a sketch of site-related sections. The data from site-related sections were used for traffic projections.

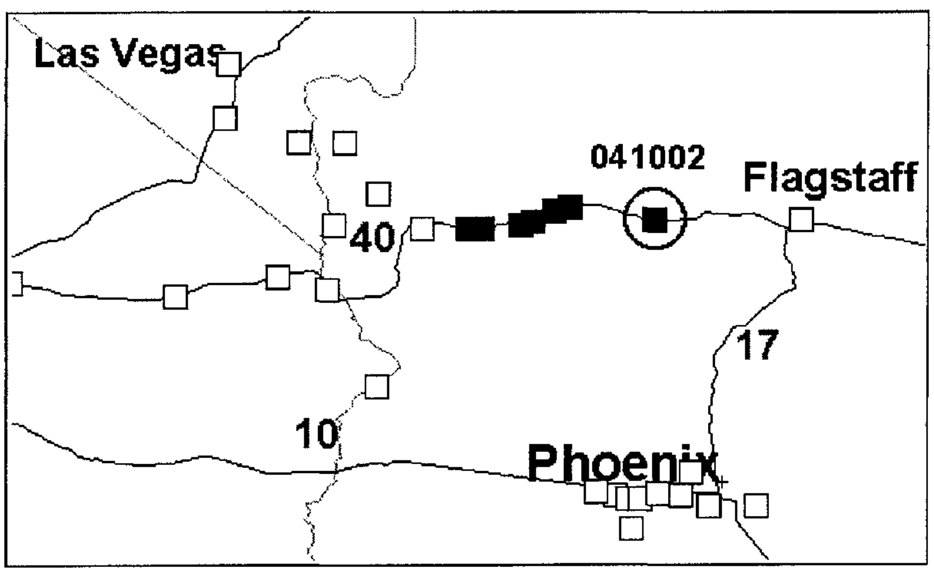


Figure 15. Location of site-related sections for Site 04-1002.

Step 4. Develop Annual Traffic Data Projection Sheet.

The Annual Traffic Data Projection Sheet is used to summarize and compare trends in the values of all traffic variables available for the LTPP lane that are expressed as annual values and are available for both historical and monitoring years.

In general, the following annual traffic variables are available:

- AADT volumes.
- AADT truck volumes (for FHWA vehicle classes 4 through 13 inclusive).
- Annual average daily number of ESAL.
- Average number of ESAL per truck, "truck factor" (third item in this list divided by the second item).

However, for sites belonging to Categories 3 and 4, ESAL monitoring data are not available. It should also be noted that AADT volumes are frequently missing from the IMS monitoring information table.

To facilitate the assessment of changes in the annual variables (first through fourth bulleted items above), the bottom part of the Annual Traffic Data Projection Sheet shows annual percent change since the site was opened to traffic.

For years with missing annual summary data in table TRF_MONITOR_BASIC_INFO (see step 3, third bullet), it is necessary to calculate the average truck factors (fourth bulleted item above) from the truck factors available for individual vehicle classes. This is done by calculating a weighted average:

$$TF = \frac{\sum_{i=4}^{i=13} TF_i * truck_i}{total\ trucks} \tag{1}$$

where: TF = Average annual truck factor.
i = FHWA vehicle classes 4 through 13.
TF_i = Average annual truck factor for vehicle class i.
$truck_i$ = Average annual number of vehicles in Class i.
$total\ trucks$ = Average annual total of vehicles in Classes 4 through 13.

Note: The above calculation of missing average truck factors provides useful trend data, but may not always be necessary.

An example of an Annual Traffic Data Projection Sheet is shown in figure 13.

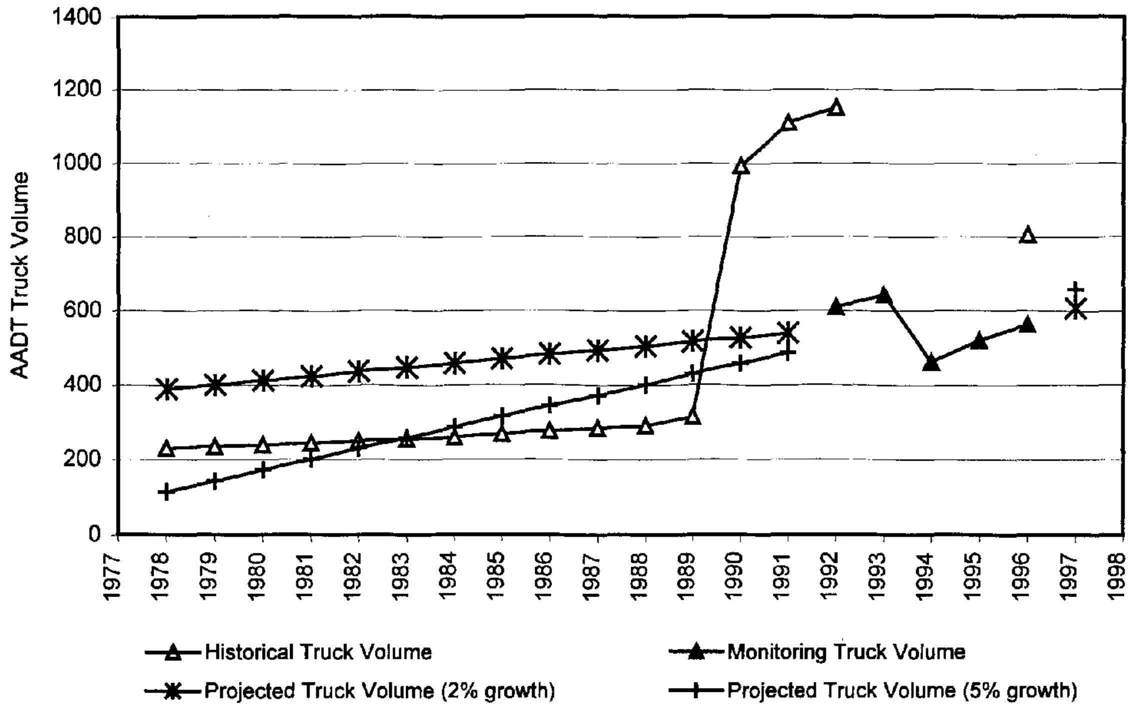


Figure 16. Annual growth trends for Site 05-3059.

Step 5. Develop Annual Traffic Data Projection Model.

Step 5.1. Systematically and Critically Review Data Plotted on the Annual Traffic Data Projection Sheet.

The objective is to identify common trends in annual traffic data and to provide diagnostic assessment of the data. The diagnostic assessment of data is the basic quality assurance activity to ascertain the reliability of the relationship between monitoring data obtained for different years and between historical and monitoring data. The assessment should identify data problems, abnormalities and idiosyncrasies, and their possible causes. In addition to considering annual traffic data given on the Annual Traffic Data Projection Sheet (figure 13), quality and quantity of underlying monitoring data (obtained in step 3) should also be taken into account.

Example for Site 05-3059, shown in figure 13:

- *Considering historical data, there was a steady growth in AADT and truck volume between 1977 and 1989. In 1990, there was a sudden jump. Steady growth in AADT resumed after 1990. In 1996, however, there was a sudden drop in truck volume based on historical data.*
- *Monitoring AADT and truck volumes, as well as annual ESALs, are flat or are declining.*

- *Monitoring truck factors, equal to about 1, appear to be high for an urban freeway, but are acceptable considering the rigid pavement on this site.*
- *The estimated 1996 truck factor (2.9) is apparently incorrect. (For other years, monitoring truck factors were close to 1.)*

In some cases, particularly where truck factors seem to be problematic or "out of line," it may be necessary to also evaluate annual vehicle spectra to ascertain probable reasons for the atypical values and to decide what importance should be placed on problematic data when making projections. For further discussion, refer to step 7.1 (Categories 1 and 2) and step 7.2 (Category 3).

Step 5.2. Formulate Annual Traffic Data Projection Model and Summarize Reasons for Its Selection.

The Annual Traffic Data Projection Model is used to project annual load spectra for all years (between the year the site was opened to traffic and the terminal year). Thus, the years for which the projections are particularly required include years with historical data, monitoring years with missing or evidently problematic (monitoring) data, and years after the monitoring period. Although no annual predictions are required for years with acceptable annual monitored spectra, the projections may be done for consistency. For the purposes of the Phase 1 study, 1997 was selected as the terminal year, because this is the last year with reported traffic data in the current IMS release.

Ideally, the Annual Traffic Data Projection Model should be based mainly on monitoring annual average daily ESALs because:

- Monitoring data, which are based on actual measurements, should be more reliable than historical data, which are usually based on estimates.

- ESALs combine both vehicle classification volumes and axle loads.

Also, ideally, the model should be based on regression analysis of trends in monitoring ESAL data.

However, in practice, monitoring annual load spectra may be available for only 1 or 2 years, or may be missing entirely. Thus, it is necessary to consider all trends in annual traffic data presented on the Annual Traffic Data Projection Sheet and to consider their associated quality and quantity. For example, the values of variables based on many months of monitoring data may be assigned more weight than the values based on only a few days of monitoring data.

Example for Site 05-3059:
Based on the combined evidence provided by historical monitoring data and assessed in step 5.1 (AADT and truck volumes, annual ESALs that do not exhibit growth, and historical truck volume data exhibiting about a 4-percent annual growth rate during the period of 1978 through 1989, as shown in figure 15), the use of a linear projection model corresponding to a simple 2-percent annual growth rate is recommended.

The projection was based on AADT truck volumes by superimposing the 2-percent annual growth rate trend line on the monitored AADT truck volumes, as illustrated in figure 16.

Because of the uncertainty involved in developing the Annual Traffic Data Projection Model, the consequences of using a different annual growth rate—a 5-percent annual growth rate—will also be evaluated.

Step 6. Select Category for Projecting Traffic Loads.

The selection of the projection method must fit the available AVC and WIM monitoring data in order to achieve the best utilization. The four basic projection categories were described in chapter 3. The selection of the projection category should be based on:

- Available AVC and WIM data in terms of quantity of data. There are many possible combinations of available AVC and WIM data.
- Quality and reliability of monitoring data.
- Site-specificity of monitoring data.
- Availability of applicable regional vehicle classification and weight data.

Consequently, the selection of the load spectra projection method requires judgment. For example, the mere existence of AVC and WIM monitoring data does not guarantee the use of Category 2 predictions.

Example for Site 05-3059:
Category 2 projections were selected because of the existence of site-specific AVC and WIM data that passed the quality assurance review based on annual trends of historical and monitoring data. The amount of AVC and WIM data is insufficient for Category 1 projections.

STEP 7 FOR CATEGORY 1 AND 2 PROJECTIONS

Step 7. Develop Base Annual Load Spectrum To Be Used for Projection.

In this step, references are often made to comparing and evaluating data, and to identifying inconsistencies in data. The data in this case are annual load spectra obtained for different years and sites. To effectively assess this type of data, it is necessary to develop guidelines enabling the analyst to judge the expected values. For example, what is the expected or acceptable load spectrum for two-axle six-tire trucks? What is the expected average truck factor for a rural Interstate? What is the expected annual load spectrum for urban arterial roads? To provide answers to such questions in a systematic way, the development of a set of typical values of traffic loading data is proposed.

The need to have a set of typical traffic loading values for comparison and traffic data management purposes is the basic idea behind the proposal presented in chapter 6 to develop and use summary statistical measures for comparing and evaluating axle load distributions and cumulative axle loadings, and the proposal to develop a pavement traffic loading guide.

Step 7.1. Obtain and Critically Assess the Annual Load Spectra for All Available Years.

Critical assessment and review of the spectra is basically a quality assurance exercise to ensure that annual load spectra, used for the subsequent projections, are sound. Four mutually complementary procedures are suggested. The procedures (1 through 4) are listed in the order of increasing detail and complexity. The use, and the extent of the use, of these procedures will depend on the quality and the amount of monitoring data and on the match between monitoring and historical data.

1. Develop normalized annual load spectra for single, tandem, and tridem axles for all monitoring years and examine them against each other and against the typical load spectra for differences and possible inconsistencies.

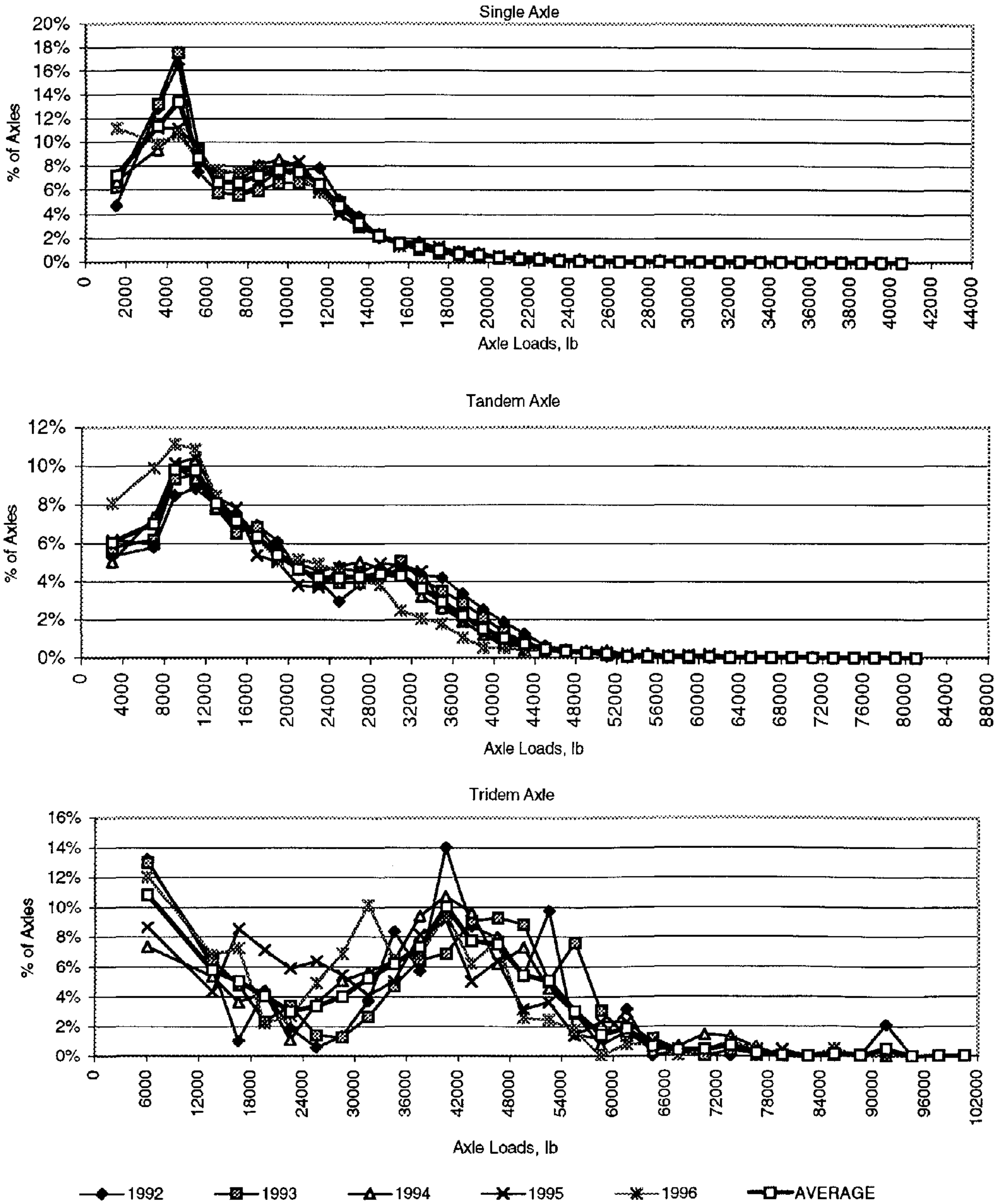
Example:
Refer to figure 17. The results suggest that, in spite of differences in spectra obtained for the five different years, all spectra appear to be valid.

2. Calculate and critically assess load spectrum coefficients (LSC) for single, tandem, and tridem axles (LSC_1, LSC_2, LSC_3). The need for LSCs and their function is described in chapter 6. The calculation is given in equation 2.

$$LSC = \sum_{i=1}^{i=l} \left(\frac{\left(\frac{mid\text{-}load\ range_i}{L} \right)}{18{,}000} \right)^{3.8} * \frac{load\text{-}range\ count_i}{total\ count} * L \qquad (2)$$

where: LSC = Load spectrum coefficient used to compare normalized load spectra.
l = Number of load ranges (the numbers differ for single, tandem, and tridem axles).
$mid\text{-}load\ range_i$ = Average load range in pounds for load range i, e.g., if the load range is 6,000 to 6,999, use 6,500.
$load\text{-}range\ count_i$ = Number of axles in load range i.
L = 1 for single axles, 2 for tandem, and 3 for tridem. (L converts the effect of tandem and tridem axles into that for single axles.)

Because LSCs characterize the entire spectrum using one number, LSCs can be used to compare load spectra obtained for different years by comparing a few numbers. They can also be used to compare site-specific spectra with typical spectra. The calculation of LSCs may not be necessary if a visual comparison of spectra clearly indicates similarity between spectra obtained for different years.



1 lb = 0.00445 kN

Figure 17. Comparison of normalized annual load spectra for Site 05-3059.

Example for Site 05-3059:
Load spectra coefficients were calculated for single, tandem, and tridem axles for all monitoring years (1992 through 1996) and were plotted in figure 18. Data in figure 18 indicate that there are relatively small differences between load spectra obtained for individual monitoring years. The exception are LSCs for tridem axles, which declined from 1.60 in 1992 to 1.00 in 1998.

3. Develop normalized annual load spectra for vehicle classes 4 through 13 for selected years and examine them for possible inconsistencies. Compare site-specific spectra with expected spectra. The proposed LTPP Traffic Loading Guide (chapter 6) will contain representative load spectra. Emphasis should be placed on Class 9 vehicles.

Example:
The calculation of annual load spectra for individual load classes requires processing of raw Level 2 data, a time-consuming process. Because total annual spectra were judged to be reasonable, spectra for individual vehicles were not calculated for this case study. An example of normalized load spectra for individual vehicles is given in appendix B.

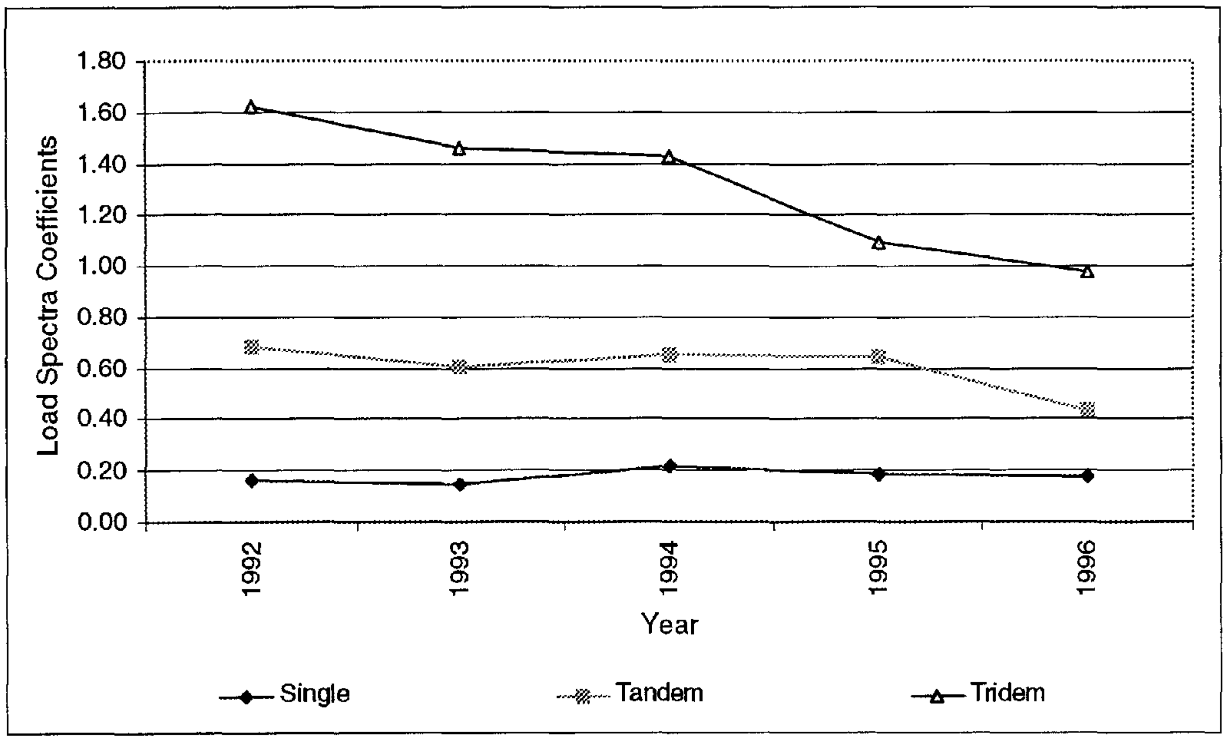


Figure 18. Load spectra coefficients for Site 05-3059.

4. Calculate and assess load spectra coefficients for vehicle classes 4 through 13, according to equation 2.

5. Calculate annual gross vehicle weight distributions of Class 9 vehicles for selected years and assess their properties.

   The validity of the weight data obtained by WIM scales can be effectively assessed using the GVW distribution of five-axle single-trailer trucks (five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit). In jurisdictions that limit GVW to 356 kN (80,000 lb), up to 80 percent of pavement traffic loads are imposed by this vehicle type. Specific procedures have been developed to use the GVW distribution of these trucks as a quality assurance calibration check for WIM scales [16, 17]. The five-axle single-trailer trucks are Class 9 vehicles. Another frequently used check includes the relationship between the weight of steering axles and the GVW of Class 9 vehicles.

Example:
The calculation of GVW distribution of Class 9 vehicles requires retrieval of data from Level 4 of CTDB and customized processing of data. The interpretation of the results requires judgment and knowledge of local conditions. The use of GVW for the assessment of WIM data has not been demonstrated by a case study. The feasibility and usefulness of the procedure are well documented in references 16 and 17.

Concluding Remarks

Quality assurance of annual traffic load monitoring spectra is a demanding, labor-intensive task. However, this task is essential, and it is also cost-effective. For example, in a situation where there are two annual monitoring vehicle spectra (for two consecutive years) that differ significantly to the point that one is probably invalid, it is possible, through the procedures described above, to ascertain the validity of the spectra and to produce valid traffic projections. The resources required to do so (through systematic analysis of available data) pale in comparison to the resource that have been spent or that would have to be spent to collect traffic data in the field.

Step 7.2. Determine/Select Base Annual Load Spectrum.

Base annual load spectrum is used for projecting traffic loads for years without monitoring load spectra. A review of more than 150 LTPP sections indicates that there are usually about 1 to 4 monitoring years, whereas the total number of in-service years is about 10 to 25.

The selection of the annual load spectra should consider the differences in the spectra obtained in step 7.1 and the quality and quantity of underlying monitoring data determined in step 3. Particular attention should be paid to trends in average annual ESALs (middle part of figure 13).

Typically, an average annual load spectrum for all monitoring years will be used. However, if one of the available annual spectra is clearly superior to the other spectra (for example, because of quality and quantity of AVC and WIM data), the sole use of this spectrum may be warranted. In an ideal situation, if several (say, five or more) annual load spectra all fit well into the Annual Traffic Data Projection Model, it is advisable to use the first and the last annual load spectra as the base annual load spectrum. That is, the first available annual load spectrum can be used for backcasting, and the last annual load spectrum can be used for forecasting. The use of two base annual spectra will increase the effort required to complete step 9.

The base annual load spectrum is assigned to the base year. The base year is typically the average year for the years used in the calculation of the base spectrum.

Example for Site 05-3059:
There are differences in the amount of available monitoring data. According to table 7, the best AVC year is 1994 (with 201 monitoring days), and the best WIM year is 1993 (with 37 monitoring days). The best combined year appears to be 1996 (with 172 AVC days and 17 WIM days). Because of the variation in the annual spectra shown in figure 17, use of the average annual spectrum for the years 1992 through 1996 as the base spectrum for projection is recommended.

Considering the uncertainty involved in determining the base annual spectrum, the consequences of using a different annual spectrum were investigated. Specifically, in addition to using the average 1992 through 1996 spectrum, the 1996 annual load spectrum alone was also used. The 1996 spectrum was selected because the shape of this spectrum appears to differ more than other spectra from the average 1992 through 1996 spectra, as shown in figure 19 and as indicated by load spectra coefficients shown in figure 18.

STEP 7 FOR CATEGORY 3 PROJECTIONS

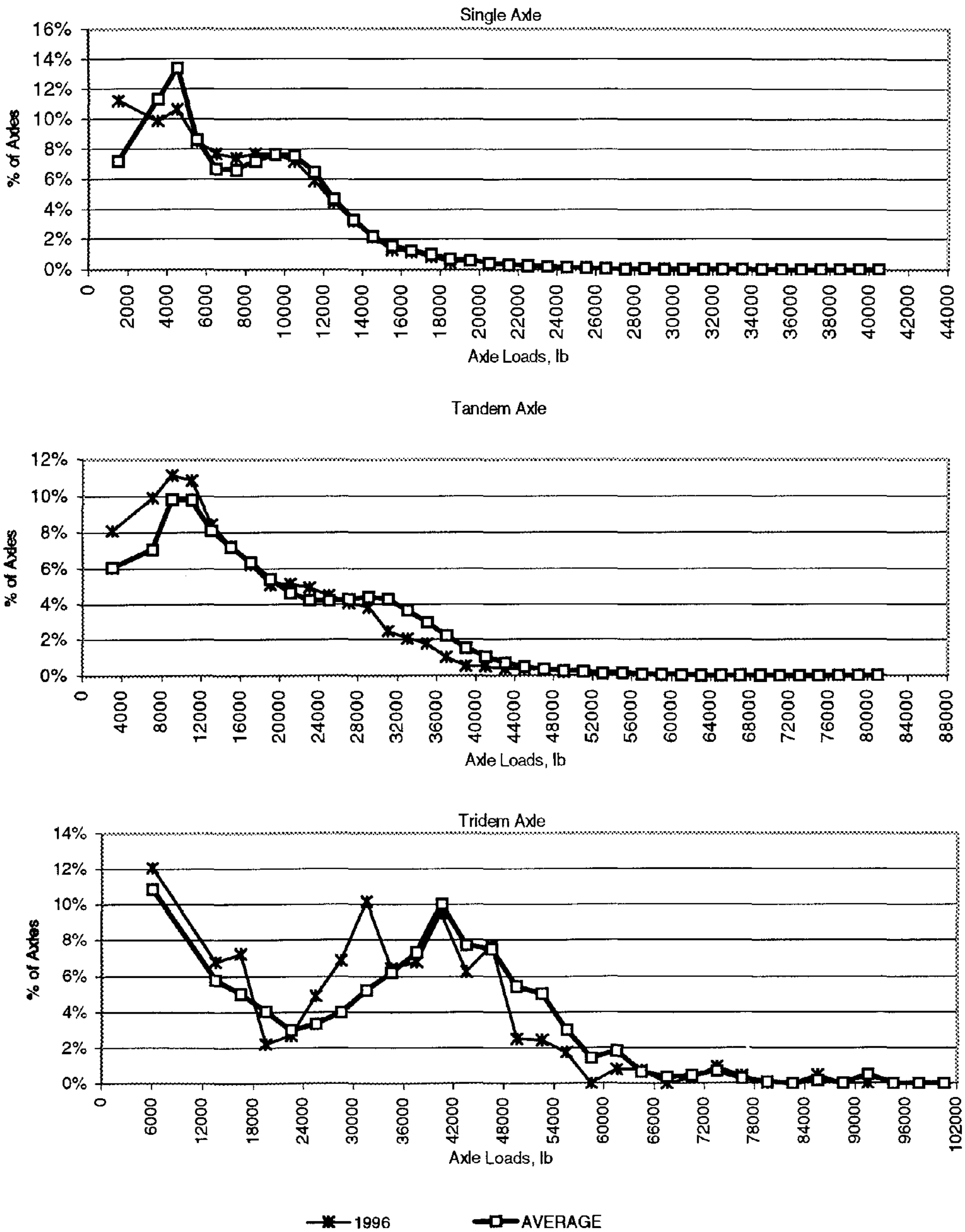
Step 7. Develop Base Annual Load Spectrum To Be Used for Projection.

Step 7.1. Obtain and Critically Assess the Annual Vehicle Volume Distributions for Classes 4 Through 13 for All Available Years.

Annual vehicle volumes are available in CTDB Level 2 as processed data.

Step 7.2. Determine/Select Base Annual Volume Distribution and Base Total Annual Truck Volume.

Typically, the base annual volume distribution will be calculated as an average of the available monitored distributions. Similarly, as in the process of selecting annual load spectrum



1 lb = 0.00445 kN

Figure 19. Comparison of normalized average and 1996 annual load spectra for Site 05-3059.

in Categories 1 and 2, if one of the available annual volume distributions is clearly superior to the other volume distributions, the sole use of this volume distribution may be warranted. Also, in an ideal situation with many years of high-quality AVC data, the use of the first and the last annual volume distributions as base volume distributions is recommended. In this case, the first annual volume distribution will be used for backcasting, and the last annual volume distribution will be used for forecasting.

The establishment of the base total annual truck volume (for vehicle classes 4 through 13) follows the procedure for establishing the base annual volume distribution described above.

Example for Site 37-3807:
The base annual volume distribution was obtained as an average distribution for the years 1993 through 1995. The results are summarized in table 8 and figure 20. Figure 20 also shows the presence of Class 14 vehicles. In general, Class 14 vehicles are vehicles that could not be classified into the 13 vehicle classes and include both cars and trucks.

Table 8. Vehicle class distribution for Site 37-3807.

Year	**Percentage of Vehicles for Vehicle Classes 4 Through 13**										**Total Truck Volume**
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
1993	0.86	4.62	6.16	0.29	8.75	62.4	0.42	4.55	1.58	0.06	290,600
1994	1.07	5.71	6.68	0.31	9.23	63.8	0.51	4.01	1.74	0.10	376,300
1995	0.80	13.11	6.09	0.67	8.26	60.6	0.53	5.22	1.60	0.17	319,700
Average	0.92	7.79	6.34	0.42	8.77	62.4	0.49	4.56	1.65	0.12	328,900

Step 7.3. Obtain/Select Load Spectra for Vehicle Classes 4 Through 13.

Load spectra for vehicle classes 4 through 13 were expected to be obtained by site-specific WIM measurements. However, because the load spectra are not available for Category 3 predictions, they need to be estimated.

The following possible sources of surrogate representative load spectra for vehicle classes are listed in the order of preference.

1. Site-related load spectra.
2. Regional load spectra obtained for:
   - Similar site(s) in the same jurisdiction, or
   - Site(s) with a similar functional classification as the site in question.
3. Typical load spectra.

For comparison and calculation purposes, it is preferable to obtain normalized load spectra rather than actual spectra. As proposed in chapter 6, the development of a Pavement Loading Guide will facilitate judicious selection of representative load spectra.

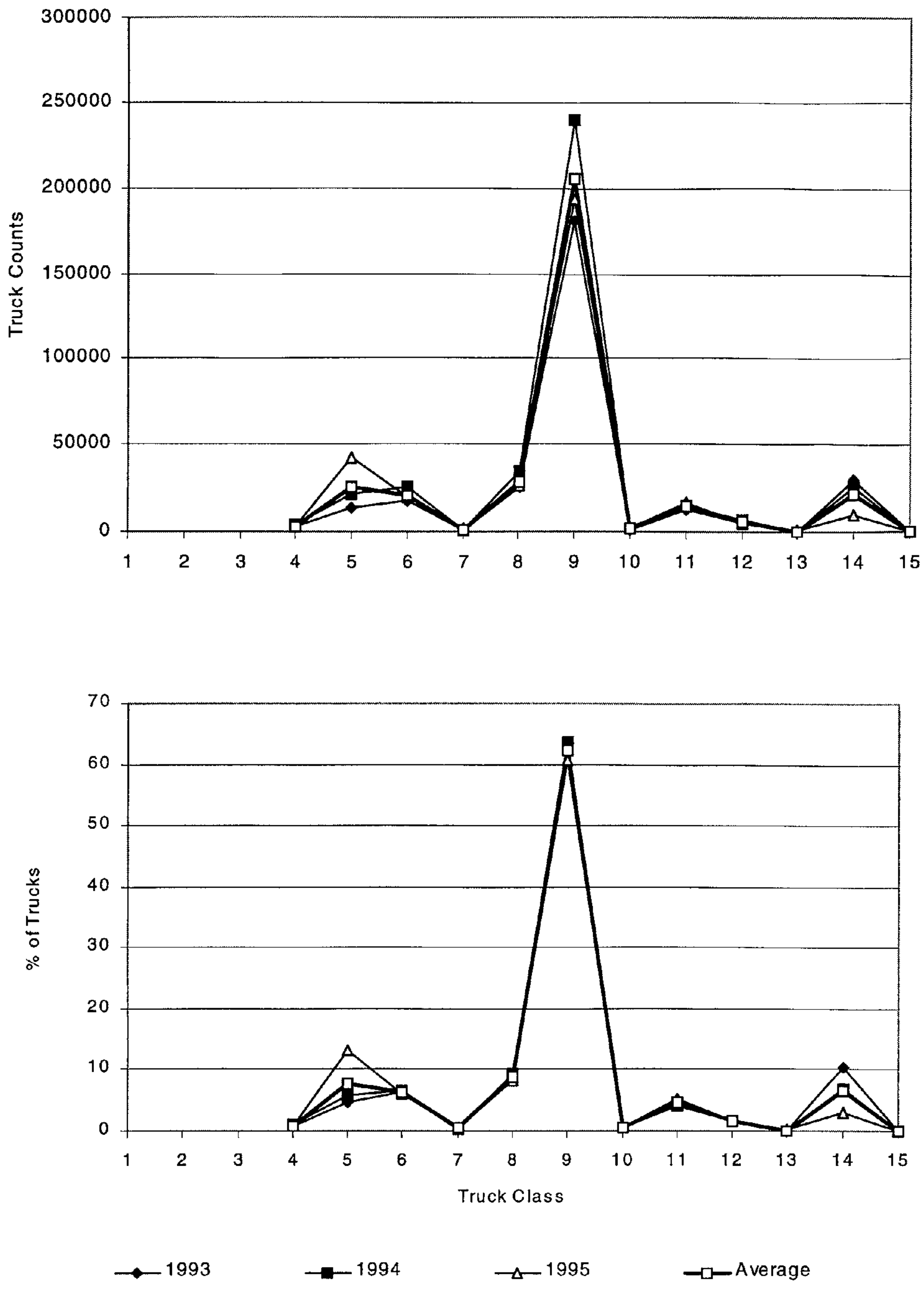


Figure 20. Truck distribution by class for Site 37-3807.

Example for Site 37-3807:
For the purposes of this case study, the typical load spectra for the 10 truck classes, given in appendix B, were used.

Step 7.4. Obtain Total Annual Load Spectra for Monitoring Years.

Two approaches should be considered for calculating annual monitoring year spectra:

- Use of monitored AVC volumes obtained for specific years – Typically, annual load spectra for monitoring years (the years for which classified vehicle volumes were obtained by AVC equipment), should be obtained by multiplying, for each vehicle class, the normalized load spectra (obtained in step 7.3) by the appropriate vehicle volumes (the volumes obtained by AVC equipment for the particular monitoring year).

- Use of base annual volume distribution – If annual vehicle volume distributions (obtained and evaluated in step 7.2) vary in quality and quantity, or the volume distributions are available for a few years only, it may be advantageous to use the base annual volume distribution for the calculation of annual load spectra for all monitoring years. It should be recalled that the selection of base annual volume distribution takes into account the quality and quantity of AVC data obtained for different monitoring years, and that base annual volume distribution can average the differences between annual distributions. Consequently, this approach may predominate.

Calculation of annual load spectra for a given monitoring year is summarized by equations 3 through 5.

$$s = \sum_{i=4}^{i=13} s_i \; a_i \; v_i \; V \qquad \textbf{(3)}$$

$$d = \sum_{i=4}^{i=13} d_i \; b_i \; v_i \; V \qquad \textbf{(4)}$$

$$t = \sum_{i=4}^{i=13} t_i \; c_i \; v_i \; V \qquad \textbf{(5)}$$

where: s = Load spectrum for single axles (vector containing the number of single axles belonging to each of the pre-defined load categories for single axles).
s_i = Vector containing normalized load spectra for class i vehicles.
a_i = Single-axle coefficient (number of single axles per vehicle) for vehicle class i. (Axle coefficients are required to transfer normalized vehicle load spectra into actual load spectra for a given number of vehicles.)
v_i = Percentage of vehicles of class i for a given monitoring year.
V = Annual volume of vehicles in Classes 4 through 13 for a given monitoring year.

$d, t =$ Load spectrum for tandem and tridem axles, respectively.
b_i, c_i = Tandem- and tridem-axle coefficients, respectively.

Example for Site 37-3807:
Average annual vehicle volume distribution (for the years 1993 through 1995, i.e., the base volume distribution) was used. It was assumed that the use of the average volume distributions will produce robust spectra for the projections. The base volume distributions were multiplied by the typical load spectra (appendix B) in accordance with equations 3 through 5. Annual vehicle volume distributions for the years 1993 through 1995 are shown in figure 20.

Step 7.5. Calculate Base Annual Load Spectrum.

The calculation of the base annual spectrum (the spectrum used to project traffic loads for years without monitoring spectra) is similar to the calculation of monitoring year spectra given by equations 3 through 5. However, instead of the option of using monitoring year-specific v_i and V, base values of these variables, established in step 7.2, are always used.

Example for Site 37-3807:
The calculation was identical to that described in step 7.4.

STEP 7 FOR CATEGORY 4 PROJECTIONS

Step 7. Develop Base Annual Load Spectrum.

It is assumed that there are no significant AVC and WIM data. However, it is assumed that truck volumes were reliably estimated by ATRs or by other means.

Step 7.1. Obtain/Select Representative Vehicle Volume Distribution and Load Spectra for Vehicle Classes 4 Through 13.

The order of preference for the selection of annual vehicle volume distributions and spectra is:

1. Site-related vehicle distribution.
2. Regional vehicle distribution obtained for:
   - Similar site(s) in the same jurisdiction, or
   - Site(s) with a similar functional classification as the site in question.
3. Typical load spectra.

Step 7.2. Estimate Annual Volumes for Vehicle Classes 4 Through 13.

Vehicle volume distributions selected in step 7.1 will be typically normalized distributions. To obtain actual base vehicle volume distributions, the normalized distribution are multiplied by the site-specific total truck volumes.

Example for Site 17-5423:
1997 was considered the base year, with a total AADT truck volume of 1,934. The results are summarized in table 9.

Table 9. Estimated vehicle class distribution for Site 17-5423.

Vehicle Distribution	Distribution of Vehicles for Vehicle Classes 4 Through 13										Total Truck Volume
	4	5	6	7	8	9	10	11	12	13	
Representative Normalized Distribution, %	2.19	7.11	3.61	0.89	4.50	76.0	1.40	2.95	0.55	0.77	100%
Base Distribution	42	138	70	17	87	1,470	27	57	11	15	1,934

Step 7.3. Calculate Base Annual Load Spectra.

Calculation of annual load spectra is based on equations 3 through 5. However, instead of using monitoring year-specific v_i and V, base values of these variables, established in steps 7.1 and 7.2, are used.

Example for Site 17-5423:
A representative vehicle distribution was selected using currently available data. Representative load spectra given in appendix B were used. The above selections were made mainly to demonstrate the feasibility of computations. It is possible that a detailed review of available data would permit the use of regional-based vehicle classifications and load spectra or that the availability of the LTPP Pavement Loading Guide will facilitate the selection of better fitting typical load classifications and load spectra.

STEPS 8 THROUGH 12 - APPLICABLE TO ALL CATEGORIES

Step 8. Develop Annual Projection Factors.

The Annual Traffic Data Projection Model is used to calculate annual traffic projection factors. Traffic projection factors are multipliers used to project annual traffic load spectra from the base annual spectrum. For Category 1 and 2 projections, annual projection factors for monitoring years may not be required because these spectra are accepted as reported in the CTDB.

Example for Site 05-3095:
The base annual load spectrum is assigned to 1994. Using a simple 2-percent growth rate, the annual projection factors for the years 1978 through 1997 are shown in table 10.

Table 10. Annual projection factors for Site 05-3059.

Year	Annual Projection Factor
1978	0.68
1979	0.70
1980	0.72
• • •	• • •
1996	1.04
1997	1.06

Step 9. Calculate Annual Load Spectra for All In-Service Years.

Annual load spectra for all in-service years are obtained by multiplying all axle counts (for all load ranges of single, tandem, and tridem axles) of the base annual spectrum by the annual projection factors.

For quality assurance purposes, and to facilitate communication with pavement professionals, it is recommended to calculate the resulting ESALs for all historical and monitoring years and cumulatively for all years.

Example:
The cumulative ESAL computation sheet for Site 05-3059 is given in table 11.

Step 10. Provide Recommendations for Enhancement.

Summarize what should be done to improve the accuracy and reliability of traffic loadings for the site. Consideration should be given to both field traffic data collection and the traffic data projection process.

Example for Site 05-3059:
Traffic monitoring on this site should continue in order to verify the recent trend of decreasing ESALs. The following specific issues should be discussed with a representative of the Arkansas DOT:

- *Assumed annual growth rate of 2 percent.*
- *Estimated truck factor for 1996, which appears to be high.*

- *The reason for the sudden increase in the estimated truck volumes reported for 1990 through 1992.*

Step 11. Conduct Sensitivity Analysis.

Sensitivity analyses have been conducted selectively as part of the Phase 1 study. The objective was to identify key assumptions made during the projection process, particularly the assumptions made where other defendable alternatives existed, and to evaluate and compare the consequences of these alternative assumptions.

Example for Site 05-3059:
It was assumed that truck traffic was growing at a simple growth rate of 2 percent. This assumption was based mainly on judgment—a higher growth rate is a possibility. Also, as discussed in step 7.2 for Categories 1 and 2, different base spectra can be selected. In summary, the following three cases were evaluated:

- *Base Case: Average annual load spectra and 2-percent growth factor.*
- *Sensitivity 1: Average annual load spectra and 5-percent growth factor.*
- *Sensitivity 2: 1996 annual load spectra and 2-percent growth factor.*

In each case, annual load spectra for all years between 1978 and 1997 were calculated together with the cumulative annual load spectrum (from 1992 through 1997) and the corresponding cumulative ESALs. The results, summarized in table 11 and figure 21, indicate that the use of alternative load spectra can have an influence on the change in cumulative ESALs (from 3.64 to 3.07 million) comparable to the change in growth rate from 2 percent to 5 percent (from 3.64 to 2.82 million). The higher cumulative ESALs obtained for the 2-percent growth rate (compared to the 5-percent rate) are caused by applying the 2-percent growth rate to higher initial truck volumes.

Step 12. Monthly Variation.

Step 12.1. Develop Monthly Traffic Data Projection Sheet and Critically Review Available Monthly Data.

The Monthly Traffic Data Projection Sheet is used to summarize and compare monthly trends in total truck volumes, ESALs, and ESALs per truck. In addition to comparing monthly trends in total truck volume, it is also possible to compare monthly trends for individual vehicle classes. This type of comparison was done by Hallenbeck [7], who recommended the aggregation of the 10 individual truck classes into a few major classes to obtain more definite monthly trends. However, based on case study analysis, even the aggregation of all trucks into one class may not reveal systematic, repeatable monthly trends.

Table 11. Cumulative ESALs computation sheet for Site 05-3059.

Year	Historical ESALs per day	Monitoring ESALs per day	Base Case	Sensitivity 1	Sensitivity 2
1978	244		390	115	301
1979	249		401	143	310
1980	255		413	172	320
1981	260		424	201	329
1982	266		435	229	338
1983	271		447	258	348
1984	277		458	287	357
1985	285		470	315	367
1986	293		481	344	376
1987	304		493	372	385
1988	310		504	401	395
1989	334		516	430	404
1990	1052		527	458	414
1991	1175		539	487	423
1992	1219	682	682	682	682
1993		616	616	616	616
1994		540	540	540	540
1995		557	557	557	557
1996		470	470	470	470
1997			607	659	479

Cumulative ESALs for Base Case = 3,639,245
Cumulative ESALs for Sensitivity 1 = 2,823,552
Cumulative ESALs for Sensitivity 2 = 3,069,581

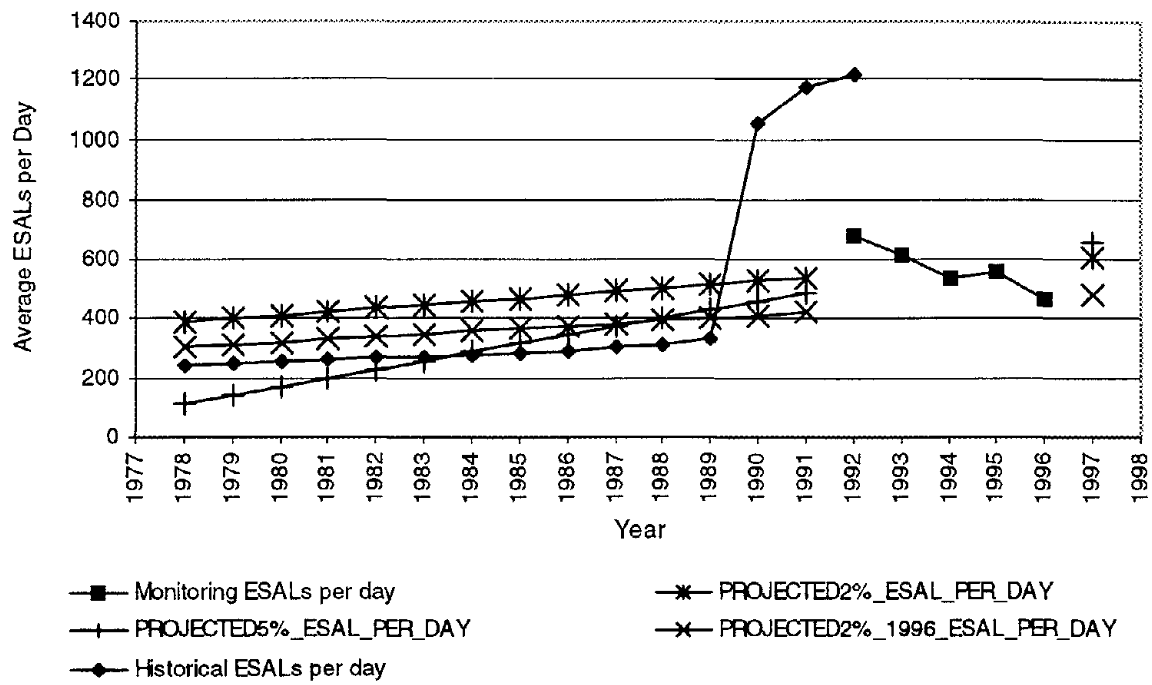


Figure 21. Comparison of projected, historical, and monitoring ESALs for Site 05-3059.

Example for Site 12-4000:
The Monthly Traffic Data Projection Sheet in figure 22 shows no discernable monthly pattern for the total truck volumes and indicates a weak trend toward higher loads (ESALs per day) during warmer months. Figure 23 compares average monthly load spectra and is an example of the work done to ascertain the reliability of monthly load spectra obtained for different years.

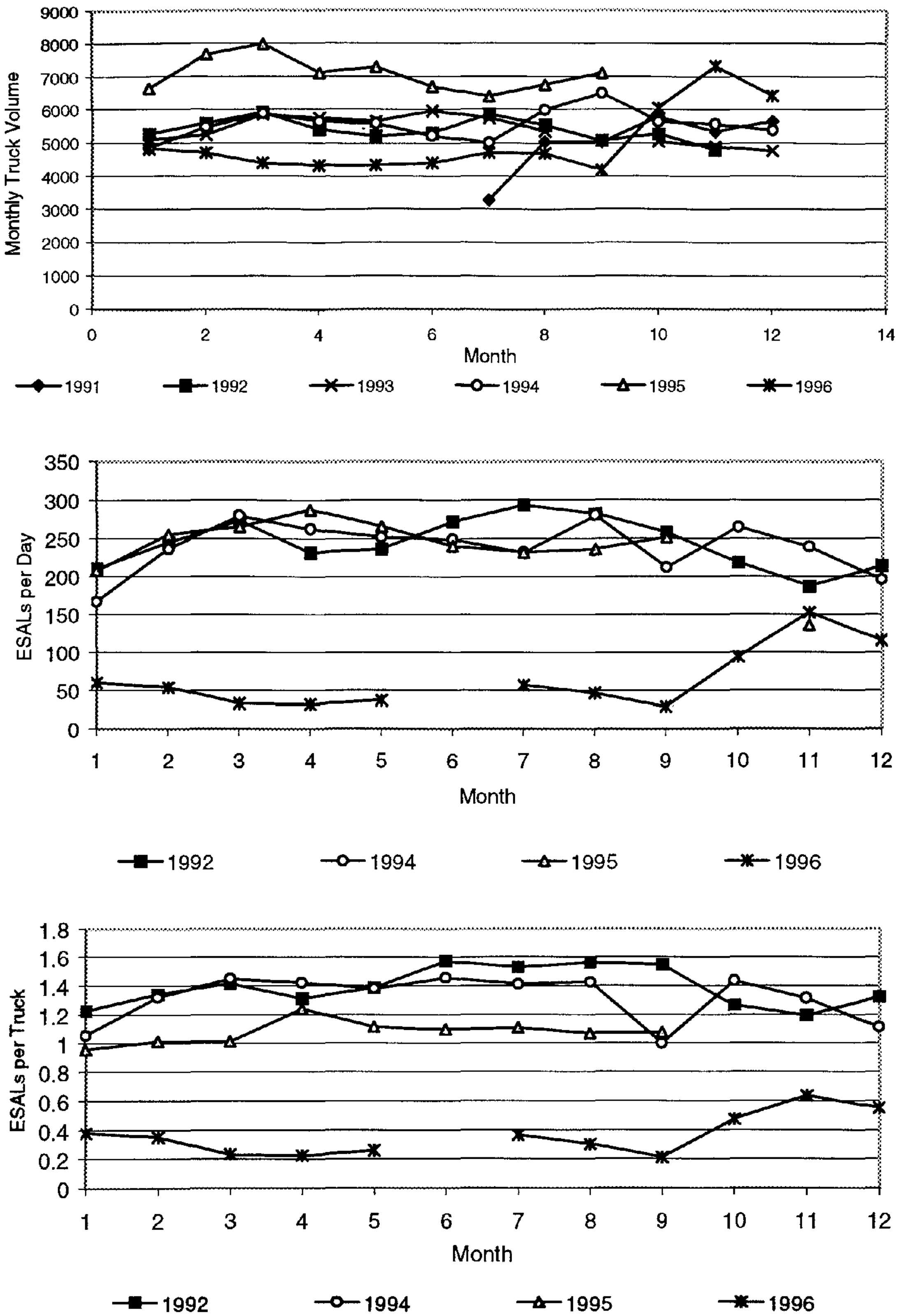
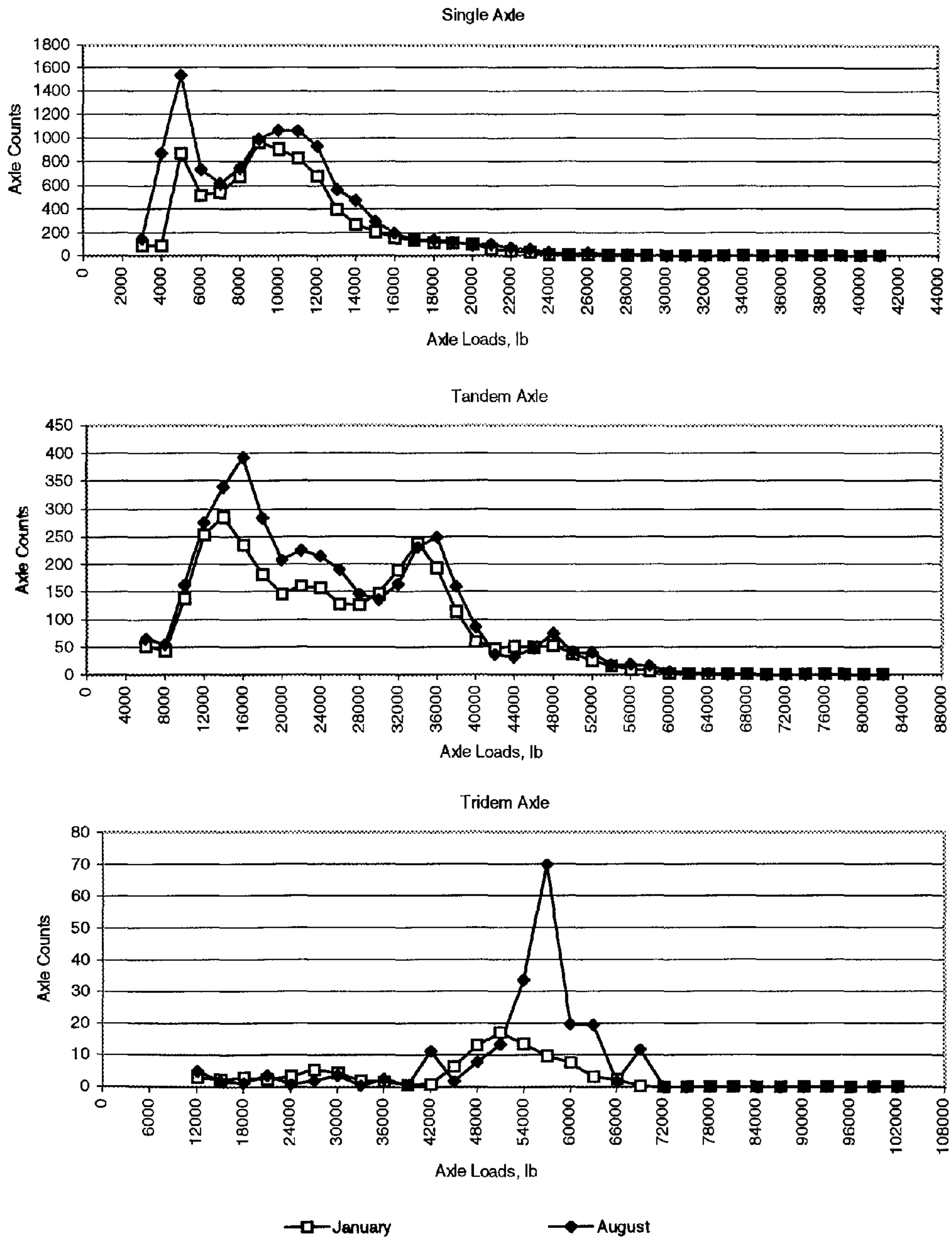


Figure 22. Comparison of monthly traffic variations for Site 12-4000.



1 lb = 0.00445 kN

Figure 23. Comparison of average monthly load spectra for Site 12-4000.

Step 12.2. Develop Monthly Distribution Factors and Summarize Reasons for Their Selection.

Monthly adjustment factors are used to distribute the annual load spectra into 12 months. Based on data evaluated so far, it is recommended that only one set of monthly distribution factors be used for all projection years.

Example for Site 12-4000:
Monthly ESALs were used for the development of the monthly distribution factors. The monthly ESALs obtained for 1992, 1994, and 1995 were averaged (figure 24) and used to obtain monthly distribution factors (table 12). Considering the data variability on which the monthly distribution factors are based and the discrepancies between the historical and monitoring trends in traffic data (refer to the case study for Site 12-4000 in chapter 5), the monthly distribution factors given in table 12 should be accepted with caution.

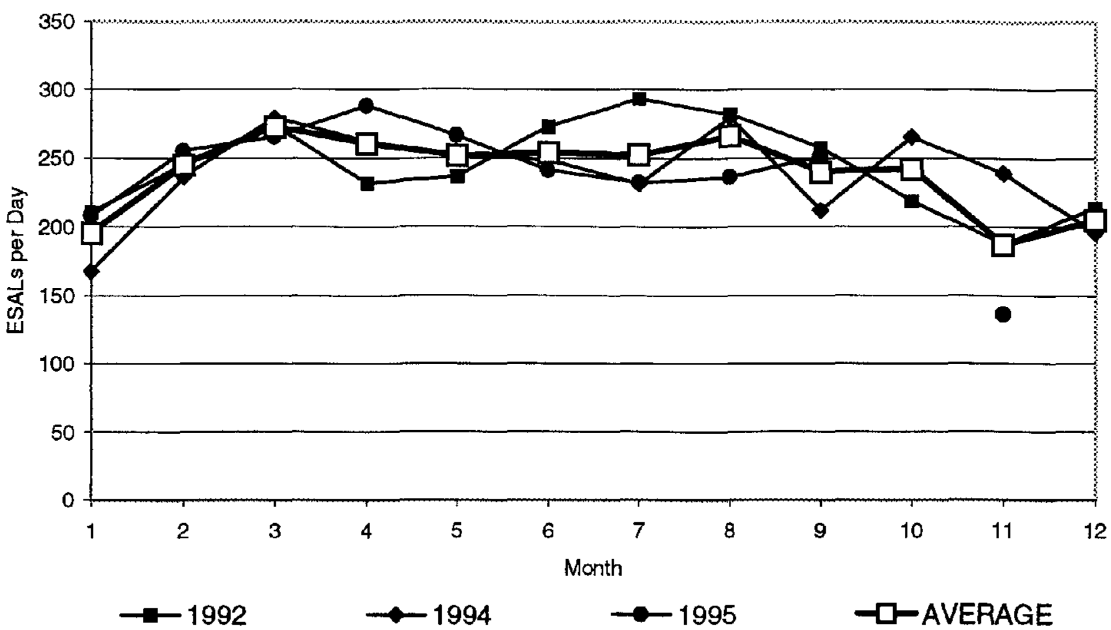


Figure 24. Comparison of monthly ESALs per day variation for Site 12-4000.

Table 12. Computation of average ESALs per day.

Month	1992	1994	1995	Average	Monthly Distribution Factors, %
1	210	168	208	195	6.8
2	246	236	255	246	8.5
3	274	279	265	273	9.5
4	232	262	288	261	9.1
5	237	252	266	252	8.8
6	273	249	241	254	8.8
7	294	232	232	252	8.8
8	282	280	236	266	9.3
9	258	212	251	240	8.4
10	219	265	–	242	8.4
11	187	239	136	188	6.5
12	214	196	–	205	7.1

CHAPTER 5. CASE STUDIES AND SENSITIVITY ANALYSES

This chapter describes 12 case studies and the results of sensitivity analyses conducted as part of the case studies. The objective of the case studies was to verify and document the feasibility of the procedure for projecting traffic loads and to identify possible site-specific challenges and data problems. The sensitivity analyses address the following topics:

- *Effect of Key Assumptions* – Exploratory analyses were carried out by evaluating the influence of key assumptions used for the projection of traffic loads, such as growth rates, the selection of base annual traffic load spectra, and vehicle distribution by class, during the course of the case studies. In particular, such analysis was carried out for case studies and situations where the key assumptions were based on doubtful data.

- *Reliability of Historical Traffic Loading Estimates* – While the historical and monitoring data were compared systematically during the course of carrying out case studies, and the major discrepancies between historical and monitoring data were assessed, it was not possible to resolve all the differences between these two types of data, or to decide which data type is more accurate for a specific set of circumstances. To do so would require the involvement of SHAs supplying historical and monitoring data.

- *Effect of Quantity of Monitoring Data* – In addition to the sensitivity analyses done in the course of carrying out case studies, a separate analysis was done to assess the potential effect of the amount of monitoring data on the precision of the projected traffic load estimates.

SELECTION OF SITES FOR CASE STUDIES

According to the work plan, three case studies were carried out for each projection category. The LTPP sites for the case studies were selected to represent different geographical areas, functional load categories, traffic volumes, and data availability. The main objective in selecting case study sites was to obtain a representative set of sites so that generalizations could be made, based on the case studies, regarding the required effort and expected outcome of traffic load projections for the rest of the LTPP sites.

The selected LTPP sites used for the case studies are listed in table 13. The sites are located in 10 States and on 5 functional classes of highways. The number of lanes ranges from two to six, and daily ESALs per LTPP lane range from 75 to 3,000.

Table 13. Description of LTPP sites used for the case studies.

Category	LTPP Site	State	Functional Class	No. of Lanes	Daily ESALs[1]	Comments
1	12-4000	Florida	Rural Principal Arterial	4	140	D = 8.2
	27-0501	Minnesota	Rural Principal Arterial	4	170	SPS site SN = 7.8
	29-4036	Missouri	Urban Interstate	4	2,200	Also in Category 4 D = 9.8
2	04-1002	Arizona	Rural Interstate	4	3,000	Uncertain historical growth SN = 4.7
	05-3059	Arkansas	Urban Interstate	4	800	D = 9.4
	29-5483	Missouri	Rural Principal Arterial	2	400	SN = 2.5
3	37-3807	North Carolina	Rural Principal Arterial	4	320	Good match of monitoring and historical data
	48-5287	Texas	Urban Interstate	6	700	SN = 2.5
	55-3012	Wisconsin	Rural Minor Arterial	2	75	D = 7.1
4	01-6019	Alabama	Rural Interstate	4	1,070	SN = 2.5
	04-1002	Arizona	Rural Interstate	4	3,000	Historical or 2,800 projected. Also in Category 2
	17-5423	Illinois	Rural Interstate	4	980	SN = 2.5

[1]Average daily (monitoring or projected) ESALs in the LTPP lane in 1997.
SN = Structural Number
D = PCC slab thickness in inches (1 in = 25.4 mm)

ORGANIZATION OF CHAPTER 5

The description of case studies is organized into four parts, each part describing one projection category. Each part is introduced by a summary description of the three case studies done for each category, and the summary description is followed by the description of the individual case studies. The description of case studies is illustrated by tables and figures and is accompanied by a brief commentary to point out salient features, insights, or data problems. A detailed description of each step involved in conducting the case studies is presented in chapter 4. Not all analyses, tables, and figures done in the course of carrying out case studies are presented in this report. This was done to keep the focus on the main issues and maintain the interest of the reader. The last section describes the sensitivity analysis regarding the effect of the quantity of the monitoring data on the precision of the traffic projections.

SUMMARY OF CASE STUDIES FOR CATEGORY 1

Category 1 sites include LTPP sites that have sufficient AVC and WIM data to enable the projection of monthly variation in traffic loadings.

Site 12-4000

Site 12-4000 is on a four-lane rural principal arterial highway in Florida. It is a prime example of why the traffic load prediction process requires the involvement of SHAs. The main challenge is that monitoring ESALs reported during the period between 1992 and 1997 have been declining, contrary to expectations, and are much lower than historical ESALs reported by the SHA. For example, historical truck volume for 1990 is five times higher than monitoring truck volume for 1991. The monthly variation in traffic loads suggests that a pattern of higher monthly loads during months 2 through 10, roughly in accordance with expected general trends outlined in chapter 2, is probable. This is the only site (out of three) for which a pattern of monthly variation in loads emerges from monitoring data.

Site 27-0501

Site 27-0501 is on a four-lane rural principal arterial highway in Minnesota. This is an example of an LTPP site with good agreement between historical and monitoring data, at least in terms of total truck volume. However, this site has only 2 years of monitoring data. It is also an example of a site with good quality WIM data. The axle load spectra for the individual truck classes obtained for this site were selected as typical base spectra for Category 3 and 4 projections. The hypothesis that there is a historical pattern in the monthly variation of traffic loads is not supported by available monitoring data. Truck factors (average ESALs per truck) seem to be higher during winter months, as would be expected in Minnesota, which allows 10 percent higher axle loads during winter. However, this conclusion needs to be verified by representatives of the SHA, since a similar result may be caused by calibration drift during winter months.

Site 29-4036

Site 29-4036 is on a four-lane Interstate in Missouri. It shows the best agreement between historical and monitoring data among the 12 case studies presented herein. Because of this agreement, and the extensive monitoring data following an exponential trend, annual growth factors were based on a regression line utilizing both historical and monitoring truck volumes. There is considerable variation in axle load spectra, which is usually not expected to occur on Interstate highways. No discernable pattern in monthly load variation was observed. Monthly variation in monitoring ESALs per truck for some years was more than 100 percent—another unexpected result. In view of some questionable WIM data, Site 29-4036 is another strong example of the need to involve SHAs in the traffic prediction process.

DESCRIPTION OF CASE STUDIES FOR CATEGORY 1

Site 12-4000

Site 12-4000 is located on a four-lane highway on a rural principal arterial highway in Florida. Extensive, site-specific AVC and WIM monitoring data are available for this site, as shown in table 14.

Table 14. Monitoring data available for Site 12-4000.

Data Type		Monitoring Year							
		1991	1992	1993	1994	1995	1996	1997	Total
AVC	Days	126	287	348	316	213	352	0	1642
	Month	6	12	11	12	9	12	?	62
WIM	Days	0	293	259	330	228	227	28	1365
	Month	0	12	12	12	10	11	?	57

Notes: Month = Number of months for which AVC and WIM data are available.
? = Data could not be obtained.

The available annual traffic data are summarized in figure 25. The historical and monitoring data trends are conflicting—historical trends indicate a substantial increase in truck volumes and loads, while the trend for monitoring truck volume data is declining. Particularly disturbing is the decline in ESALs per truck between 1992 and 1997. As discussed in chapter 3, because of the increased competitiveness and advances in wireless communications, an opposite trend was expected. The annual growth factor was estimated by assuming: (1) a total truck volume that was between historical and monitoring volumes, and (2) a 3-percent simple growth rate, as shown in figure 26 and table 15.

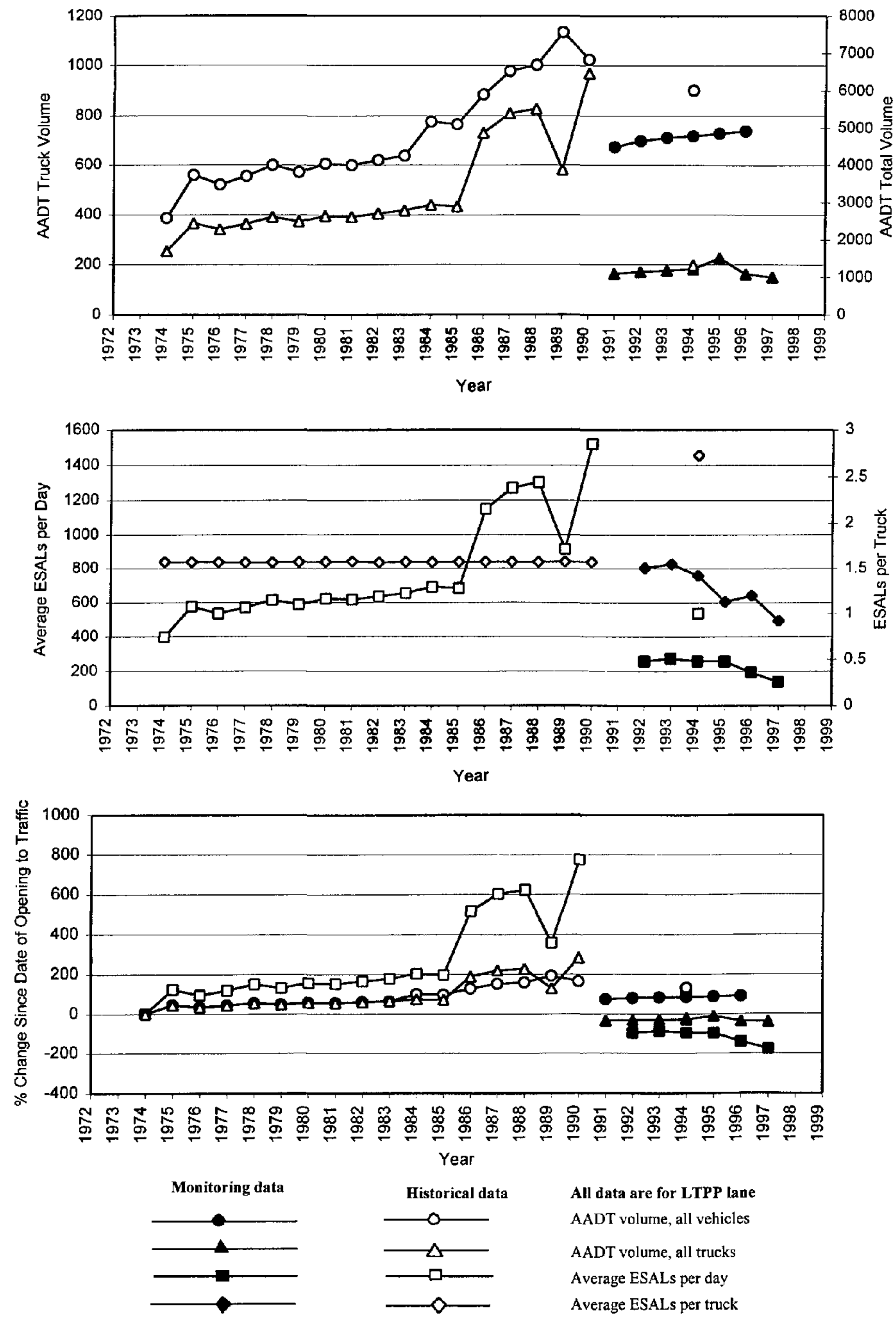


Figure 25. Annual Projection Data Sheet for Site 12-4000.

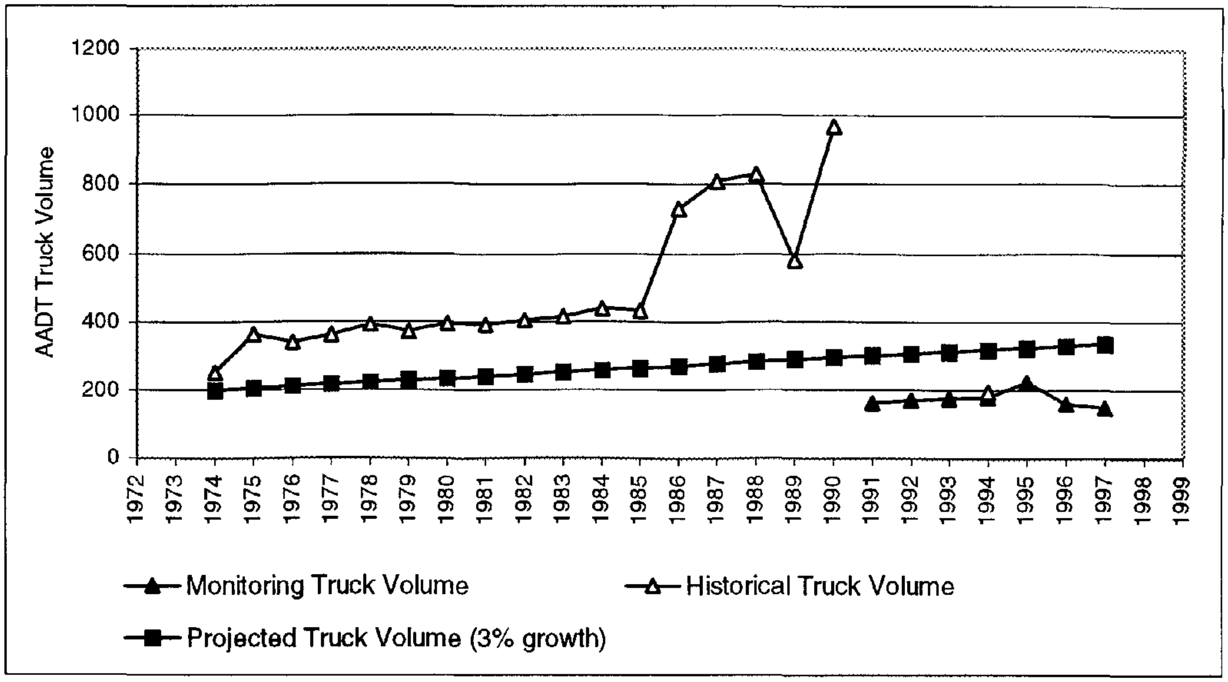


Figure 26. Comparison of truck AADT volumes for Site 12-4000.

Table 15. Comparison of truck AADT volumes for Site 12-4000.

Year	Growth Factor	Projected Truck Volume, 3% Growth	Monitoring Truck Volume	Historical Truck Volume
1974	0.59	200		253
1975	0.61	206		366
1976	0.63	212		341
1977	0.64	218		364
1978	0.66	224		392
1979	0.68	230		374
1980	0.70	236		396
1981	0.72	242		392
1982	0.73	248		406
1983	0.75	254		417
1984	0.77	260		440
1985	0.79	266		434
1986	0.80	272		731
1987	0.82	278		809
1988	0.84	284		828
1989	0.86	290		582
1990	0.88	296		969
1991	0.89		163	
1992	0.91		171	
1993	0.93		176	
1994	0.95		181	197
1995	0.96		226	
1996	0.98		161	
1997	1.00		150	

A comparison of annual axle load spectra obtained for the years 1992 through 1997 and the summaries in figure 27 indicates a considerable variation in the annual spectra. This observation is based on the variation in annual load spectra observed for other LTPP sites (which will be presented for the subsequent case studies). Specifically, the 1995 and 1997 annual load spectra, particularly for tridem and tandem axles, appear to be outliers. For this reason, the base annual load spectrum was obtained by averaging annual load spectra for 1992, 1993, 1994, and 1996 only. The resulting base annual load spectrum is shown in figure 28. The axle load spectrum for tridem axles has the primary peak at 240 kN (54,000 lb). This is clearly on the high side. A mitigating consideration is the relatively low number of occurrences. Perhaps more disturbing is the tertiary peak for the tandem axle at 205 kN (46,000 lb), with many axle counts exceeding 500. The reasons for these overloads should be clarified with the SHA.

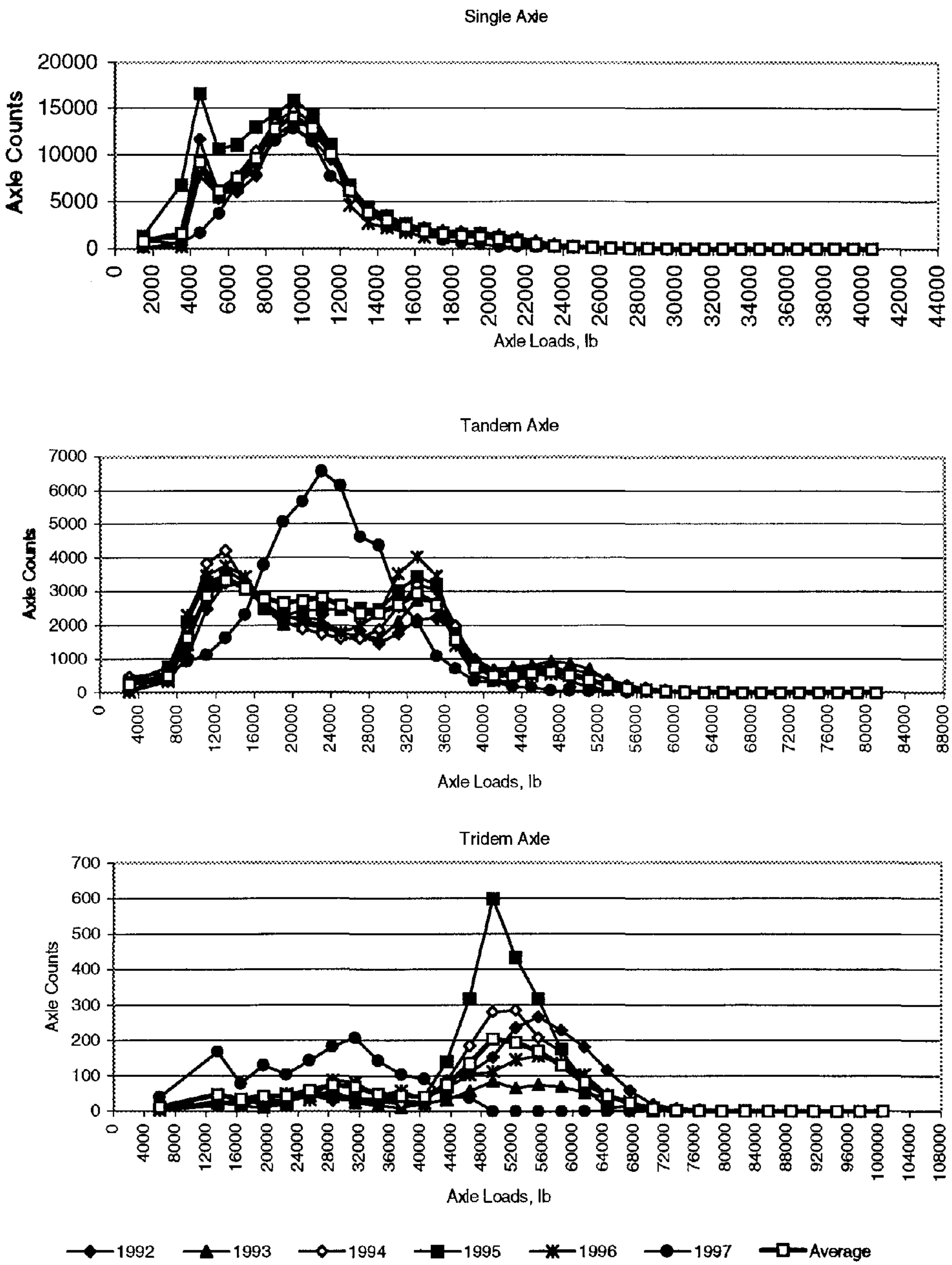
The comparison of the annual vehicle class distribution, shown in figure 29, also indicates considerable variation. Again, data for 1995 and 1997 are considered to be outliers. It is also interesting to note that few, if any, trucks have more than five axles (vehicle classes 11, 12, and 13, shown in figure 15). Thus, the reason for the overloaded tandem and tridem axles cannot be explained by the presence of larger combination trucks. However, Florida allows a truck tractor and two trailer units up to 32.3 m (106 ft) long.

Note: In order to obtain a better understanding of the variation between total annual spectra observed for all three sites used for case studies in Category 1, and to obtain typical axle load spectra required for Category 3 and 4 projections, we have developed and compared annual axle load spectra for each truck category (vehicle classes 4 through 13). The resulting load spectra are presented in appendix B. Load spectra in appendix B are the average spectra for all monitoring years, reported separately for the 3 sites and the 10 truck classes. The results indicate that for Site 29-4036, some trucks were clearly misclassified:

- *Two-axle, six-tire vehicles (Class 5) do not have tandem axles, contrary to data reported in figure 98 in appendix B.*
- *Four-axle tractor-semitrailers (Class 8) do not have tridem axles, contrary to data reported in figure 101 in appendix B.*
- *Six-axle tractor-semitrailers (Class 10) should, in general, have tridem axles, contrary to data reported in figure 103 in appendix B.*
- *Five-axle, three-unit trucks (Class 11) should not have tridem axles, contrary to data reported in figure 104 in appendix B.*

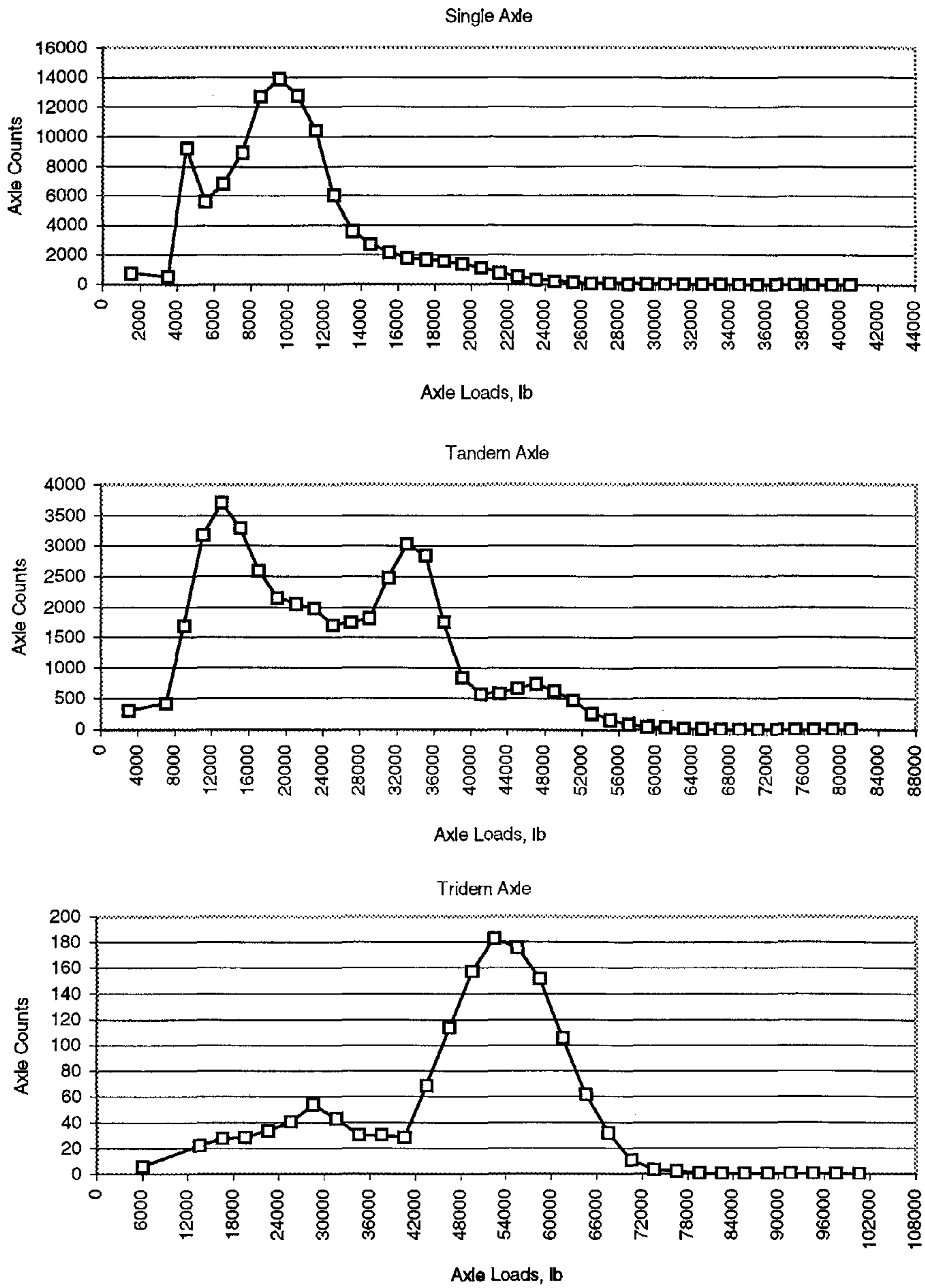
Axle load spectra for Site 12-4000 did not show major discrepancies. However, a closer examination revealed a few minor inconsistencies, such as:

- *Three-axle single-unit trucks (Class 6) show atypically high tandem-axle loads (figure 99 in appendix B).*
- *Five-axle tractor-semitrailers (Class 9) do not exhibit the typical bimodal distribution of tandem-axle weights (figure 105 in appendix B).*
- *Six-axle, two-unit trucks (Class 10) should have tridem axles (figure 106 in appendix B).*



1 lb = 0.00445 kN

Figure 27. Comparison of annual load spectra for Site 12-4000.



1 lb = 0.00445 kN

Figure 28. Base annual load spectrum for average of 1992 through 1994 and 1996 data for Site 12-4000.

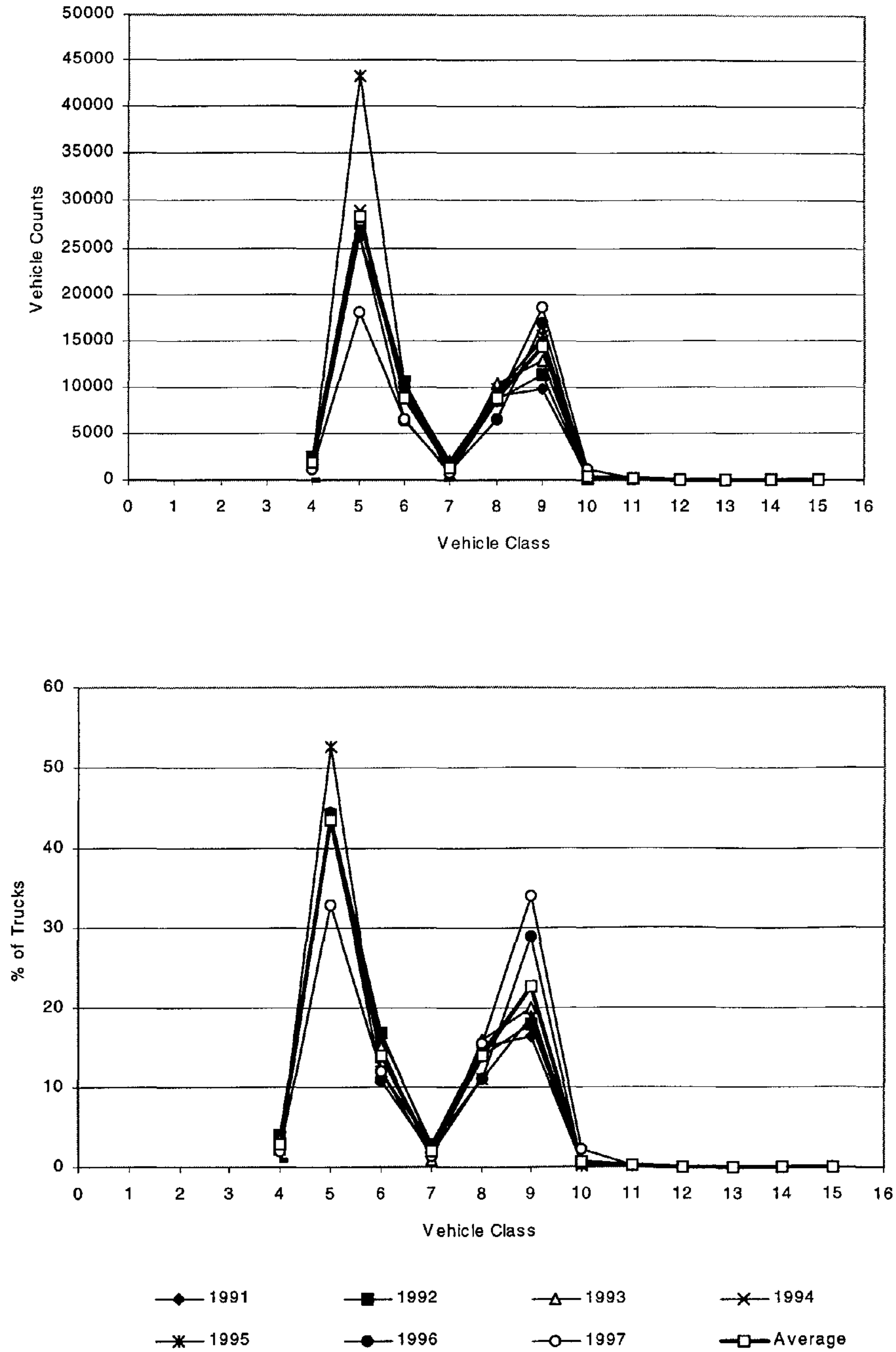


Figure 29. Truck distribution by class for Site 12-4000.

Axle load spectra for individual vehicle types for Site 27-0501 appeared to be problem-free. For this reason, these spectra were selected as base spectra for Category 3 and 4 predictions.

For quality control purposes, the projected annual load spectra were converted into ESALs and are given in table 16 and figure 30. The total ESALs between 1974 and 1997 is about 1.7 million. This number is unusually low for a rural Interstate with a rigid pavement. Again, local involvement is essential for determining the causes of such discrepancies.

The projection of monthly variation in traffic loads for this site was previously discussed in chapter 4, step 12.

In summary, in spite of the extensive AVC and WIM data available for this site, the overall traffic load projection is weak and unconvincing. The discrepancy between historical data and conventional expectations on one side, and the results of the monitoring data on the other, cannot be resolved without local involvement.

Site 27-0501

Site 27-0501 is located on a four-lane rural principal arterial road in Minnesota. Available AVC and WIM monitoring data are summarized in table 17.

The Annual Traffic Data Projection Sheet (figure 31) shows a reasonable correspondence between historical and monitoring truck volumes. The 1991 AADT and truck volume show an unexpected spike. However, the annual 1991 data are based on only 8 days of AVC data, and 1991 data were not used in the projection. The correspondence between historical and monitoring ESALs is poor. The historical assumption of 0.7 ESALs per truck is not supported by monitoring data. The annual growth factors were estimated by fitting a 7.3-percent simple growth trend to the historical and monitoring truck volumes (figure 32 and table 18). The base annual axle load spectrum was obtained by averaging 1992 and 1994 spectra, which are quite similar (figure 33). Figure 34 and table 19 summarize traffic projection results in terms of ESALs.

Monthly data were obtained from Level 3 CTDB through the data extraction process described in appendix A. Data given in the Monthly Traffic Data Projection Sheet (figure 35) do not show any historical trend, with the exception of the ESALs per truck ratio, which appears to be higher during winter months.

In summary, we are comfortable with traffic projections at this site. The difference between historical and monitoring ESALs per truck should be brought to the attention of the SHAs.

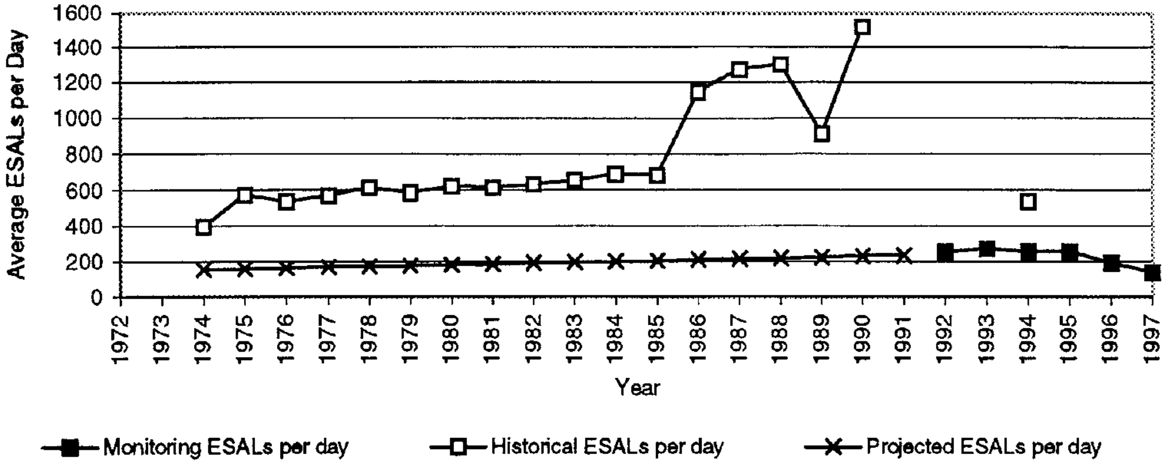


Figure 30. Comparison of ESAL volumes for Site 12-4000.

Table 16. Comparison of ESAL volumes for Site 12-4000.

Year	Monitoring ESALs per Day	Historical ESALs per Day	Projected ESALs per Day
1974		3 97	154
1975		575	159
1976		534	164
1977		570	168
1978		614	173
1979		586	177
1980		622	182
1981		616	187
1982		636	191
1983		655	196
1984		690	201
1985		682	205
1986		1148	210
1987		1271	215
1988		1301	219
1989		915	224
1990			228
1991			233
1992	257		257
1993	273		273
1994	258		258
1995	256		256
1996	193		193
1997	138		138

Cumulative ESALs = 1,774,159

Table 17. Monitoring data available for Site 27-0501.

Data Type		Monitoring Year				
		1991	1992	1993	1994	Total
AVC	Days	8	358	?	351	717
	Month	?	12	?	12	24
WIM	Days	0	349	?	353	702
	Month	?	12	?	12	24

Notes: Month = Number of months for which AVC and WIM data are available.
? = Data could not be obtained.

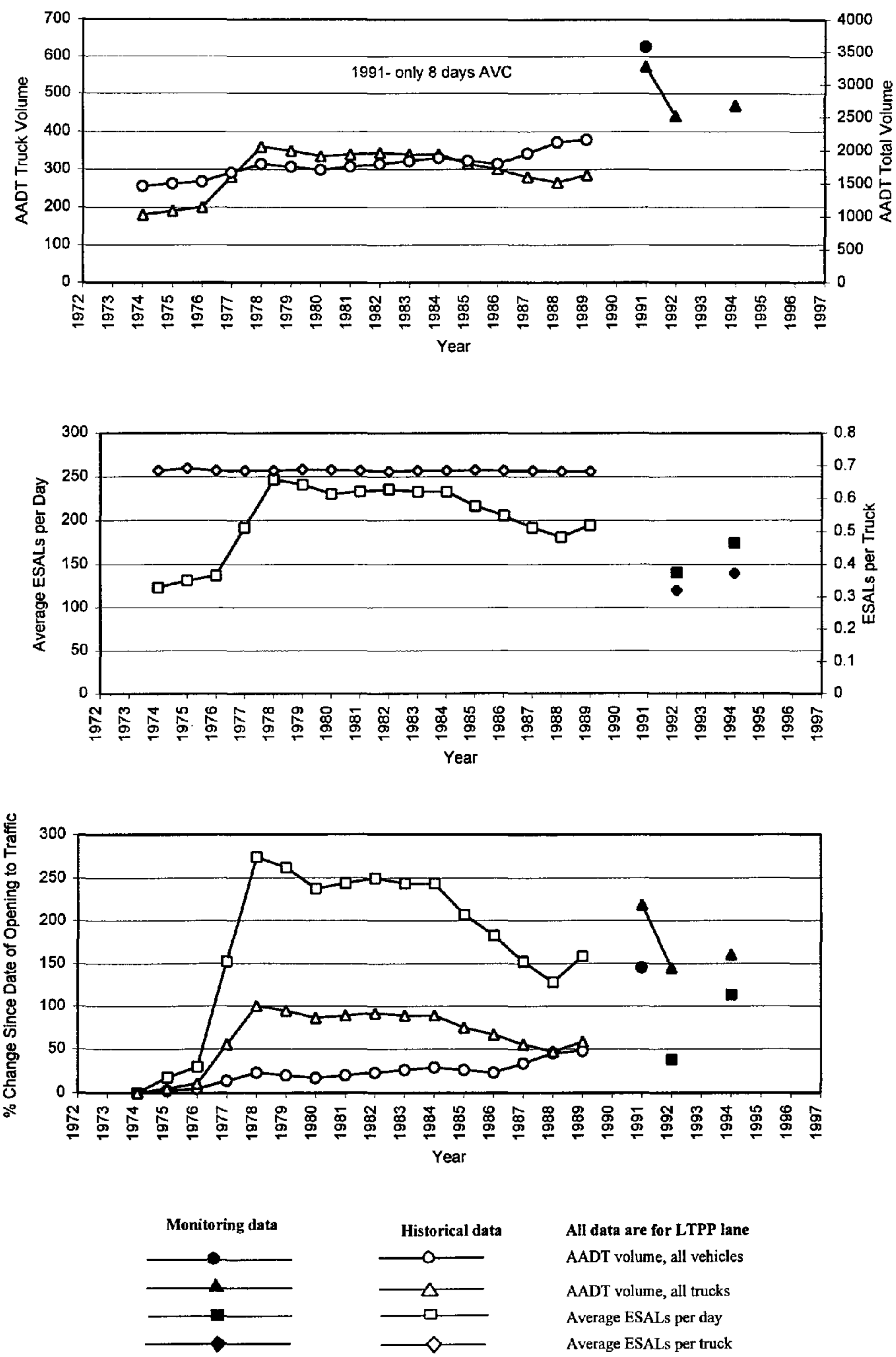


Figure 31. Annual Projection Data Sheet for Site 27-0501.

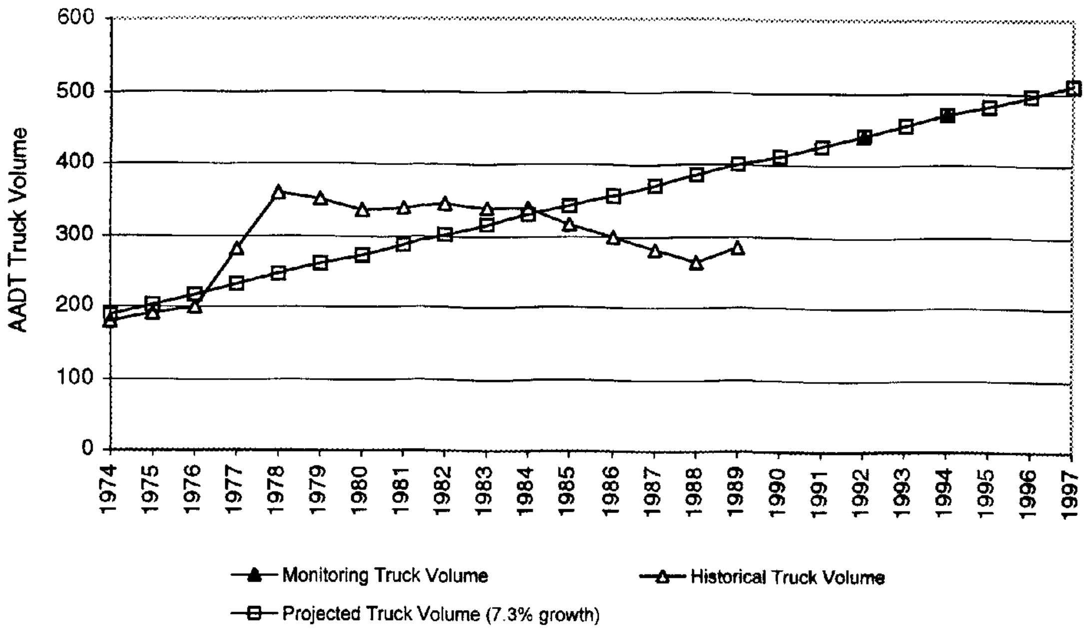
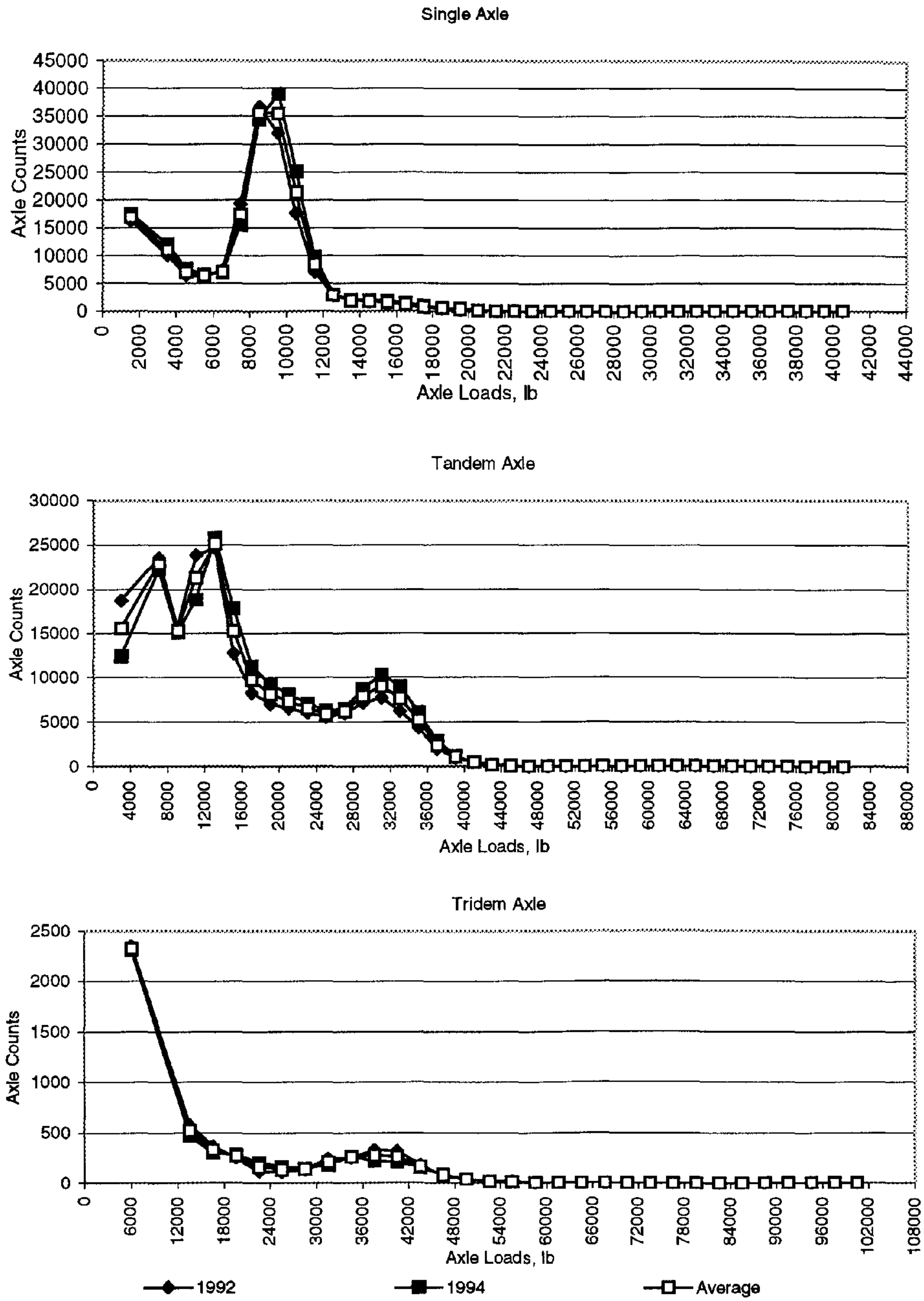


Figure 32. Comparison of truck AADT volumes for Site 27-0501.

Table 18. Comparison of truck AADT volumes for Site 27-0501.

Year	Growth Factor	Projected Truck Volume, 7.3% Growth	Monitoring Truck Volume	Historical Truck Volume
1974	0.41	190		180
1975	0.44	204		190
1976	0.46	218		200
1977	0.49	232		280
1978	0.52	246		360
1979	0.55	259		350
1980	0.58	273		335
1981	0.61	287		340
1982	0.64	301		345
1983	0.67	315		340
1984	0.70	329		340
1985	0.73	343		315
1986	0.76	357		300
1987	0.79	371		280
1988	0.82	385		265
1989	0.85	399		285
1990	0.88	413		
1991	0.91		573	
1992	0.94		441	
1993	0.97	454		
1994	1.00		469	
1995	1.03	482		
1996	1.06	496		
1997	1.09	510		



1 lb = 0.00445 kN

Figure 33. Comparison of annual load spectra for Site 27-0501.

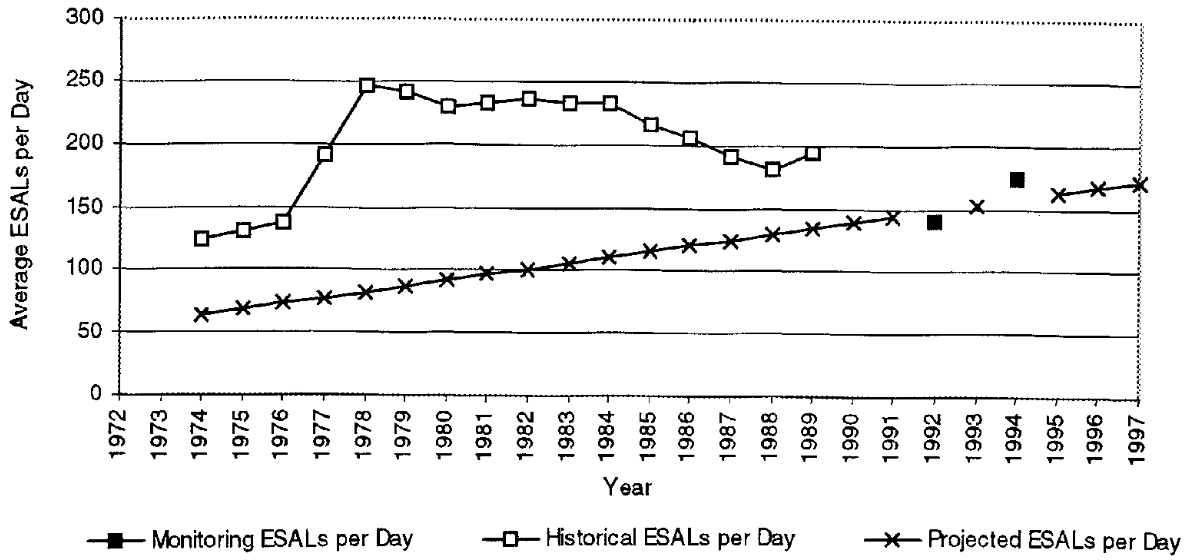


Figure 34. Comparison of ESAL volumes for Site 27-0501.

Table 19. Comparison of ESAL volumes for Site 27-0501.

Year	Monitoring ESALs per Day	Historical ESALs per Day	Projected ESALs per Day
1974		123	64
1975		132	69
1976		137	73
1977		192	78
1978		247	83
1979		241	87
1980		230	92
1981		233	97
1982		236	101
1983		233	106
1984		233	111
1985		216	115
1986		205	120
1987		192	125
1988		181	129
1989		195	134
1990			139
1991			143
1992	141		141
1993			153
1994	174		174
1995			162
1996			167
1997			172

Cumulative ESALs = 1,034,452

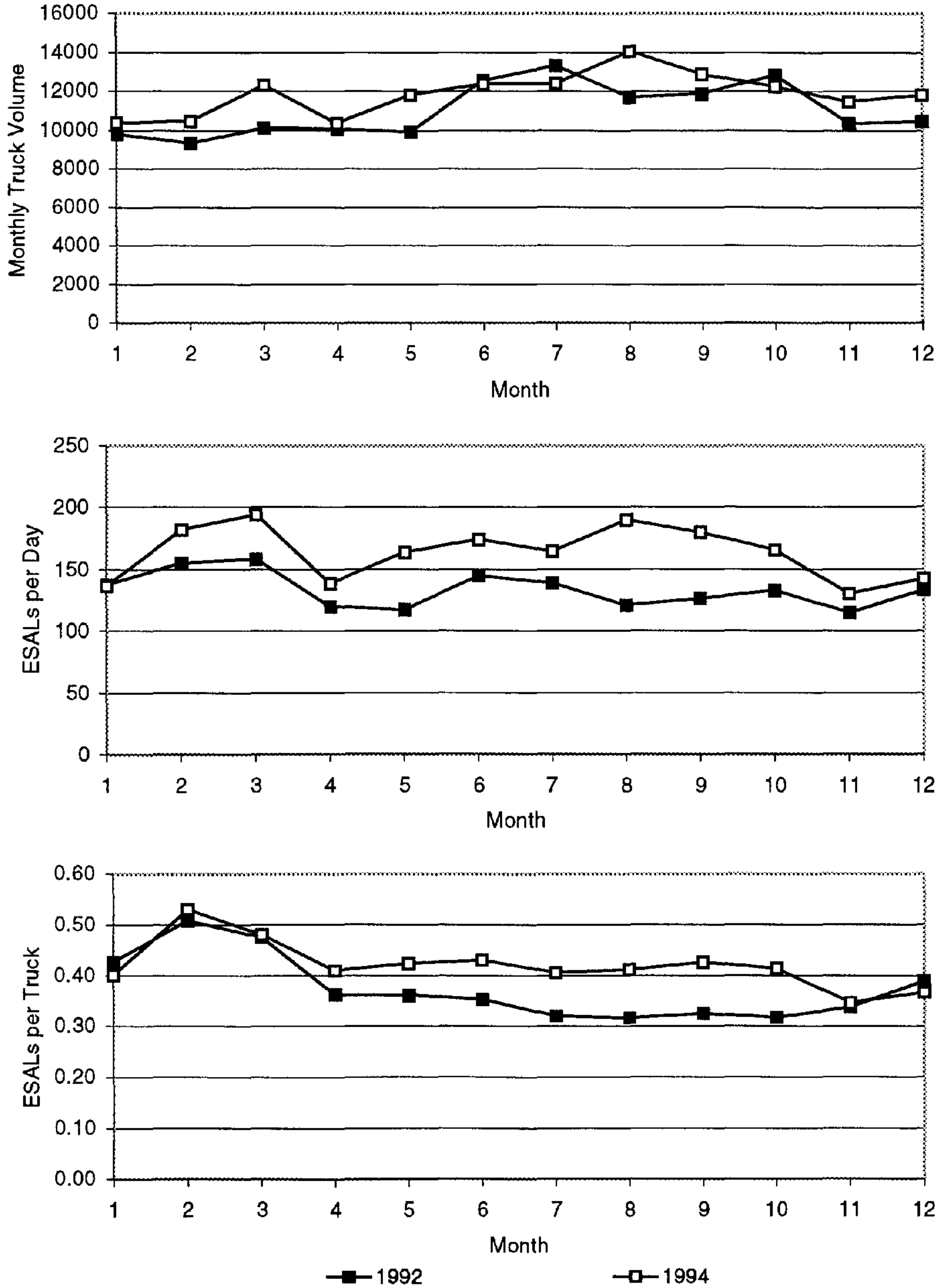


Figure 35. Comparison of monthly traffic variations for Site 27-0501.

Case Study 29-4036

Site 29-4036 is located on a four-lane urban Interstate in Missouri. There is very good agreement between historical and monitoring data (figure 36), and monitoring data are supported by extensive AVC and WIM records (table 20). The trend in the annual truck volumes was utilized to develop an exponential function for the calculation of annual growth factors (figure 37 and table 21).

Table 20. Monitoring data available for Site 29-4036.

Data Type		Monitoring Year								
		1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**Total**
AVC	**Days**	4	3	36	337	331	316	298	352	1,677
	Month	1	1	2	12	12	11	?	?	39
WIM	**Days**	0	0	124	343	149	73	296	352	1,337
	Month	0	0	6	12	5	4	?	?	27

Notes: Month = Number of months for which AVC and WIM data are available.
? = Data could not be obtained.

The five annual monitoring axle load spectra (for 1992 through 1996) are compared in figure 38. Compared to the two annual spectra obtained for the previous case study (figure 33), there is considerable variation between the spectra. The 1995 spectrum is clearly an outlier, and as discussed in connection with Site 12-4000, data in appendix B indicate that some vehicles were misclassified. When interpreting the variation in the annual monitoring axle load spectra, the note included in the description of the case study for Site 12-4000, discussing load spectra for individual vehicle classes, should also be considered. Figure 39 shows that a large percentage of trucks (10 to 20 percent) were not classified and were reported as Class 14. Usually, unclassified vehicles are distributed proportionally across all vehicle classes and are not reported separately in the CTDB. Base annual spectrum was obtained by averaging annual spectra for 1992, 1993, 1994, 1996, and 1997.

Annual ESALs are summarized in table 22 and figure 40. The cumulative number of ESALs for the 15-year period between 1983 and 1997 is about 7.2 million. Site 29-4036 was also used to assess the effect of the quantity of the monitoring data on the precision of traffic load projections discussed at the end of this chapter.

Monthly data summarized in figure 41 are inconclusive for developing monthly distribution factors for the annual load spectra, particularly when considering other data, including monthly spectra given in figure 42. Monthly data were obtained from Level 3 CTDB through the data extraction process described in appendix A. The large differences between the August 1995 and October 1995 load spectra appear to be unjustified.

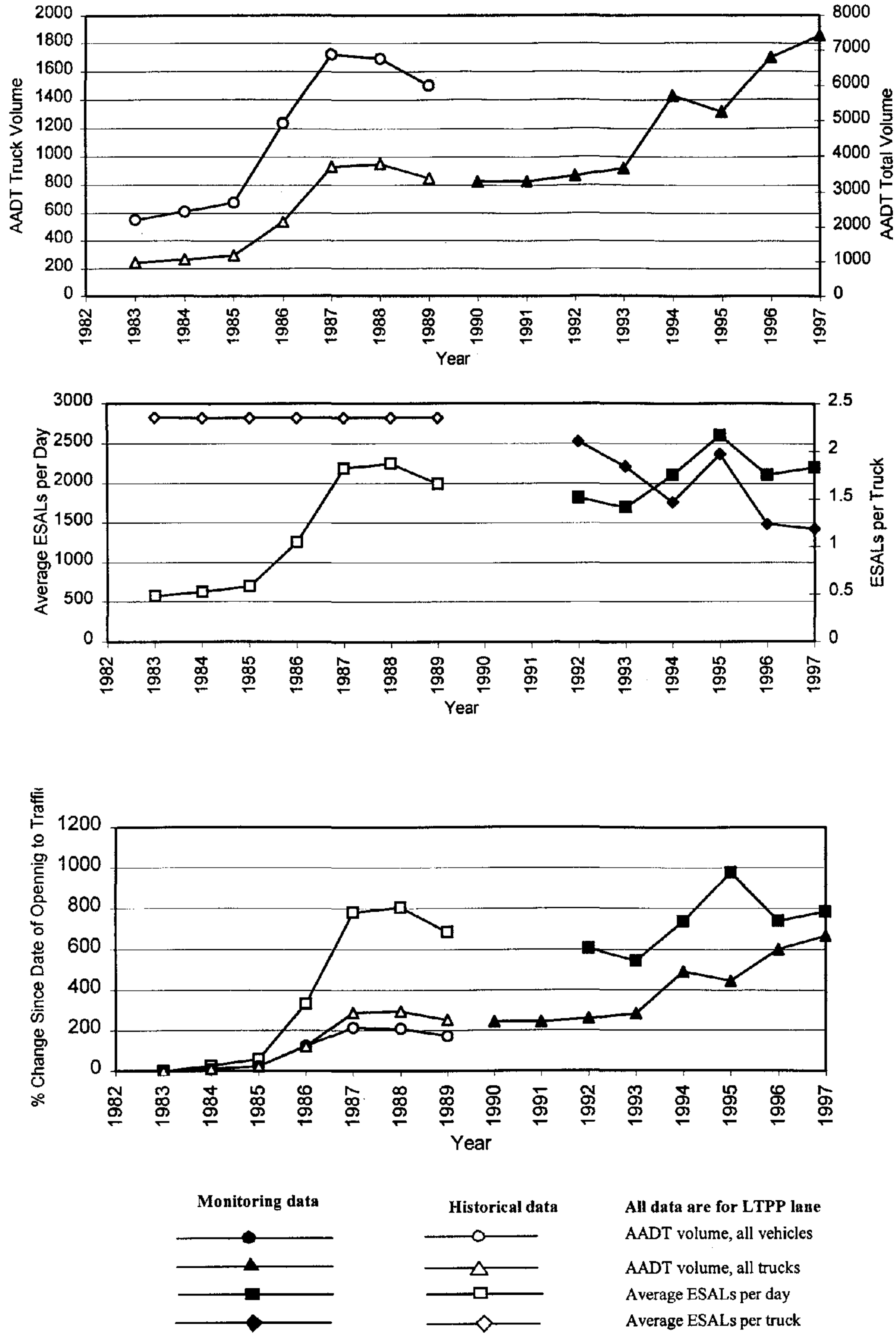


Figure 36. Annual Traffic Data Projection Sheet for Site 29-4036.

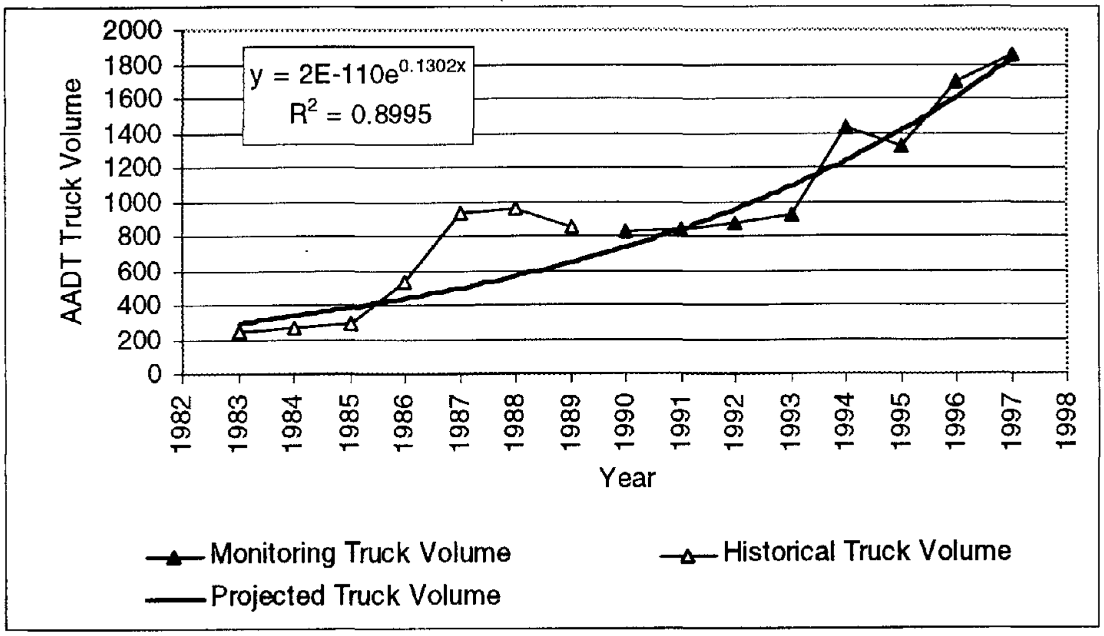
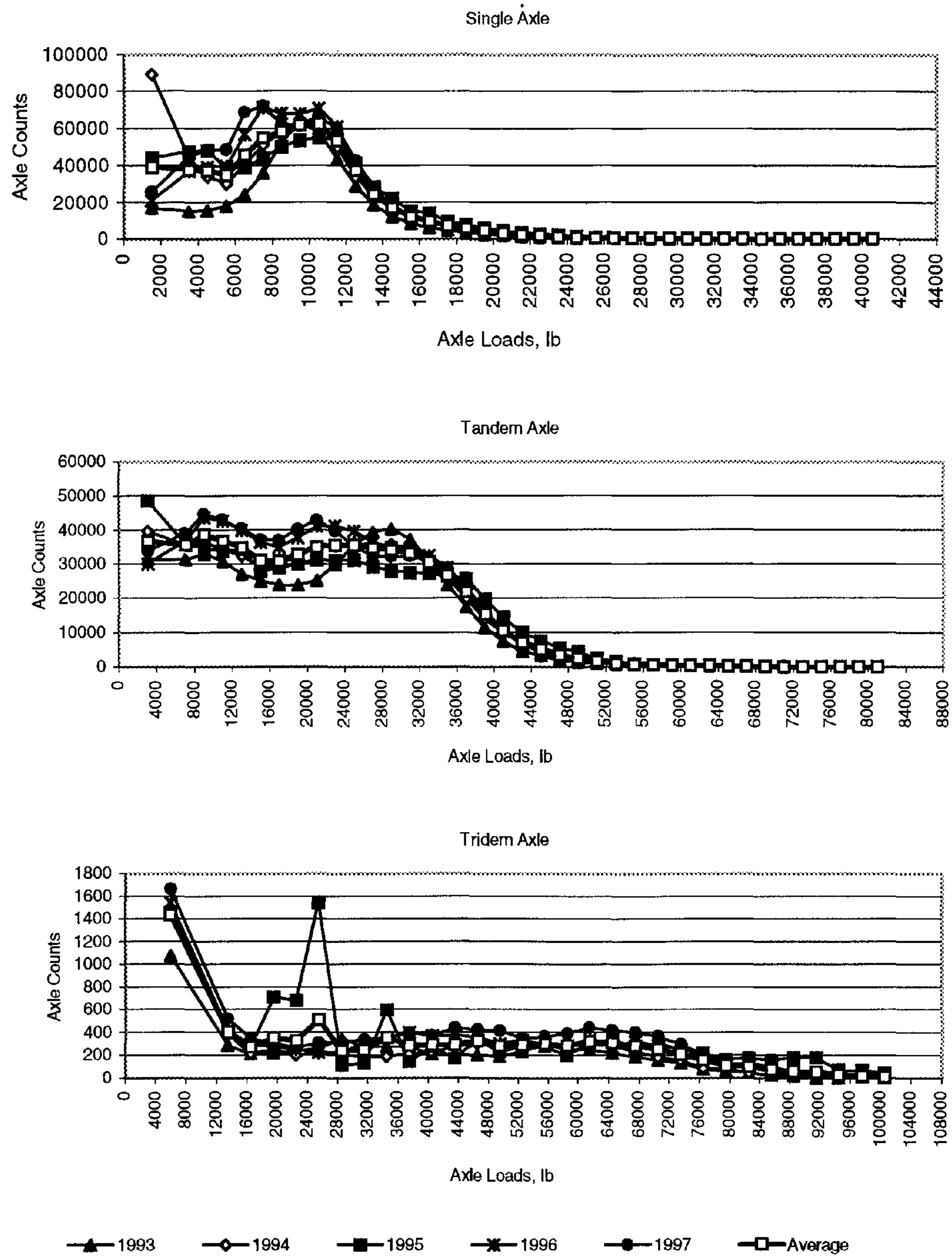


Figure 37. Comparison of truck AADT volumes for Site 29-4036.

Table 21. Comparison of truck AADT volumes for Site 29-4036.

Year	Growth Factor	Projected Truck Volume	Monitoring Truck Volume	Historical Truck Volume
1983	0.21	289		242
1984	0.24	330		266
1985	0.27	375		295
1986	0.31	428		535
1987	0.35	487		932
1988	0.40	555		954
1989	0.46	632		848
1990	0.52	720	826	
1991	0.59	820	831	
1992	0.68	934	868	
1993	0.77	1064	919	
1994	0.88	1212	1430	
1995	1.00	1380	1317	
1996	1.14	1572	1700	
1997	1.30	1791	1856	



1 lb = 0.00445 kN

Figure 38. Comparison of load spectra for Site 29-4036.

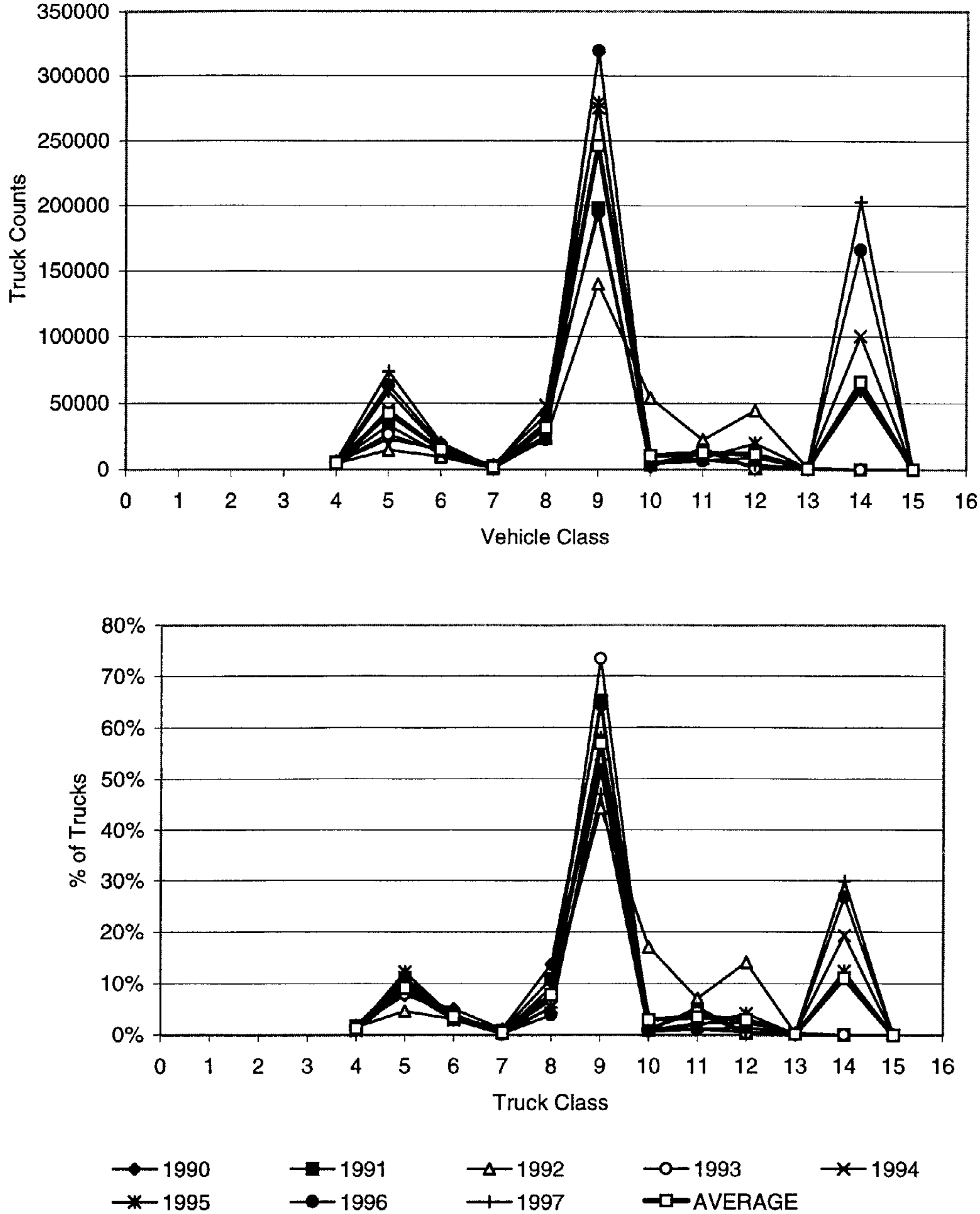


Figure 39. Truck distribution by class for Site 29-4036.

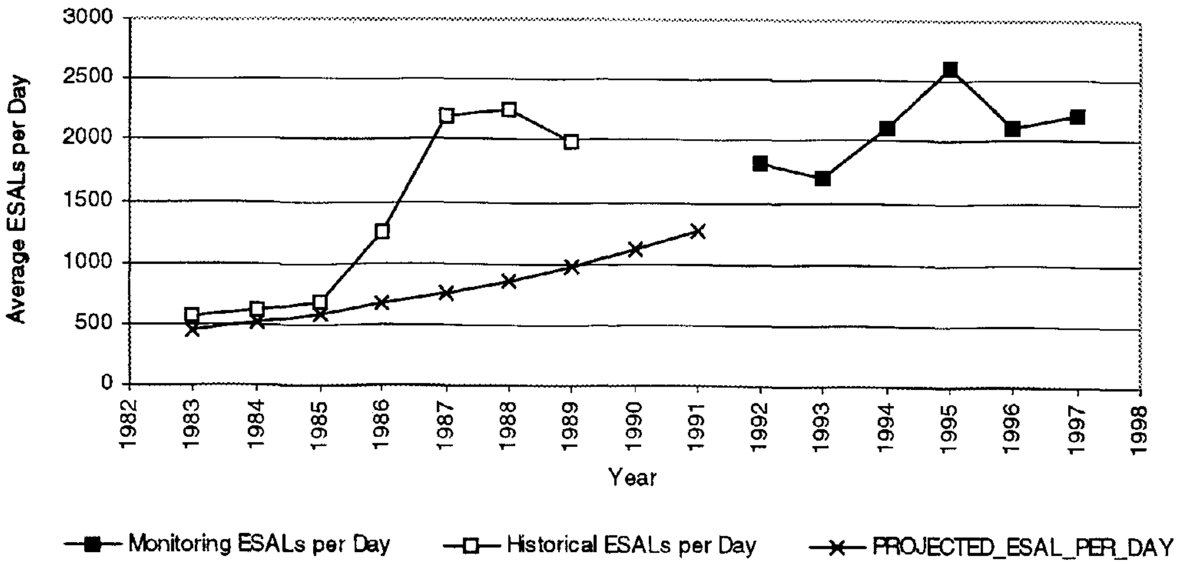


Figure 40. Comparison of ESAL volumes for Site 29-4036.

Table 22. Comparison of ESAL volumes for Site 29-4036.

Year	Monitoring ESALs per Day	Historical ESALs per Day	Projected ESALs per Day
1983		570	449
1984		625	511
1985		693	582
1986		1258	663
1987		2192	756
1988		2244	861
1989		1995	980
1990			1117
1991			1272
1992	1824		
1993	1698		
1994	2102		
1995	2603		
1996	2109		
1997	2203		

Cumulative ESALs = 7,201,762

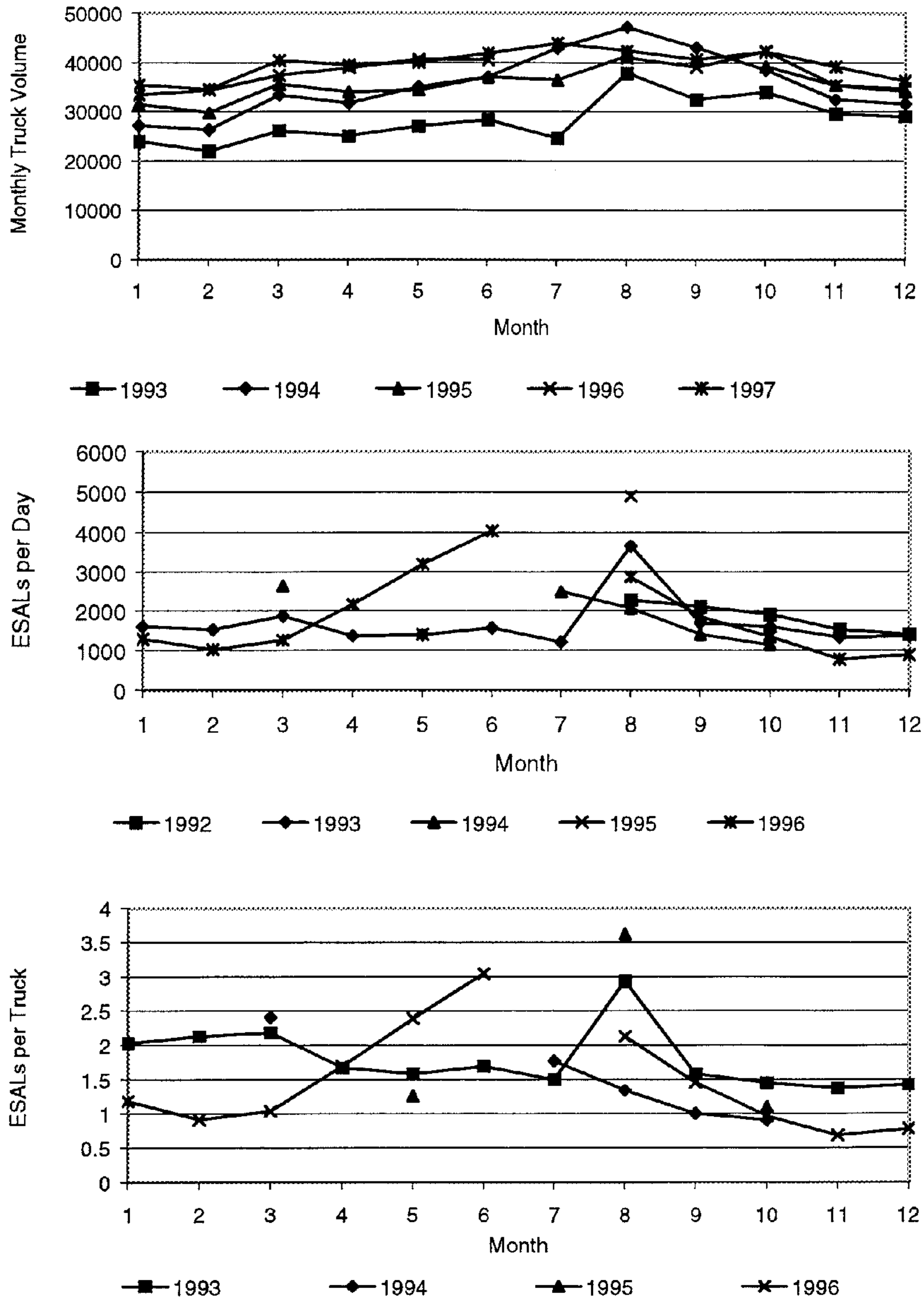
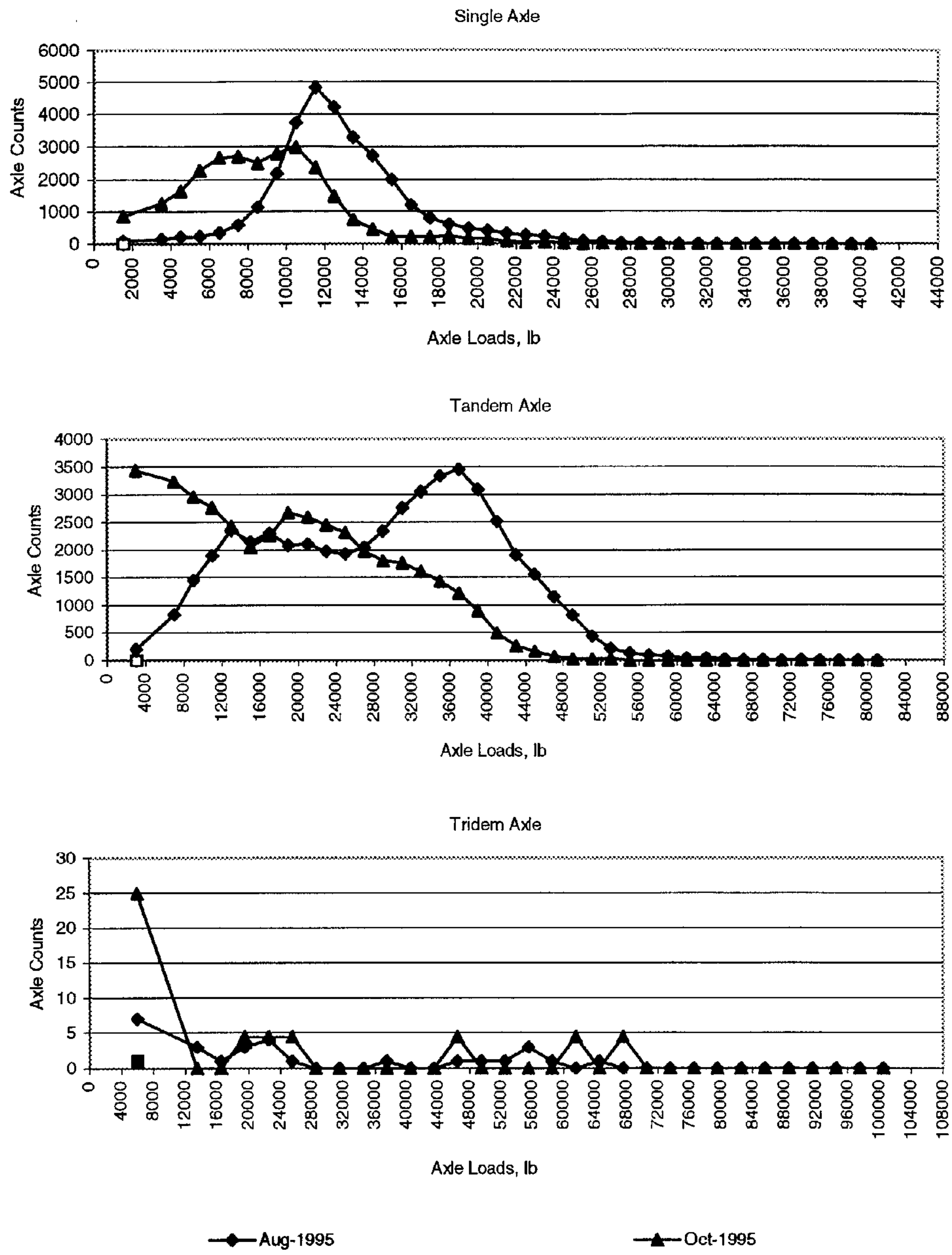


Figure 41. Comparison of monthly traffic variations for Site 29-4036.



1 lb = 0.00445 kN

Figure 42. Comparison of annual load spectra for Site 29-4036.

In summary, the extensive AVC and WIM monitoring data, and a matching trend for historical and monitoring truck volumes, provide some degree of confidence for traffic projections. It is also evident that AVC and WIM equipment were not always calibrated.

SUMMARY OF CASE STUDIES FOR CATEGORY 2

Category 2 sites include LTPP sites that have AVC and WIM monitoring data.

Site 04-1002

Site 04-1002 is located on Interstate 40, about 72 km (45 mi) west of Flagstaff, Arizona. This site was selected primarily to illustrate the potential benefits of using site-related monitoring data. For sensitivity analysis purposes, traffic projections for this site were done twice—as a Category 2 site (utilizing site-related WIM monitoring data) and as a Category 4 site (disregarding site-related WIM data). The results show the importance of locating nearby traffic monitoring sites and using site-related or surrogate data when warranted.

Site 05-3059

Site 05-3059 was used to illustrate the step-by-step procedure for conducting case studies in chapter 4 and is not discussed again in this chapter.

Site 29-5483

Site 29-5483 is located on a two-lane rural principal arterial highway about 32 km (20 mi) northeast of Kansas City, Missouri. This case study serves as an example of problems created by unreliable WIM data and is also used to illustrate the effect of different growth rates on traffic projections.

DESCRIPTION OF CASE STUDIES FOR CATEGORY 2

Site 04-1002

The location of Site 04-1002 is shown in figure 15. It is a rural, remote location on Interstate 40 about 72 km (45 mi) west of Flagstaff, Arizona. West of the site on Interstate 40 are six other LTPP sites (shown as dark squares in figure 15). There are no large truck traffic destinations along this stretch of I-40.

The available AVC and WIM monitoring data for this site, and the two closest adjacent sites (04-1024 and 04-1025) are summarized in table 23. The Annual Traffic Data Projection Sheet (figure 43) shows monitoring truck volumes to be about 60 percent lower than the historical truck volumes. Load spectra available for this section also appear to be questionable. In view of the close proximity to other LTPP sites, we have investigated the possibility of using their monitoring traffic data for traffic projections at this site.

Table 23. Monitoring data available for Site 04-1002.

Parameter		1993			1994			1995		1996	Total
Site No.		1002	1024	1025	1002	1024	1025	1024	1025	1024	
AVC	Days	92	45	157	175	229	204	185	94	269	1,450
	Month	4	2	7	?	?	?	7	4	?	24
WIM	Days	16	16	40	0	0	22	0	0	0	94
	Month	1	1	2	?	?	?	0	0	?	4

Notes: Month = Number of months for which AVC and WIM data are available.
? = Data could not be obtained.

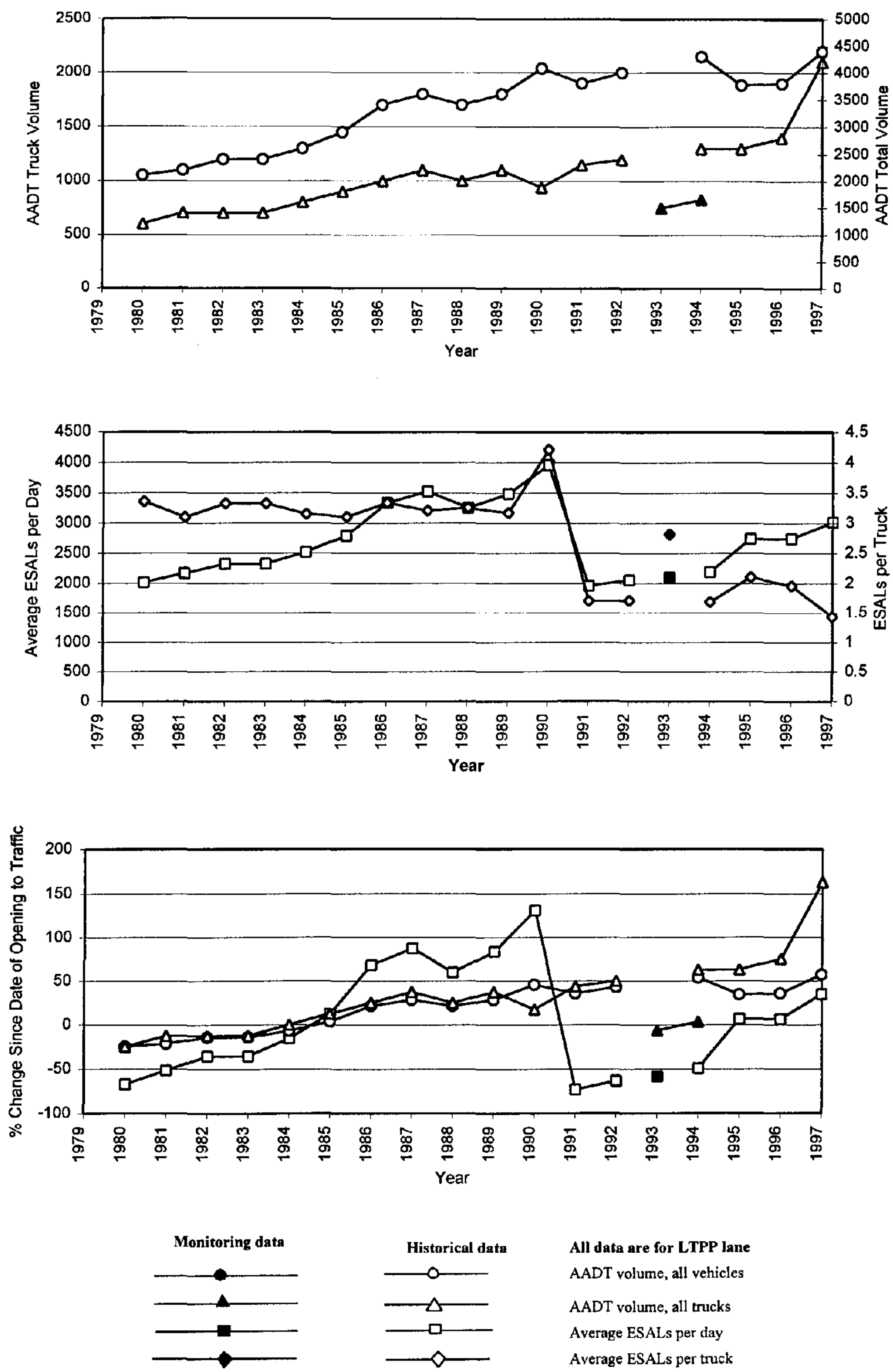


Figure 43. Annual Projection Data Sheet for Site 04-1002.

The evaluation of historical and monitoring truck volume and ESAL data given in table 24 indicates that the monitoring truck volumes obtained for Site 04-1002 are about half of those reported for the nearby sites. Considering the absence of major truck destinations, the truck volumes on all the sites listed in table 24 should be roughly equal.

Table 24. Comparison of 1993 data for nearby sites.

LTPP Site	1993 Traffic Data in LTPP Lane				
	AADT All Vehicles	**AADT Trucks, Historical**	**AADT Trucks, Monitoring**	**ESALs per Day**	**ESALs per Truck**
04-1002	4,100	1,250	750	2,050	2.9
04-1021	4,300	1,600	N/A	N/A	N/A
04-1022	4,300	1,600	N/A	N/A	N/A
04-1024	4,000	1,550	1,650	2,550	1.5
04-1025	4,100	1,500	1,500	2,450	1.5
04-1062	4,000	1,500	1,600	3,000	1.9
04-1065	4,000	1,500	1,650	1,500	1.0

N/A - Not Available

Annual growth factors were established by fitting a trend line with a 7.6-percent simple growth rate through historical traffic volumes (figure 44 and table 25). After the assessment of annual load spectra for the nearby sites, the base spectrum was obtained as an average of the 1993 load spectrum for Site 04-1024, and 1993 and 1994 load spectra for Site 04-1025 (figure 45). The difference in the 1993 annual load spectrum obtained for Site 04-1002 (only one year of WIM data was available for this section) and the base annual spectrum used for projection is shown in figure 46. The significantly lower monitoring truck volumes for the section (table 24) are reflected in the significantly lower axle counts (figure 46). Figure 47 shows that the normalized vehicle volume distribution (bottom half of figure 47) was similar on all nearby sites.

Projected annual load spectra were summarized using ESALs, and the result is presented in figure 48 and table 26. Figure 48 and table 26 also show the results of ESAL projections using the Category 4 approach. These results will be discussed in a subsequent section dealing with Category 4 projections.

In summary, by utilizing data from nearby sections, it was possible to project traffic data with increased confidence.

Site 29-5483

Site 29-5483 is located on a rural principal arterial road in Missouri. Available AVC and WIM data are shown in table 27.

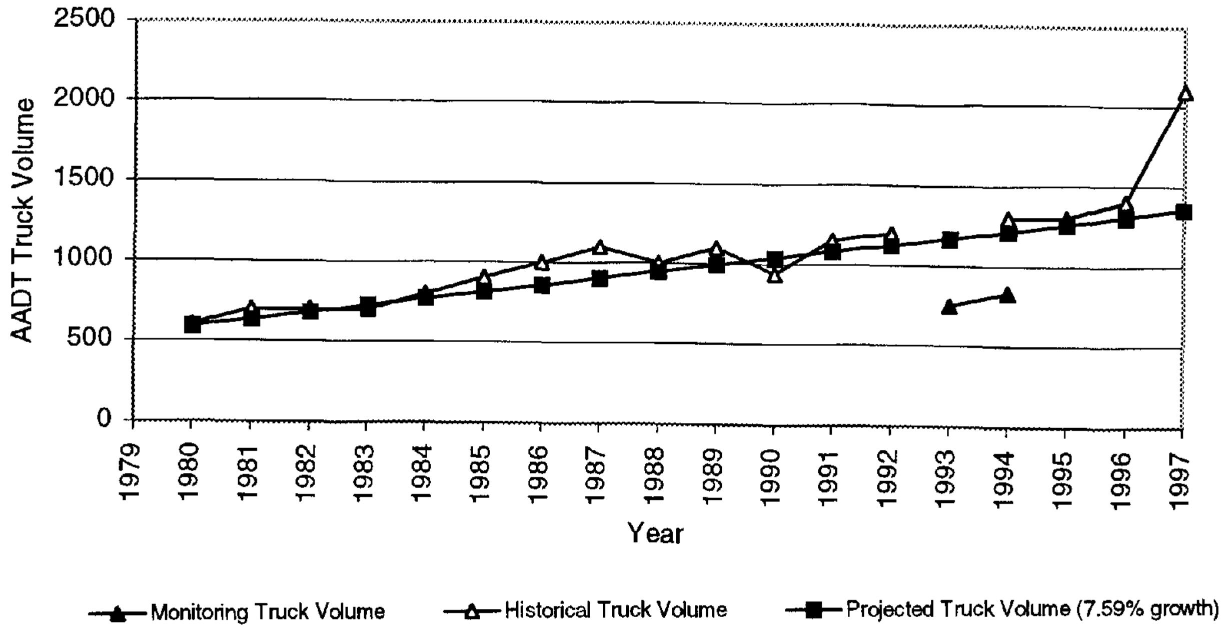
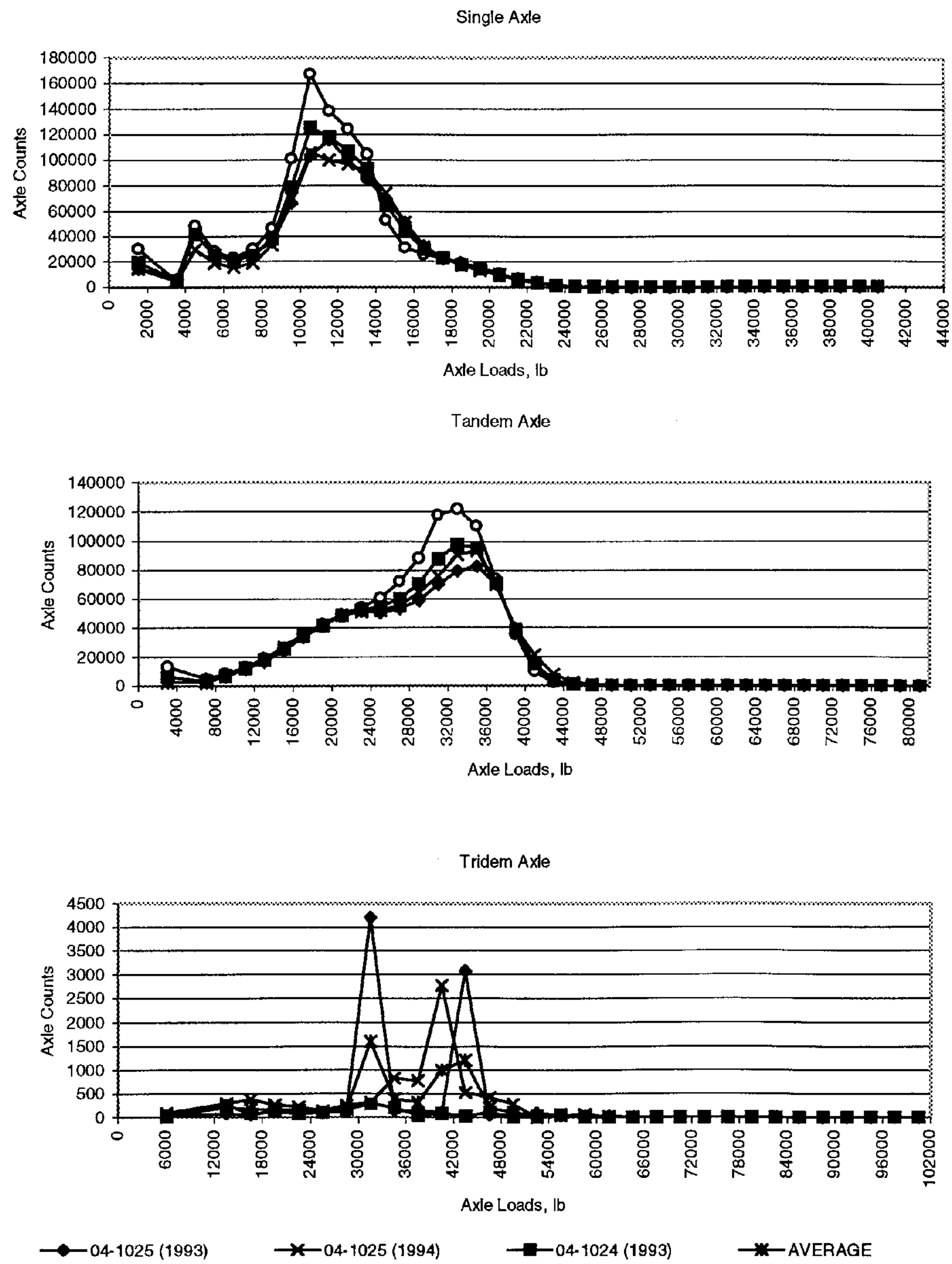


Figure 44. Comparison of truck AADT volumes for Site 04-1002.

Table 25. Comparison of truck AADT volumes for Site 04-1002.

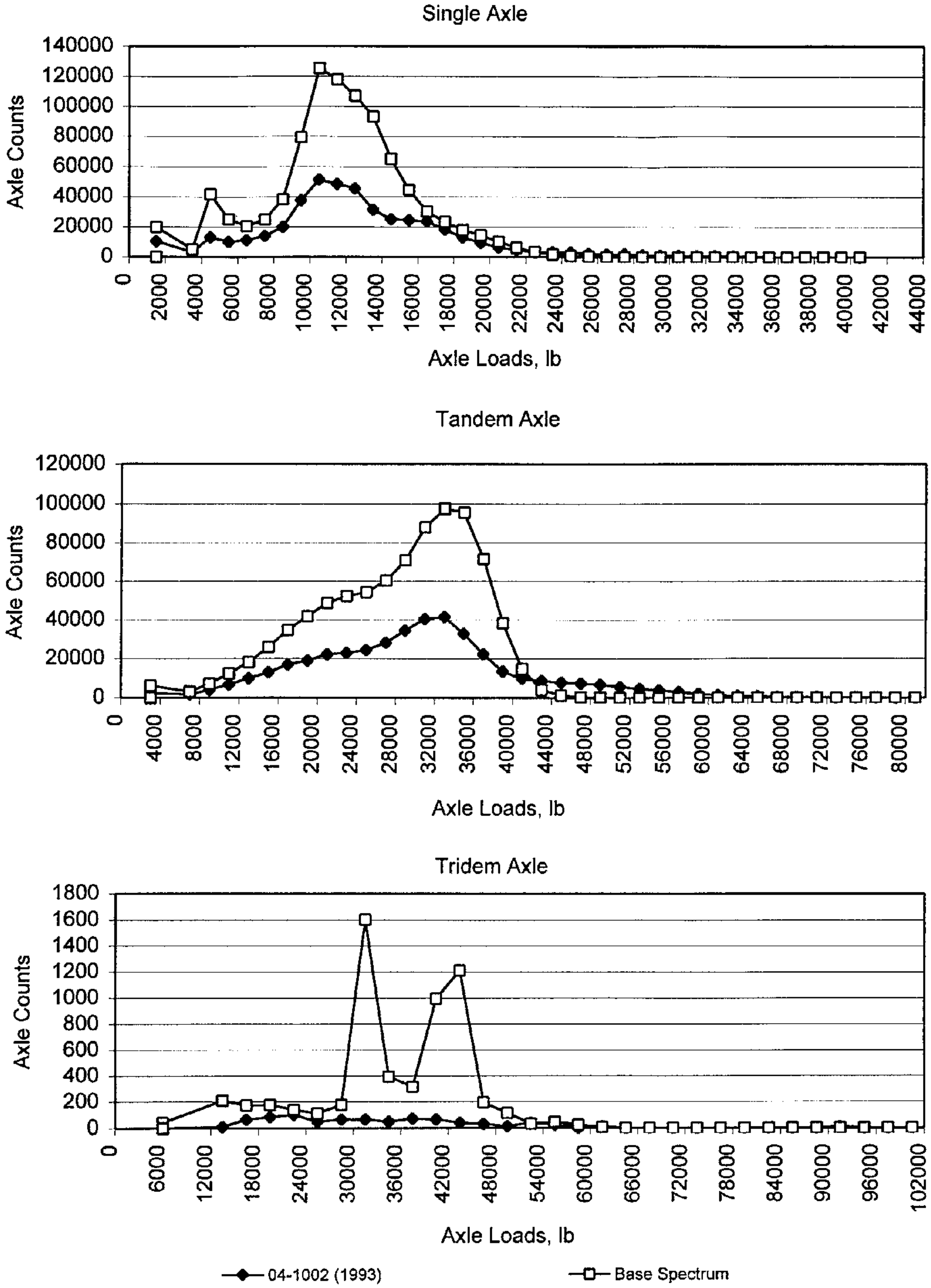
Year	Growth Factor, 7.6%	Projected Truck Volume, 7.6% Growth	Monitoring Truck Volume	Historical Truck Volume
1980	0.48	589		600
1981	0.52	634		700
1982	0.56	679		700
1983	0.60	724		700
1984	0.63	768		800
1985	0.67	813		900
1986	0.71	858		1000
1987	0.74	903		1100
1988	0.78	947		1000
1989	0.82	992		1100
1990	0.85	1037		940
1991	0.89	1082		1150
1992	0.93	1126		1200
1993	0.96	1171	748	
1994	1.00	1216	827	1300
1995	1.04	1261		1300
1996	1.07	1305		1400
1997	1.11	1350		2100

Note: Blank spaces mean that the information was not reported in the IMS database.



1 lb = 0.00445 kN

Figure 45. Load spectra used for computation of the base spectra for Site 04-1002.



1 lb = 0.00445 kN

Figure 46. Load spectra for Site 04-1002 for 1993 and base spectra.

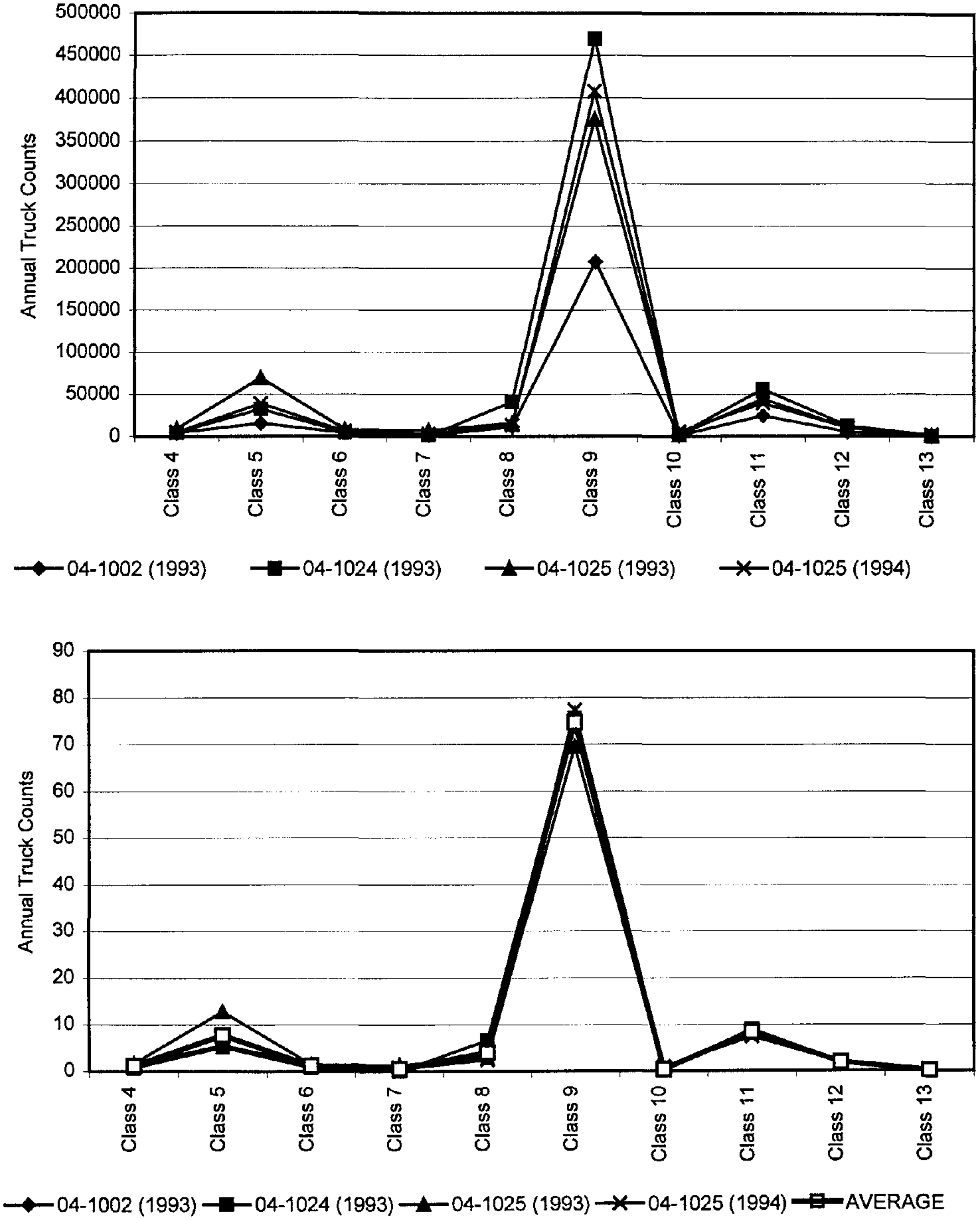


Figure 47. Annual truck count distribution by class for Sites 04-1002, 04-1024, and 04-1025.

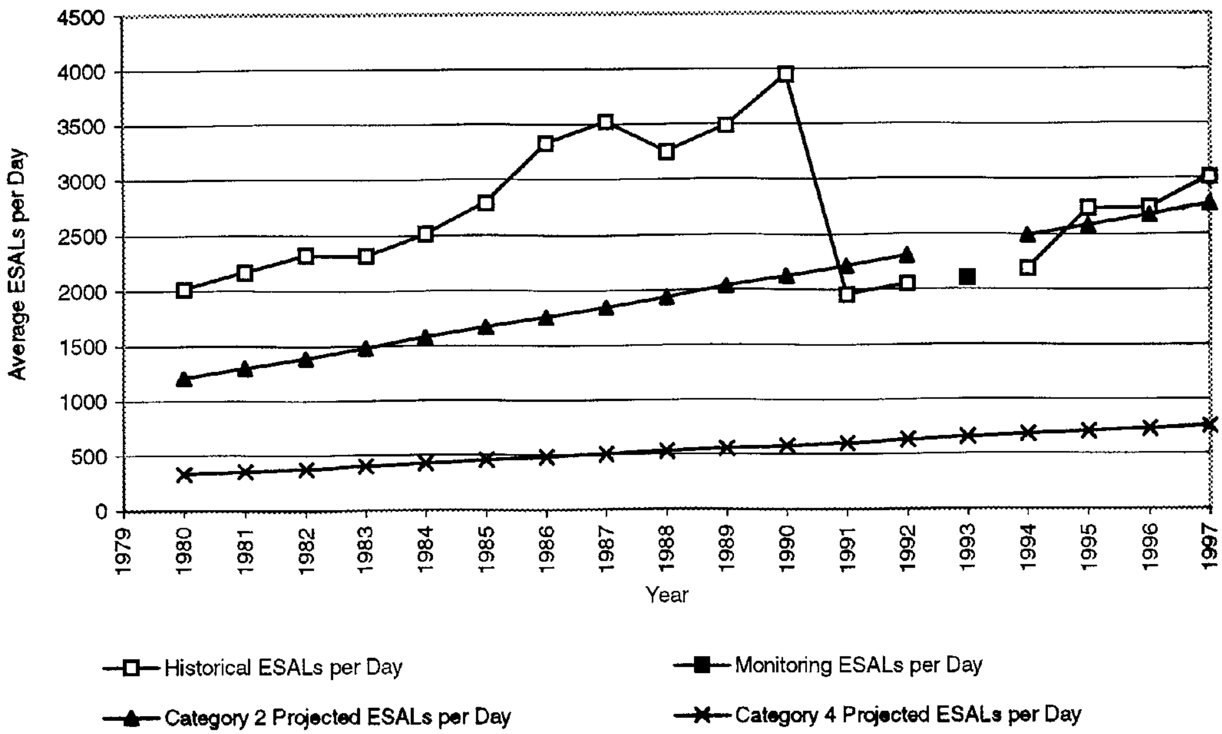


Figure 48. Comparison of annual ESAL projections for Site 04-1002.

Table 26. Cumulative ESALs computation sheet for Site 04-1002.

Year	Historical ESALs per Day	Monitoring ESALs per Day	Category 2 Projected ESALs per Day	Category 4 Projected ESALs per Day
1980	2016		1209	330
1981	2170		1300	355
1982	2326		1392	380
1983	2326		1484	405
1984	2521		1576	430
1985	2792		1667	455
1986	3334		1759	480
1987	3526		1851	505
1988	3255		1943	530
1989	3488		2034	555
1990	3953		2126	580
1991	1959		2218	605
1992	2055		2310	630
1993		2104	2104	655
1994	2192		2493	680
1995	2740		2585	705
1996	2740		2677	730
1997	3014		2768	755

Cumulative ESALs for Category 2 = 12,956,011
Cumulative ESALs for Category 4 = 3,565,068

Table 27. Monitoring data available for Site 29-5483.

Data Type		Monitoring Year								
		1990	1991	1992	1993	1994	1995	1996	1997	Total
AVC	Days	4	0	0	311	278	297	363	348	1,601
	Month	1	0	0	11	12	10	?	?	34
WIM	Days	5	0	6	14	14	36	7	24	106
	Month	1	0	2	2	2	5	?	?	12

Notes: Month = Number of months for which AVC and WIM data are available.
? = Data could not be obtained.

Monitoring truck volumes shown in figure 49 have been increasing more rapidly than the historical truck volumes. Because of this discrepancy, we have used two alternative growth rates, as shown in figure 50 and table 28. The declining ESALs, in view of increasing truck volumes, are caused by the precipitous drop in axle weights (figure 49). This site is yet another example of the need to involve SHAs in the traffic projection process.

Figure 51 shows annual axle load spectra for all monitoring years. There is a large unexpected variation in the spectra, considering that this site has a relatively high AADT of about 4,000. The assessment of the spectra revealed that the annual spectra for this site formed two clusters, one for 1992/1993 and the second for 1995 through 1997. The two sets of spectra are shown in figures 52 and 53, and their averages are compared in figure 54. Spectra for 1992/1993, unlike 1995 through 1997 spectra, show a typical bi-modal distribution for tandem axles, with the second peak at about 142 kN (32,000 lb). For this reason, the average of 1992/1993 spectra was selected as the base spectrum. Vehicle class distribution comparing 1992/1993 spectra with 1995 through 1997 spectra is shown in figure 55. The differences observed between load spectra in figure 54 are also visible in figure 55.

The projected spectra were summarized using ESALs, and the results are given in figure 56 and table 29. The difference in growth rates (2.1 percent versus 9.9 percent) was significant (5.5 million versus 4.3 million). There is a considerable difference (about 100 percent) between projected ESALs and monitoring ESALs for 1992/1993, even though the base spectra were obtained as an average of the 1992/1993 spectra. The computational audit of our procedure did not reveal the cause of this discrepancy that was attributable to the traffic projection procedure used. However, when we duplicated ESAL calculations done in the CTDB, the resulting ESALs were exactly two times higher than those reported in the CTDB summary table. This leads us to believe that ESALs reported in a CTDB monitoring data summary table and the ESALs calculated using monitoring spectra given in the CTDB are conflicting.

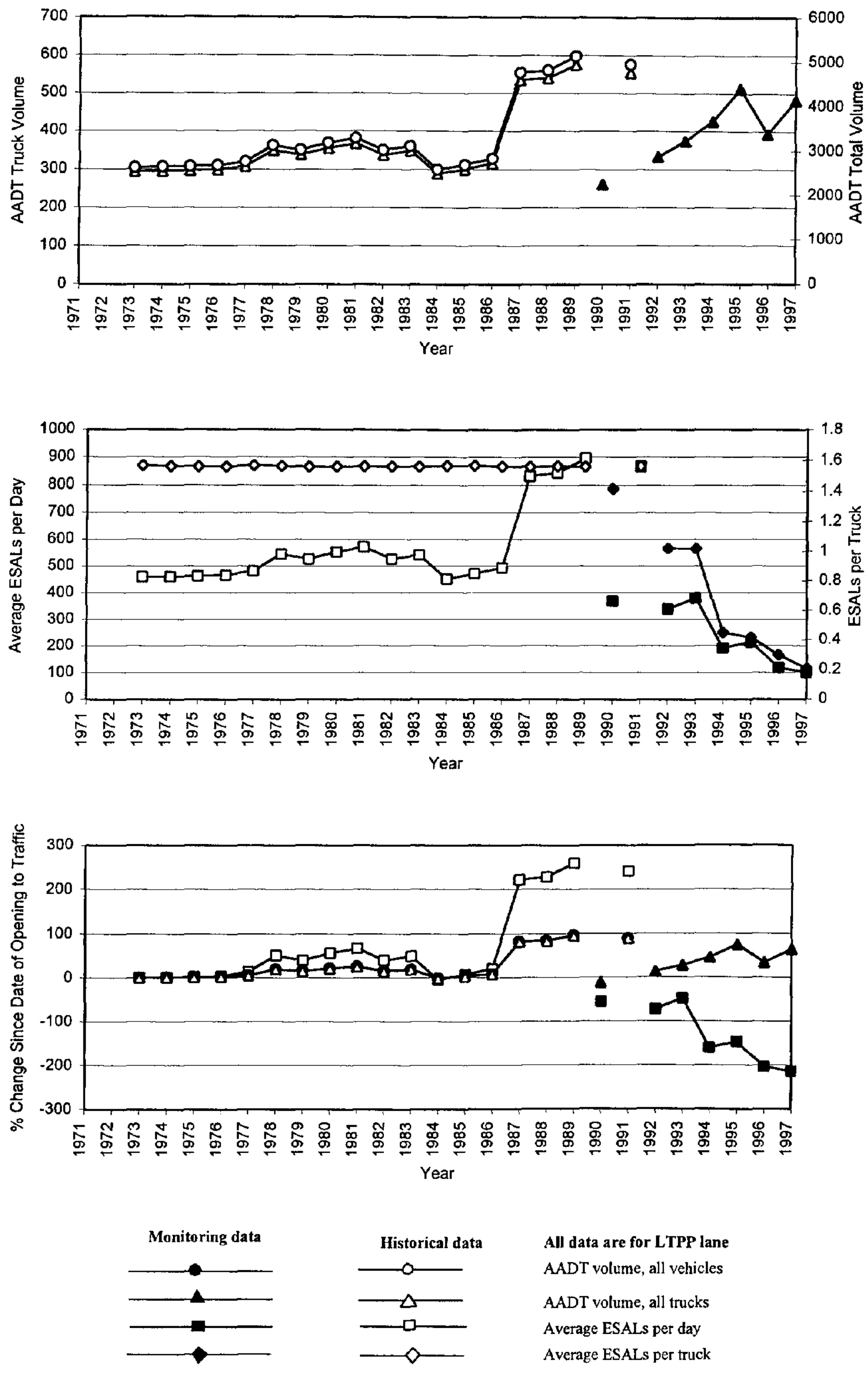


Figure 49. Annual Projection Data Sheet for Site 29-5483.

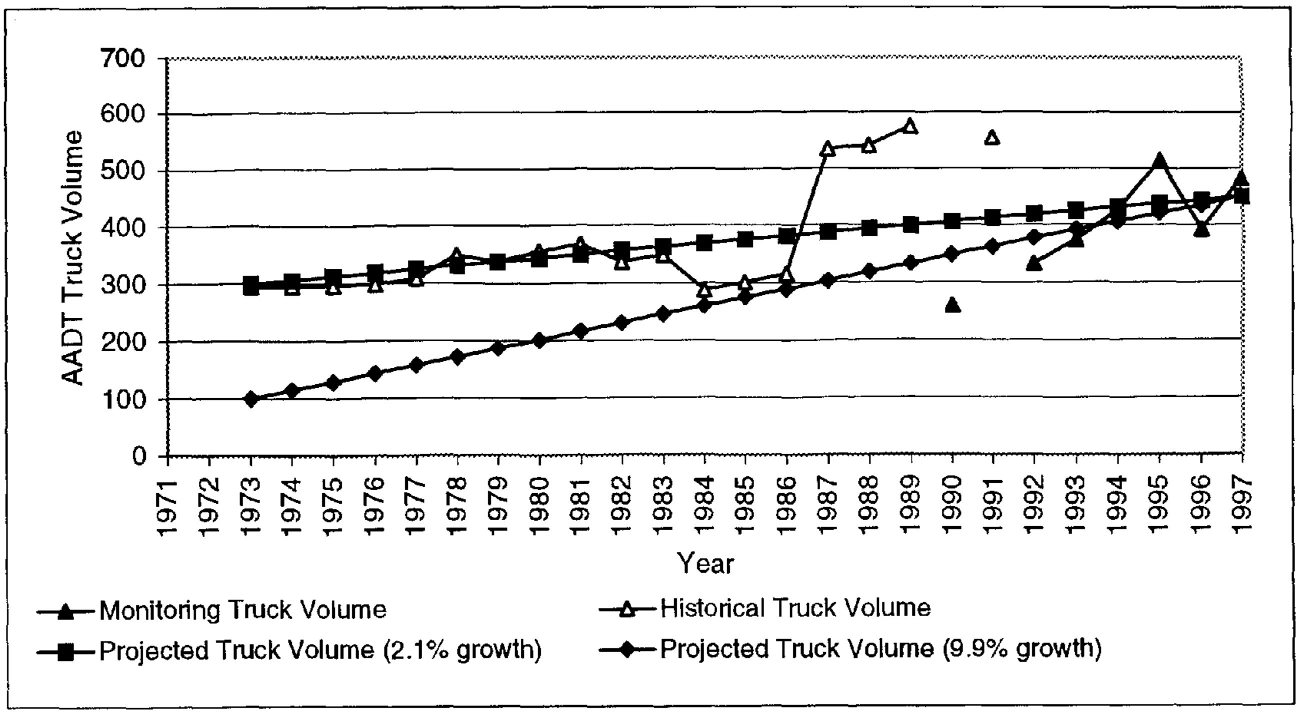
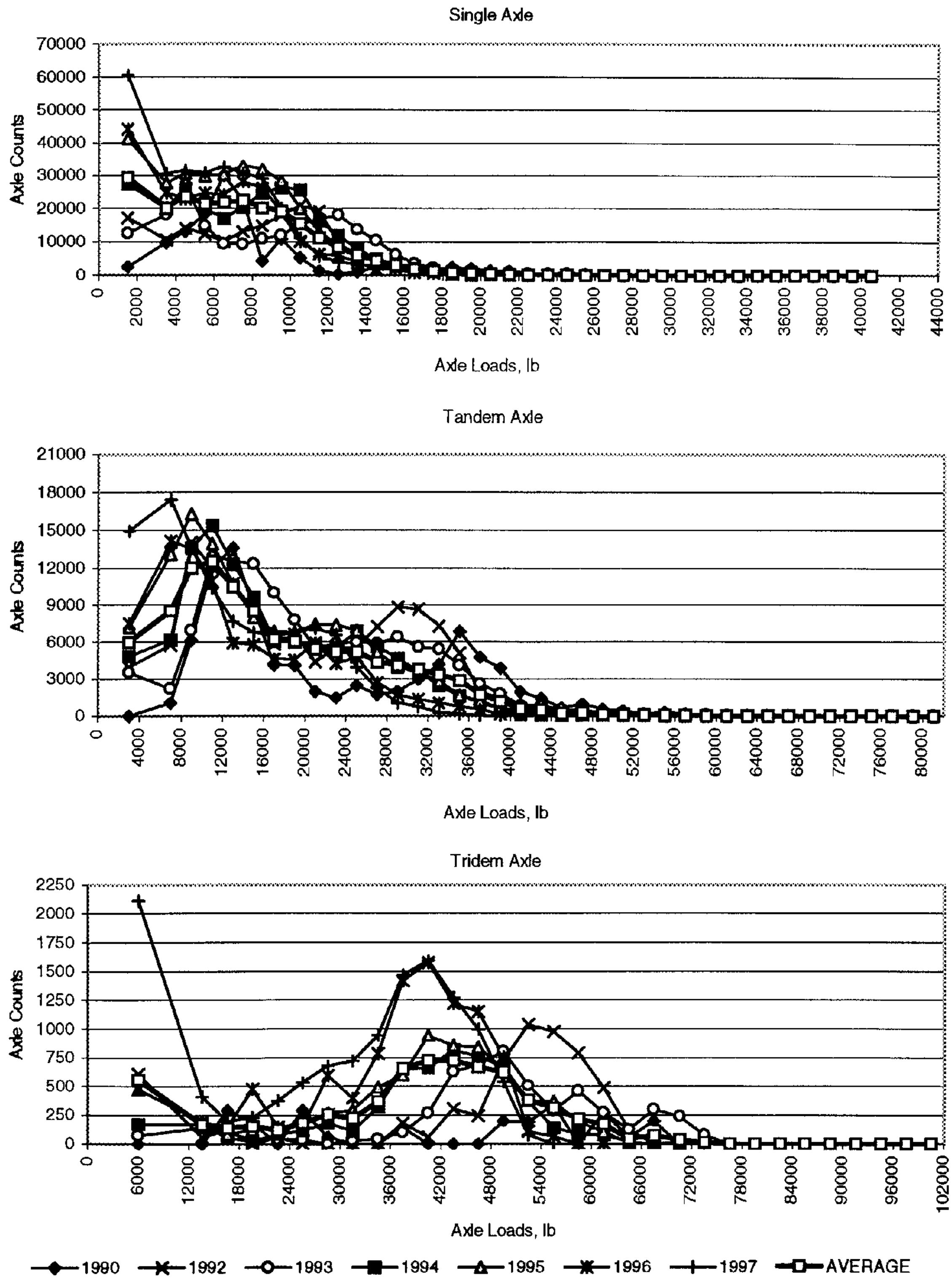


Figure 50. Projected total truck volumes for Site 29-5483.

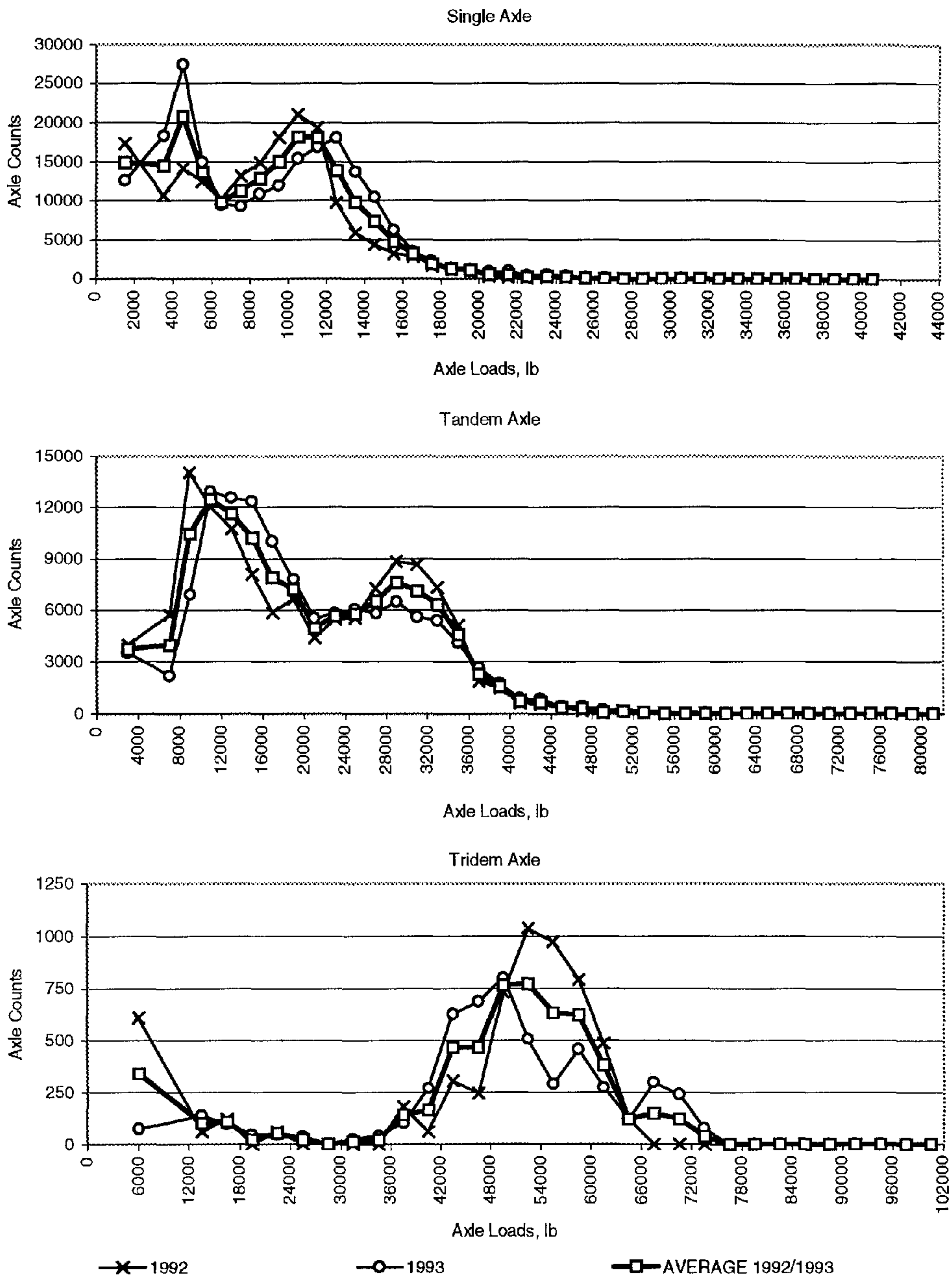
Table 28. Comparison of truck AADT volumes for Site 29-5483.

Year	Growth Factor, 2.1%	Projected Truck Volume, 2.1%	Growth Factor, 9.9%	Projected Truck Volume, 9.9%	Monitoring Truck Volume	Historical Truck Volume
1973	0.71	300	0.26	100		294
1974	0.72	306	0.29	115		295
1975	0.74	312	0.33	129		297
1976	0.75	319	0.37	144		299
1977	0.76	325	0.40	158		308
1978	0.78	331	0.44	173		349
1979	0.79	337	0.48	187		338
1980	0.81	344	0.52	202		355
1981	0.82	350	0.55	217		367
1982	0.84	356	0.59	231		337
1983	0.85	362	0.63	246		348
1984	0.87	369	0.66	260		289
1985	0.88	375	0.70	275		301
1986	0.90	381	0.74	290		316
1987	0.91	387	0.78	304		534
1988	0.93	394	0.81	319		540
1989	0.94	400	0.85	333		575
1990	0.96	406	0.89	348	260	
1991	0.97	412	0.93	362		555
1992					333	
1993					374	
1994	1.01	431	1.04	406	425	
1995	1.03	438	1.07	421	513	
1996	1.04	444	1.11	435	393	
1997	1.06	450	1.15	450	482	



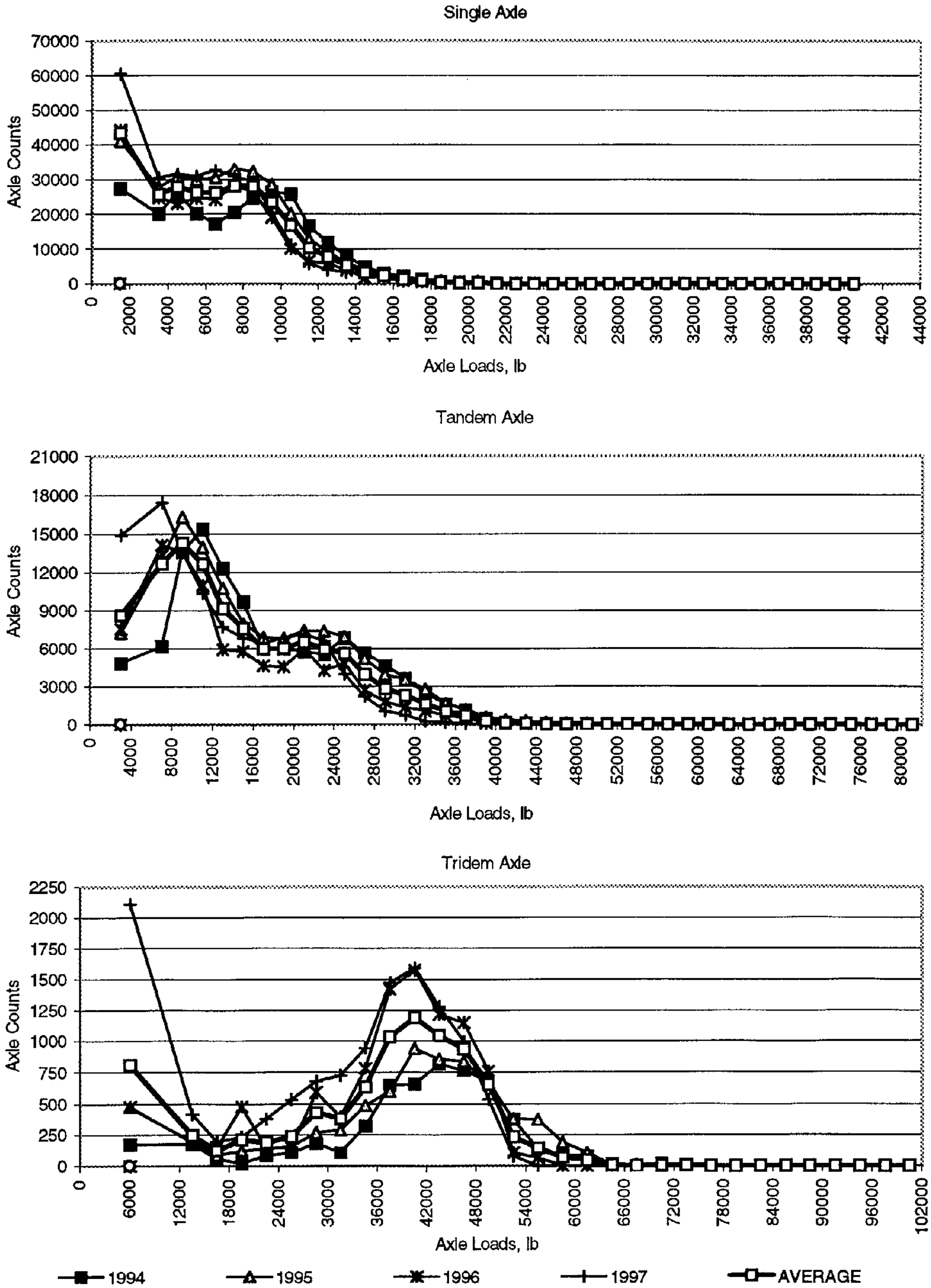
1 lb = 0.00445 kN

Figure 51. Load spectra for Site 29-5483 for all monitoring years.



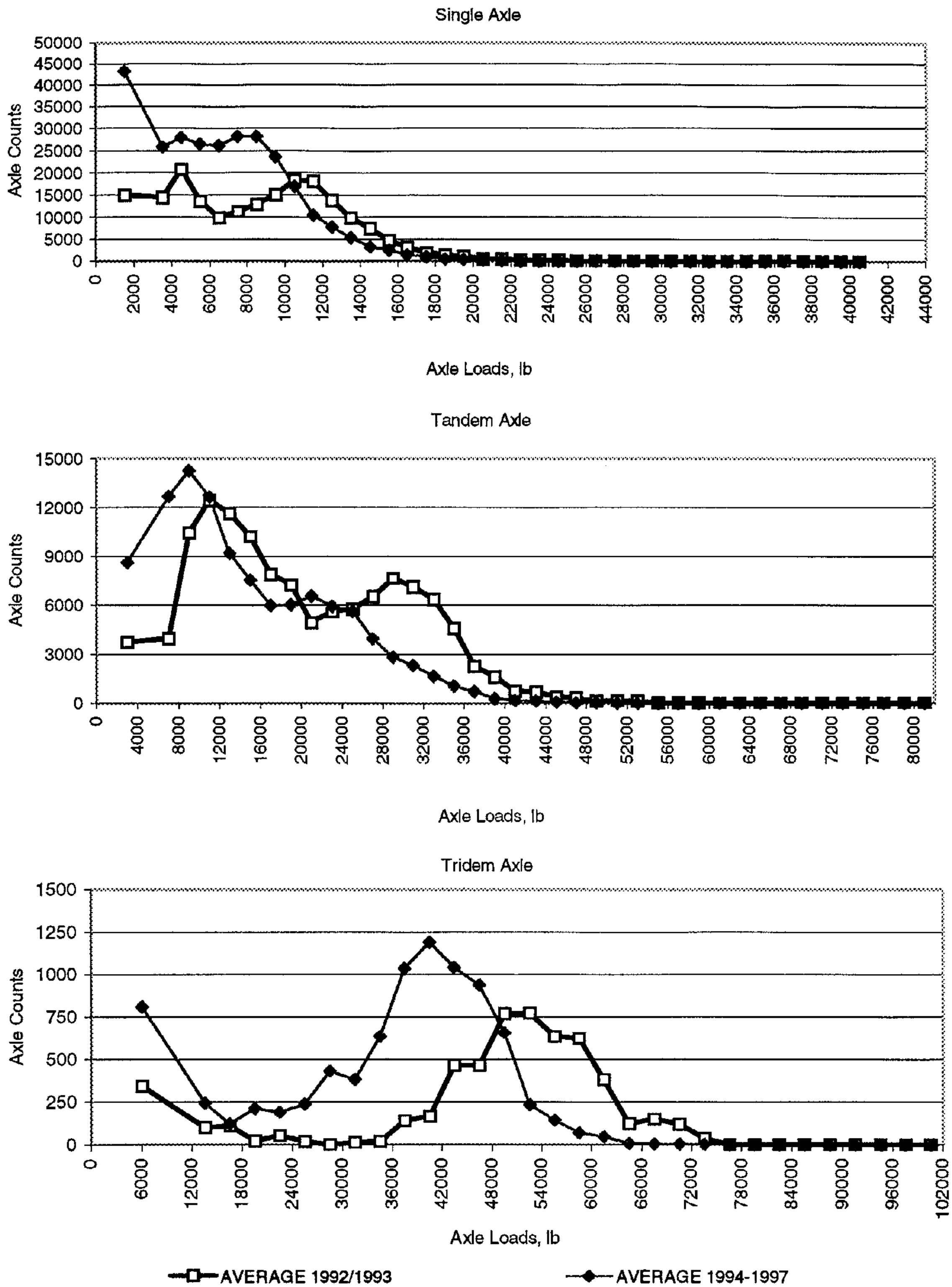
1 lb = 0.00445 kN

Figure 52. Load spectra for Site 29-5483 for 1992/1993.



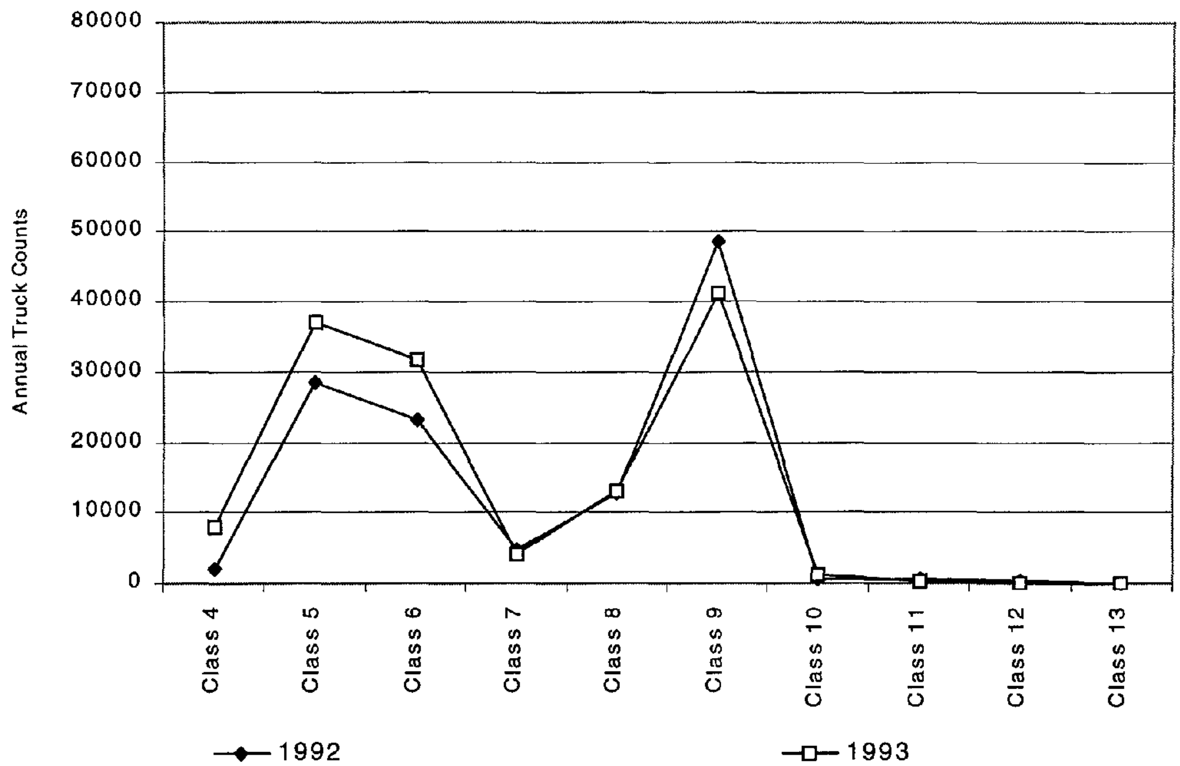
1 lb = 0.00445 kN

Figure 53. Load spectra for Site 29-5483 for monitoring years 1994 through 1997.



1 lb = 0.00445 kN

Figure 54. Comparison of average load spectra based on the years 1992/1993 and 1994 through 1997 for Site 29-5483.



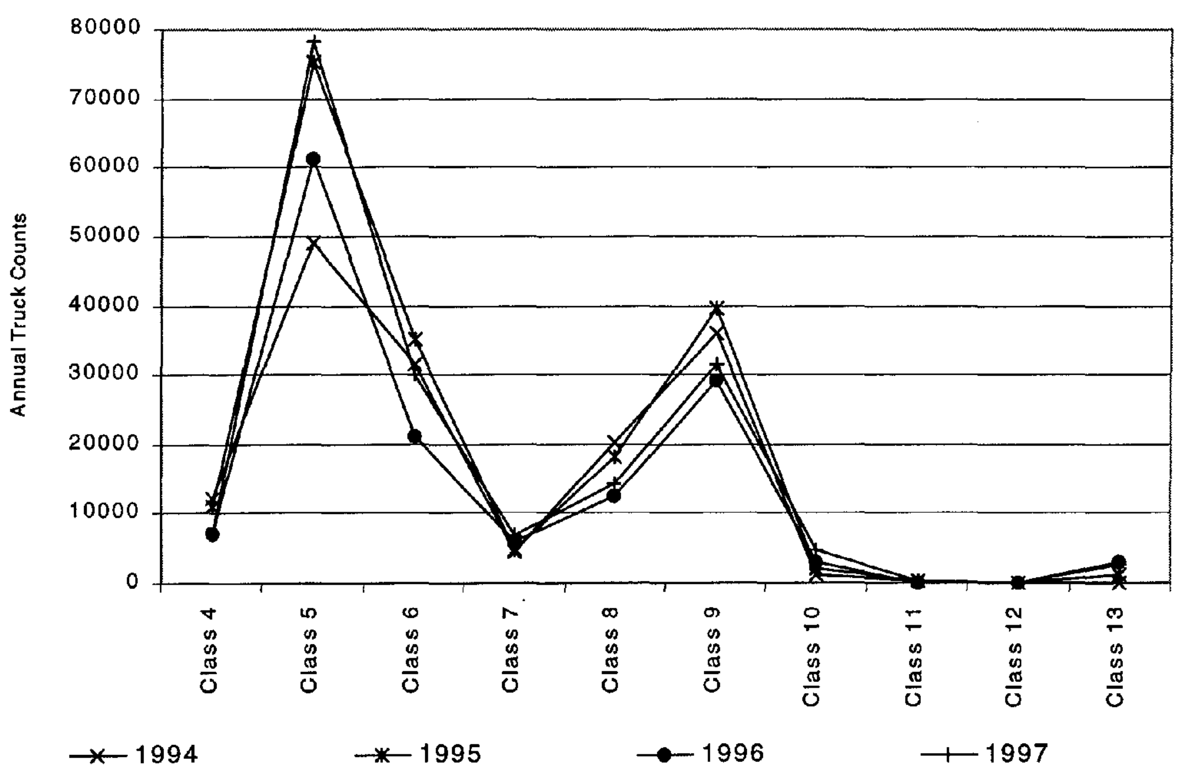


Figure 55. Annual truck count distribution by class for 1992/1993 and 1994 through 1997 for Site 29-5483.

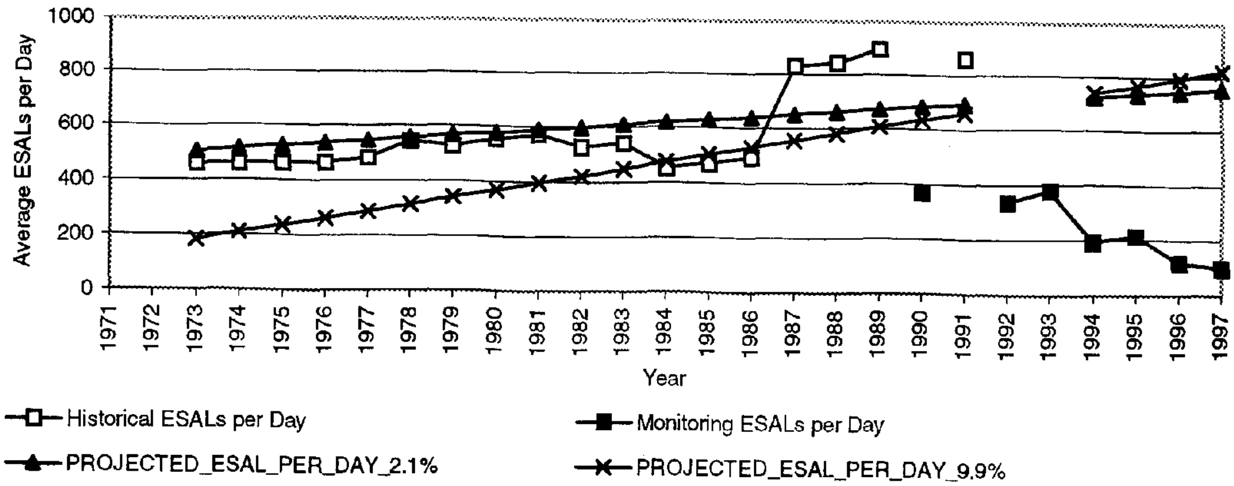


Figure 56. Annual ESAL projections for Site 29-5483.

Table 29. Cumulative ESALs computation sheet for Site 29-5483.

Year	Historical ESALs per Day	Monitoring ESALs per Day	Projected ESALs per Day, 2.1% Growth	Projected ESALs per Day, 9.9% Growth
1973	460		505	183
1974	460		515	209
1975	463		526	236
1976	466		536	262
1977	482		547	289
1978	545		557	316
1979	526		568	342
1980	553		578	369
1981	573		589	396
1982	526		600	422
1983	542		610	449
1984	452		621	476
1985	471		631	502
1986	493		642	529
1987	833		652	555
1988	844		663	582
1989	896		673	609
1990		368	684	635
1991	866		694	662
1992		339	705	662
1993		380	715	662
1994		191	726	742
1995		214	736	768
1996		117	747	795
1997		99	757	822

Cumulative ESALs for 2.1% Growth = 5,758,452 **Cumulative ESALs for 9.9% Growth = 4,553,071**

In summary, the most disturbing aspect and cause for concern is the steep (200 percent) decline in monitored axle loads between 1993 and 1997. We hope this concern can be addressed effectively by consulting the SHA.

SUMMARY OF CASE STUDIES FOR CATEGORY 3

Category 3 represents LTPP sections with solid AVC data but virtually no site-specific WIM monitoring data. Consequently, in order to obtain the base annual spectrum, a representative surrogate axle load spectrum for the 10 truck classes are required. As discussed previously in connection with the evaluation of axle load spectra for Category 1 case study sites (refer to the note for Case Study Site 12-4000), the load spectra for the individual truck classes for all three Category 1 sections were evaluated and the set of load spectra from Site 27-0501 was selected to be used for Category 3 and 4 projections. The objective was to select a set of spectra without obvious discrepancies. The selected Site 27-0501 spectra are given in appendix B (figures 155 through 164 and 168 through 177). Admittedly, the use of site-related spectra for Category 3 and 4 projections is preferable. However, the search for site-related spectra requires extensive and time-consuming processing of Level 2 CTDB data. The selection of the most suitable set of load spectra for individual vehicles would be greatly facilitated by developing a catalog of candidate spectra.

Site 37-3807

Site 37-3807 is located on a rural principal arterial highway in North Carolina. Interestingly, this section is not included in a table summarizing the availability of monitoring data (TRE_MONITOR_BASIC_INFO IMS release 9.7, June 1999). However, a table containing truck class distribution (TRE_MONITOR_VEHICLE_DISTRIB) contains monitoring AC data for this site for 1993 through 1995. Otherwise, the section provides a typical example of a Category 3 projection.

Site 48-5287

Site 48-5287 is located on an urban Interstate in Texas. In one year during the monitoring period, the truck volume dropped by more than 100 percent from its expected value. Either the monitoring value is incorrect or the LTPP lane was closed for half of the year. Only contact with the SHA can provide the answer. Otherwise, there is a good match between historical and monitoring annual truck volumes.

Site 55-3012

Site 55-3012 is located on a rural minor arterial highway in Wisconsin. Considering the low traffic volumes on this highway, there is a reasonable fit between the historical and monitoring truck volumes. It is interesting to note that the historical truck volumes were reported to be steadily increasing in a zig-zag pattern.

DESCRIPTION OF CASE STUDIES FOR CATEGORY 3

Site 37-3807

There were 161, 189, and 231 days of AVC monitoring data during 1993, 1994, and 1995, respectively. The Annual Traffic Data Projection Sheet is given in figure 57. Truck volumes were projected using a trend line with a simple growth rate of 10.5 percent (figure 58). The estimated monitoring truck volumes for 1996 and 1997 (shown in figures 57 and 58) were disregarded. The resulting projected truck volumes are summarized in table 30. Truck volume distributions for all three years (for which the AVC monitoring data were available) are very similar (figure 59), and their average was used to develop the base annual spectrum (figure 60). The base spectrum was obtained by combining the site-specific truck volumes with the typical load spectra. The projected annual axle load spectra were summarized using ESALs, and the result is shown in figure 61 and table 31.

In summary, the weak link in the prediction process for this North Carolina site is the use of typical load spectra based on a Minnesota site. The proposed LTPP Loading Guide and a consultation with the SHAs are necessary for the selection and use of more appropriate site-related load spectra.

Site 48-5287

AVC monitoring data are available for eight consecutive years (1990 through 1997). The average number of days for which these data are available is 51 per year, with a range of 27 to 82 days. Utilizing a very good agreement between the historical and monitoring truck volumes (figure 62), an exponential growth trend line was used to project total truck volumes (figure 63 and table 32). As mentioned in the summary, there was an unexpected drop in truck volumes obtained in 1996.

The 1996 truck volumes were not used for the projections. The base annual load spectrum was obtained by averaging the truck volume distributions (figure 64) and combining them with the typical load spectra. The result is shown in figure 65, whereas figure 66 and table 33 show the relationship between projected and historical (estimated) ESALs.

In summary, this site is a rather typical Category 3 site with its inherent limitations.

Site 55-3012

This Wisconsin site on a rural minor arterial highway has the following AVC monitoring data: 1993 - 31 days, 1994 - 131 days, and 1996 - 173 days. There is also a record of AVC data for 1991, but the data were disregarded because the reported average daily truck volume (11,316 on a two-lane highway) was obviously too high. It would be revealing to know why the historical truck volumes were expected to have increased in a zig-zag pattern (figure 67). The projection of truck volumes did not take this pattern into account and was based on the lowest historical values that also fit the trend in the monitoring values (figure 68 and table 34).

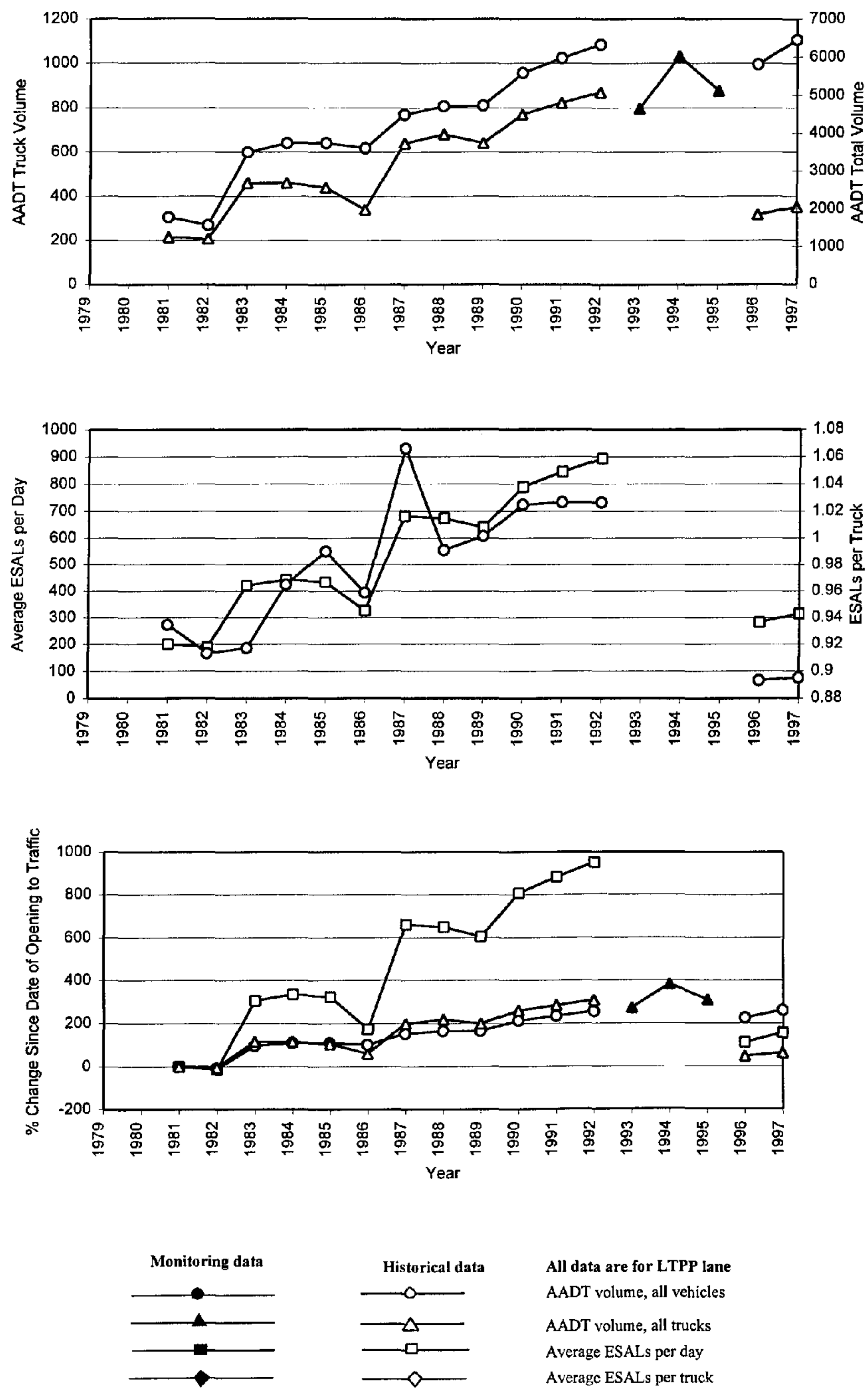


Figure 57. Annual Projection Data Sheet for Site 37-3807.

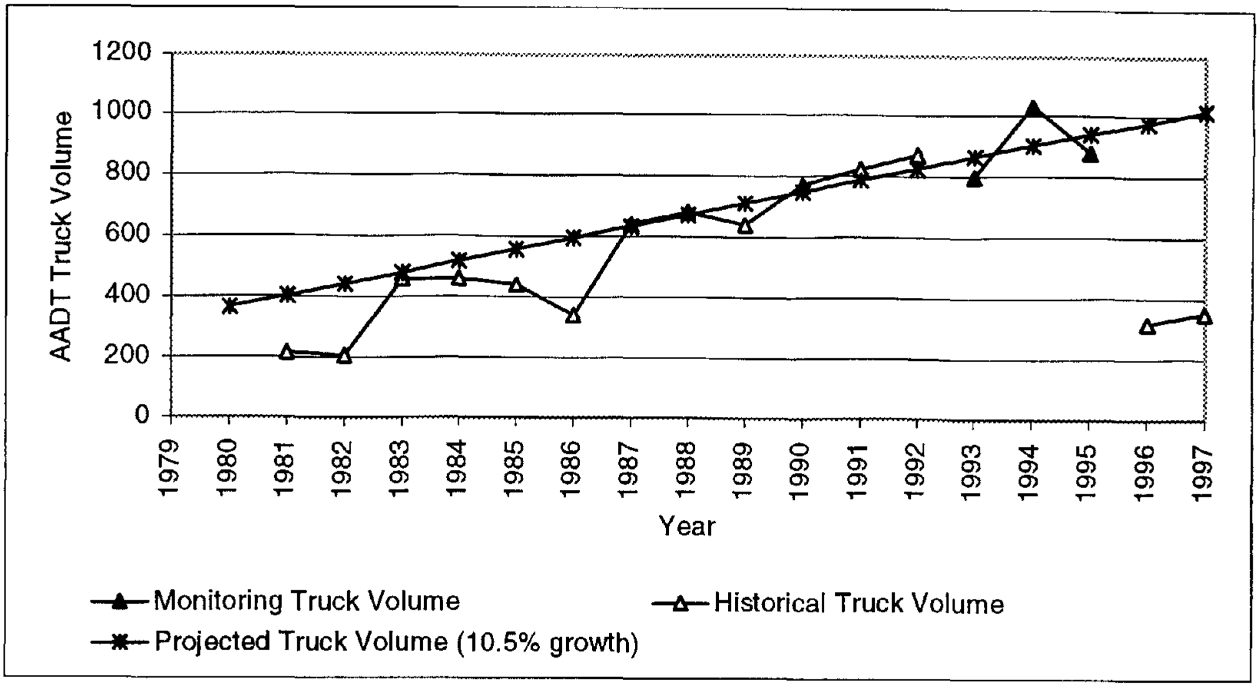


Figure 58. Comparison of truck AADT volumes for Site 37-3807.

Table 30. Comparison of truck AADT volumes for Site 37-3807.

Year	Growth Factor, 10.5%	Projected Truck Volume, 10.5% Growth	Monitoring Truck Volume	Historical Truck Volume
1980	0.41	366		0
1981	0.46	404		214
1982	0.50	442		207
1983	0.54	480		460
1984	0.59	519		460
1985	0.63	557		440
1986	0.67	595		340
1987	0.72	633		640
1988	0.76	672		680
1989	0.80	710		640
1990	0.84	748		770
1991	0.89	786		822
1992	0.93	825		870
1993	0.97	863	796	
1994	1.02	901	1031	
1995	1.06	939	876	
1996	1.10	977		316
1997	1.15	1016		352

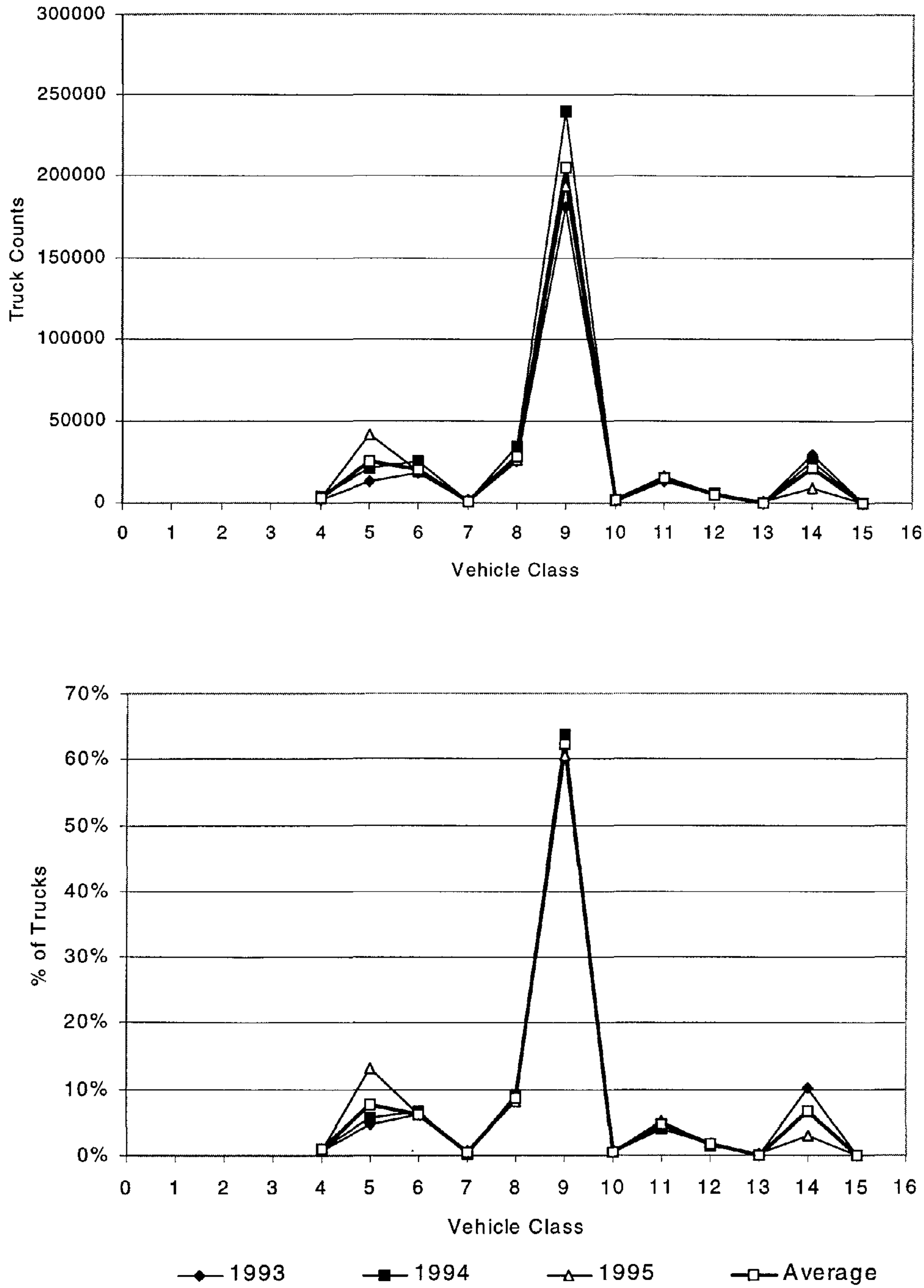
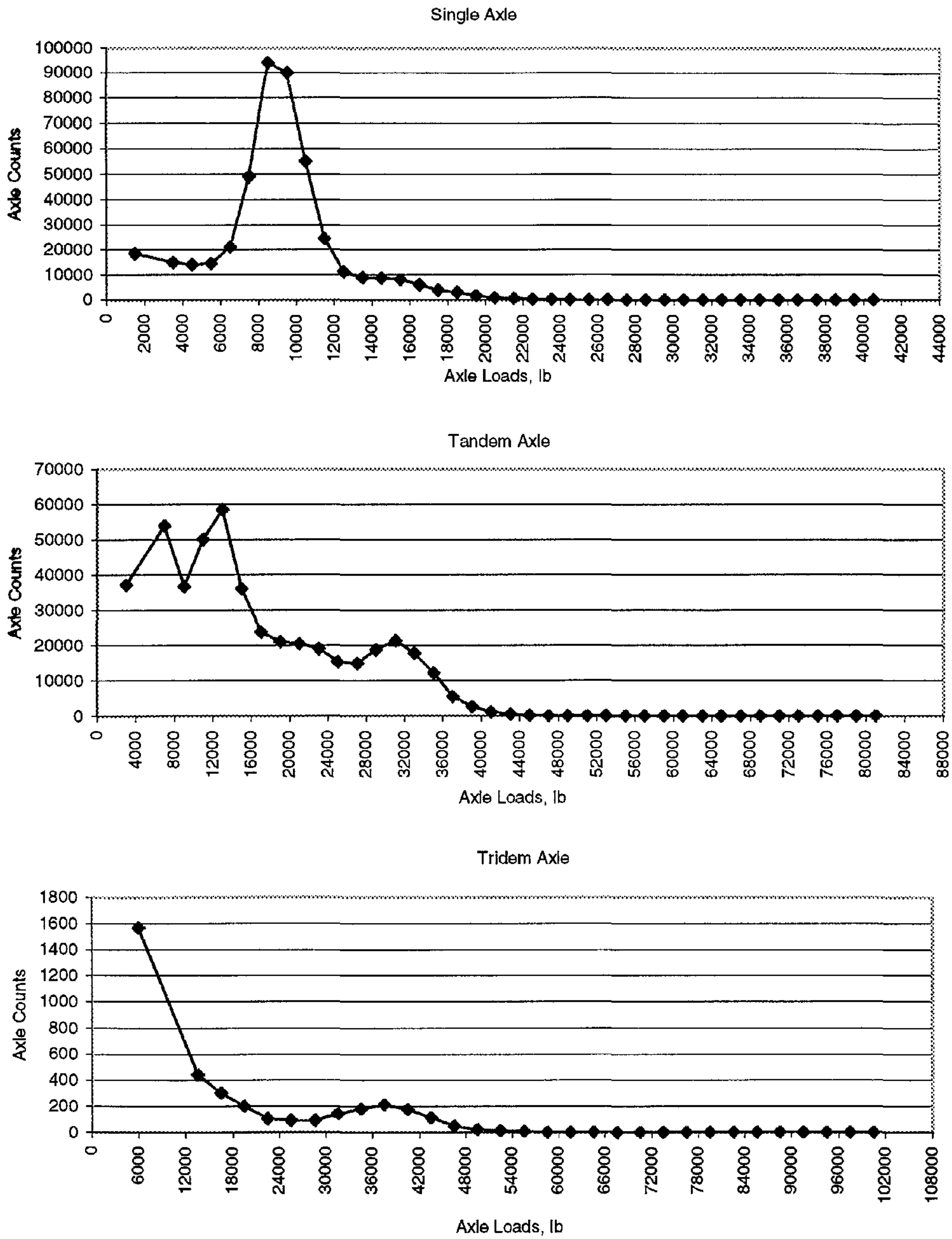


Figure 59. Truck distribution by class for Site 37-3807.



1 lb = 0.00445 kN

Figure 60. Base load spectra for Site 37-3807.

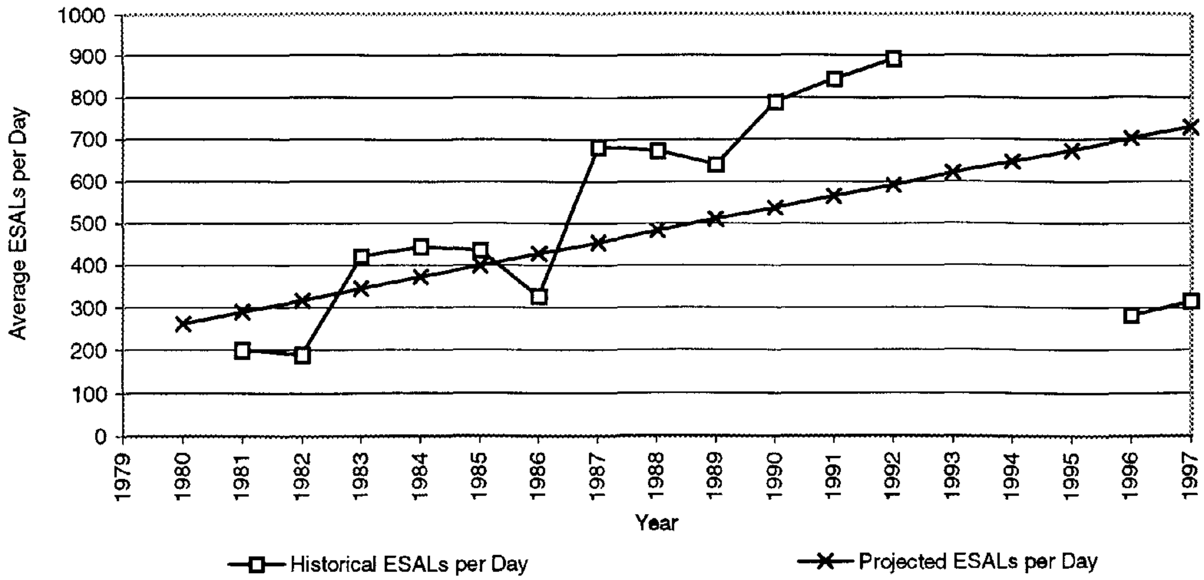


Figure 61. Comparison of projected and historical ESALs for Site 37-3807.

Table 31. Cumulative ESALs computation sheet for Site 37-3807.

Year	Historical ESALs per Day	Projected ESALs per Day
1980	0	263
1981	200	290
1982	189	317
1983	422	345
1984	444	372
1985	436	400
1986	326	427
1987	682	455
1988	674	482
1989	641	510
1990	789	537
1991	844	564
1992	893	592
1993		619
1994		647
1995		674
1996	282	702
1997	315	729

Cumulative ESALs = 3,257,433

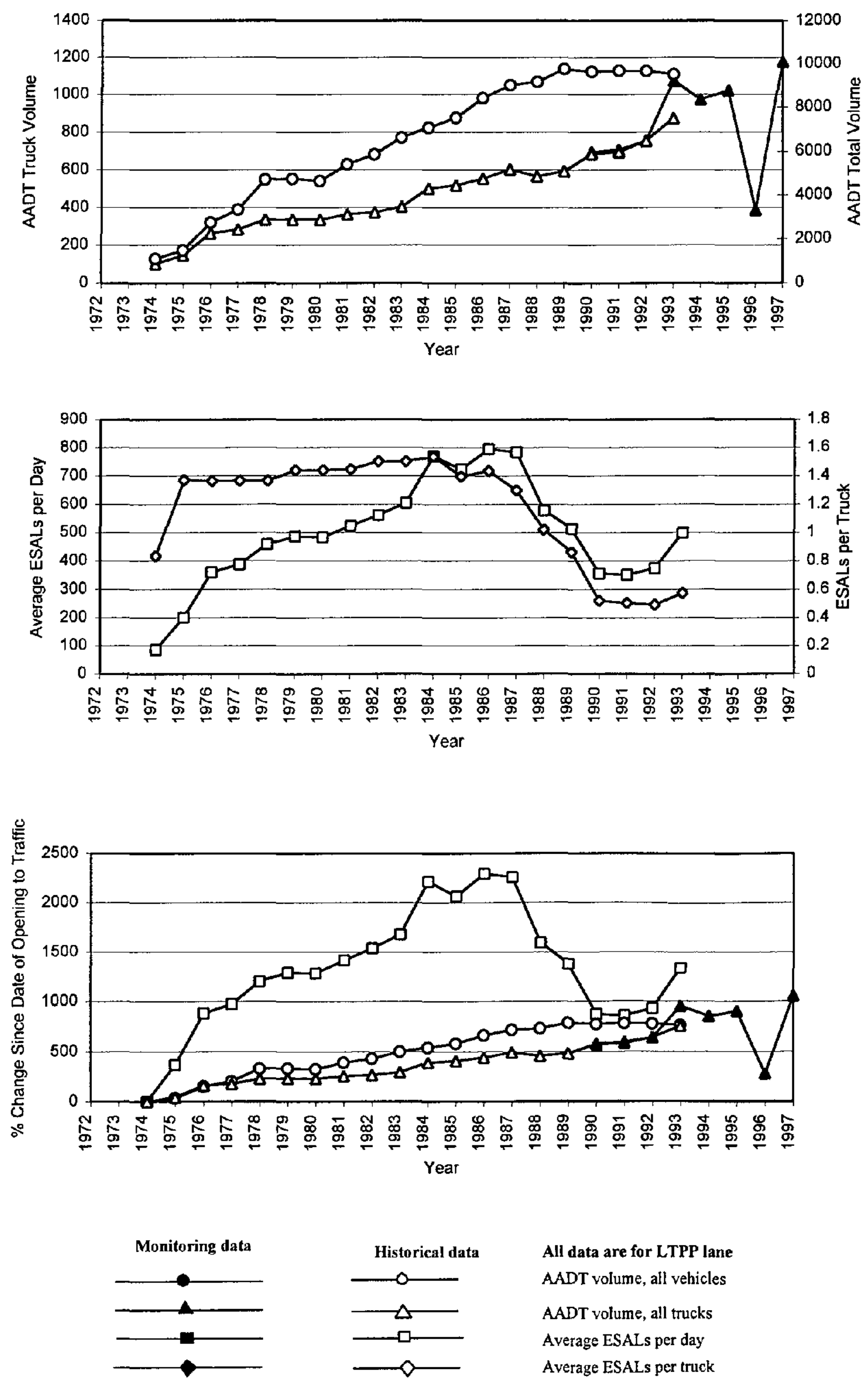


Figure 62. Annual Projection Data Sheet for Site 48-5287.

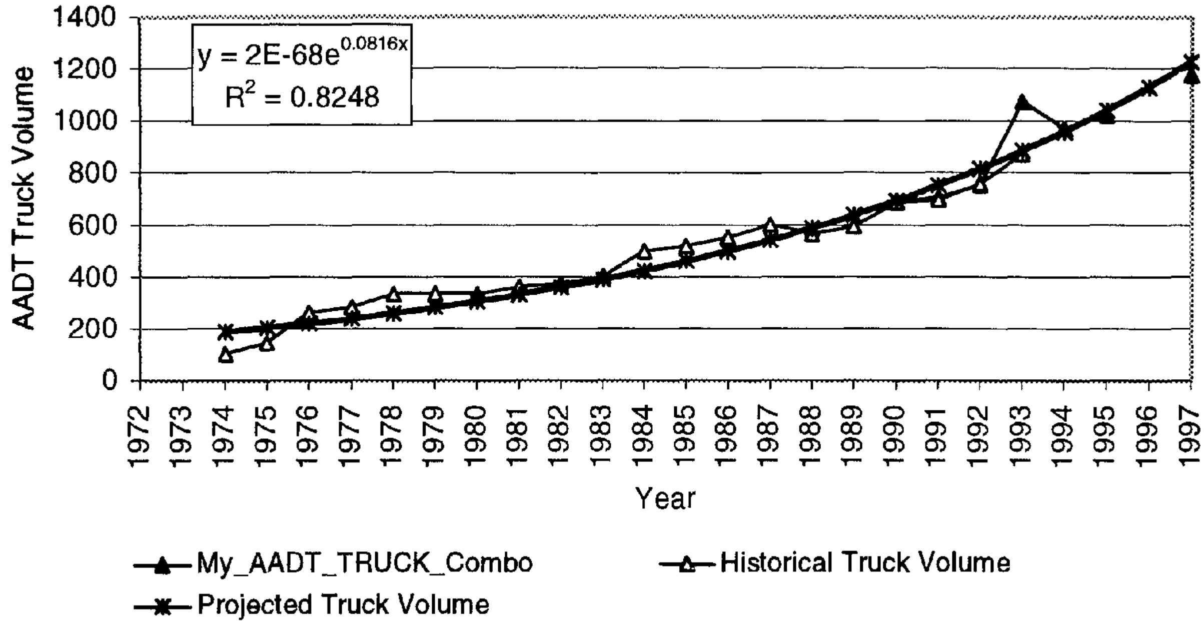


Figure 63. Comparison of truck AADT volumes for Site 48-5287.

Table 32. Comparison of truck AADT volumes for Site 48-5287.

Year	Growth Factor	Projected Truck Volume	Monitoring Truck Volume	Historical Truck Volume
1974	0.21	188		102
1975	0.22	204		146
1976	0.24	221		263
1977	0.26	240		283
1978	0.28	260		335
1979	0.31	282		337
1980	0.34	306		335
1981	0.36	332		362
1982	0.39	361		374
1983	0.43	391		403
1984	0.46	425		501
1985	0.50	461		518
1986	0.55	500		554
1987	0.59	542		603
1988	0.64	588		567
1989	0.70	638		595
1990	0.76	693	694	686
1991	0.82	752	707	696
1992	0.89	815	753	757
1993	0.97	885	1073	872
1994	1.05	960	972	
1995	1.14	1042	1022	
1996	1.24	1130	386	
1997	1.34	1226	1176	

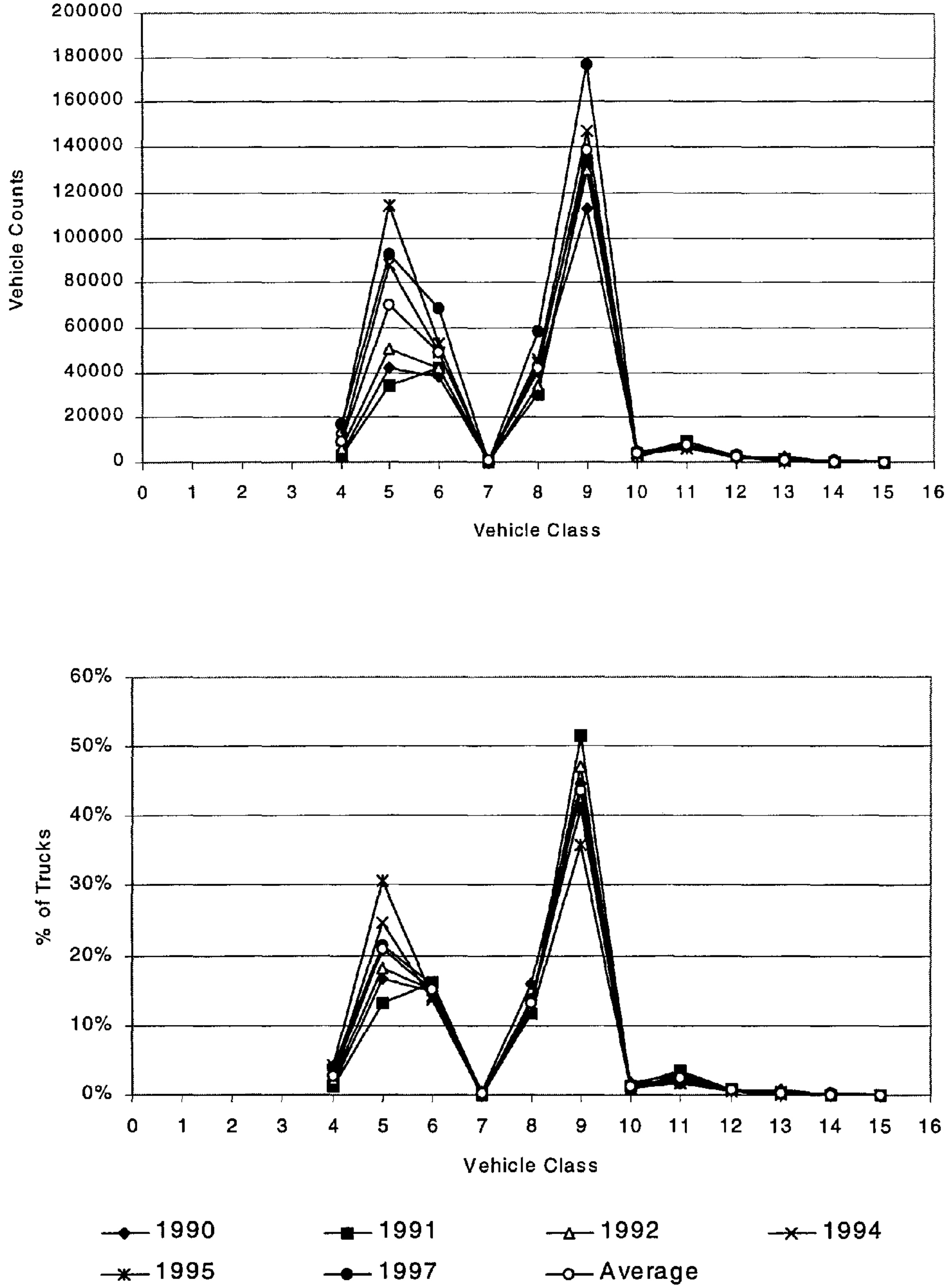
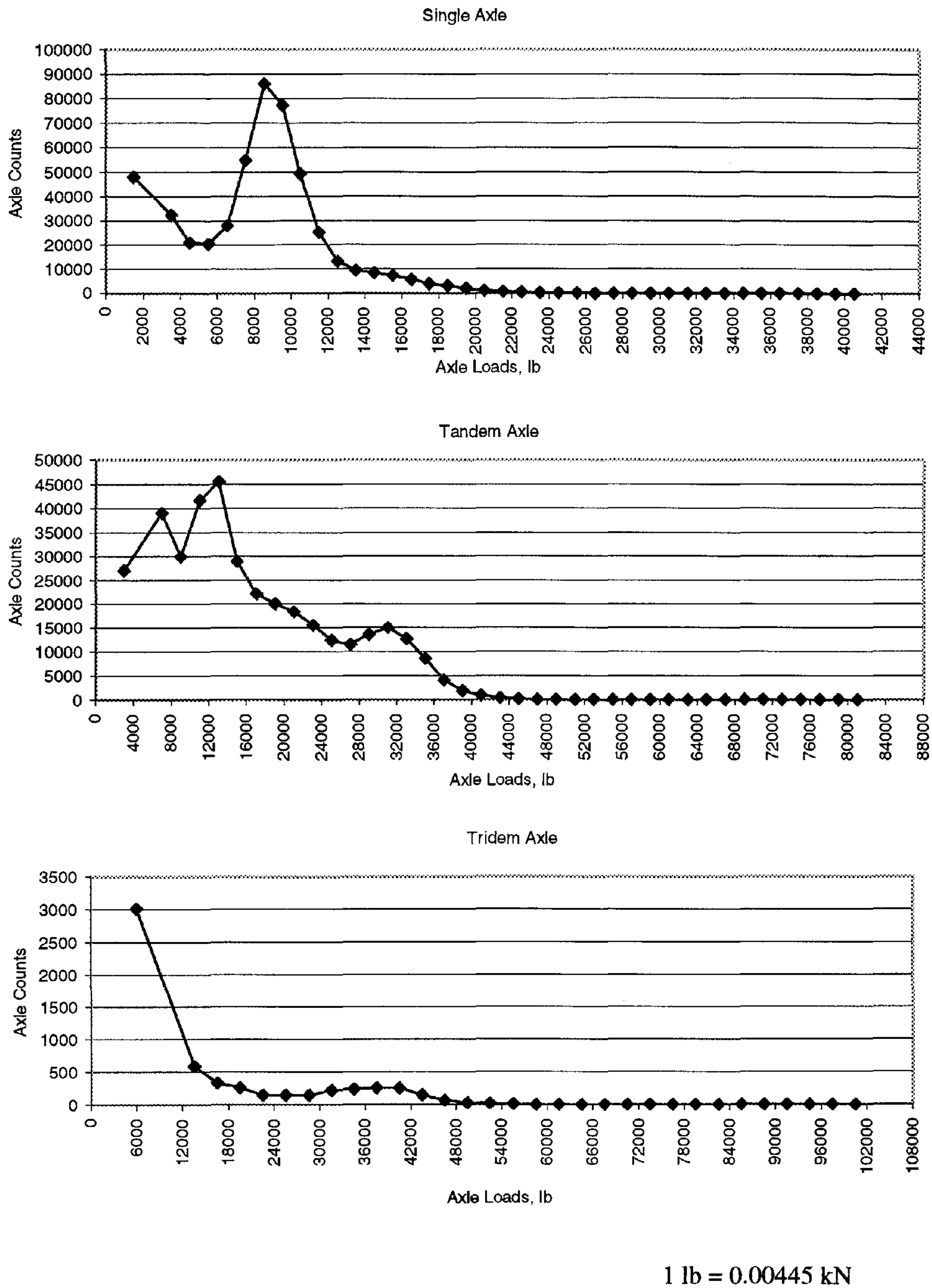


Figure 64. Truck distribution by class for selected years for Site 48-5287.



1 lb = 0.00445 kN

Figure 65. Base load spectra for Site 48-5287.

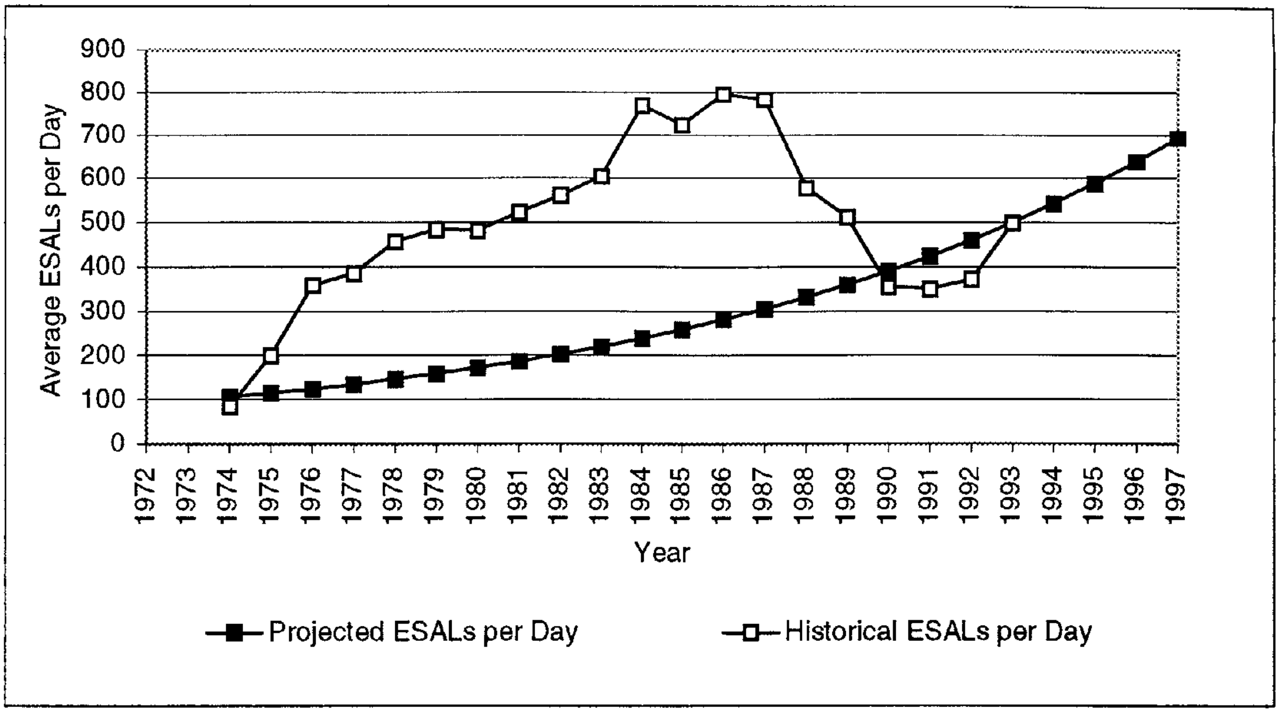


Figure 66. Projected and historical ESALs for Site 48-5287.

Table 33. Cumulative ESALs computation sheet for Site 37-3807.

Year	Projected ESALs per Day	Historical ESALs per Day
1974	106	85
1975	115	200
1976	125	359
1977	135	386
1978	147	458
1979	159	485
1980	173	482
1981	188	523
1982	204	562
1983	221	605
1984	240	770
1985	260	723
1986	282	795
1987	306	784
1988	332	578
1989	361	512
1990	391	356
1991	424	351
1992	461	373
1993	500	499
1994	542	
1995	588	
1996	638	
1997	693	

Cumulative ESALs = 2,770,764

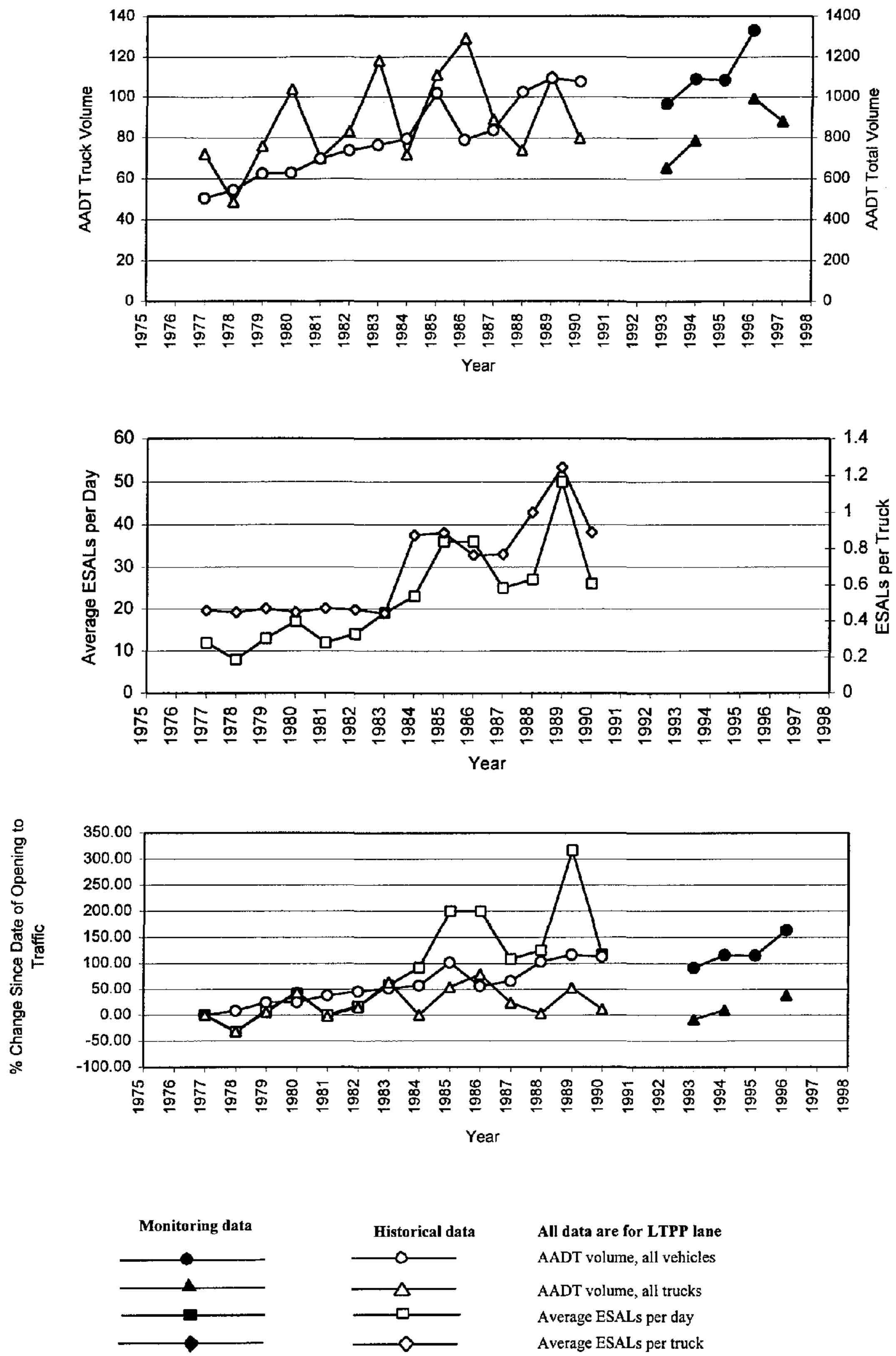


Figure 67. Annual Projection Data Sheet for Site 55-3012.

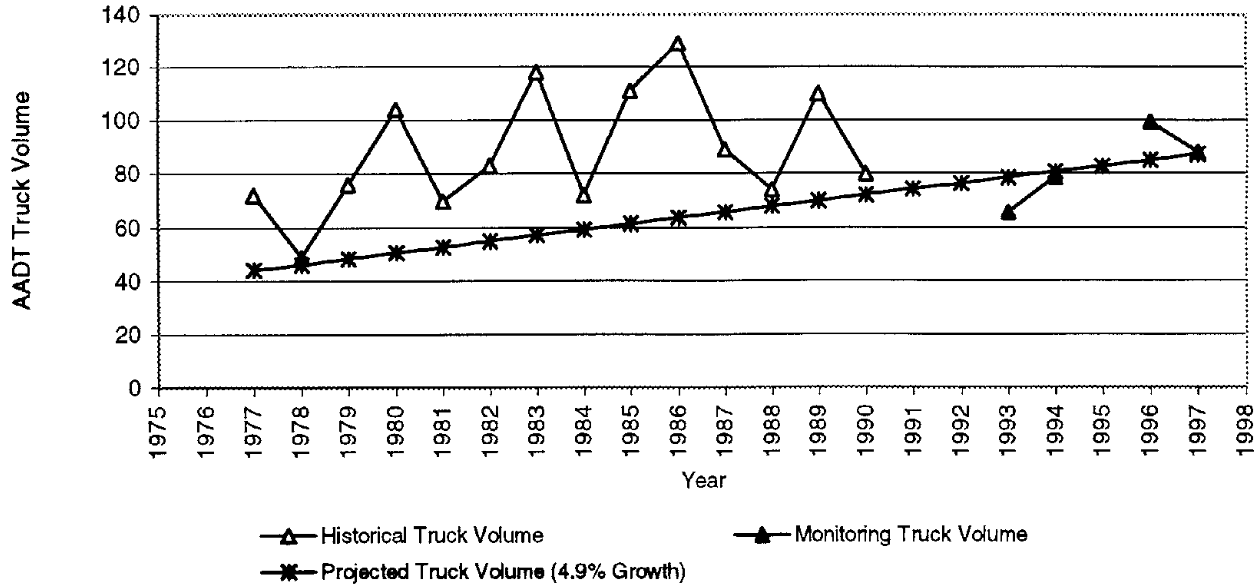
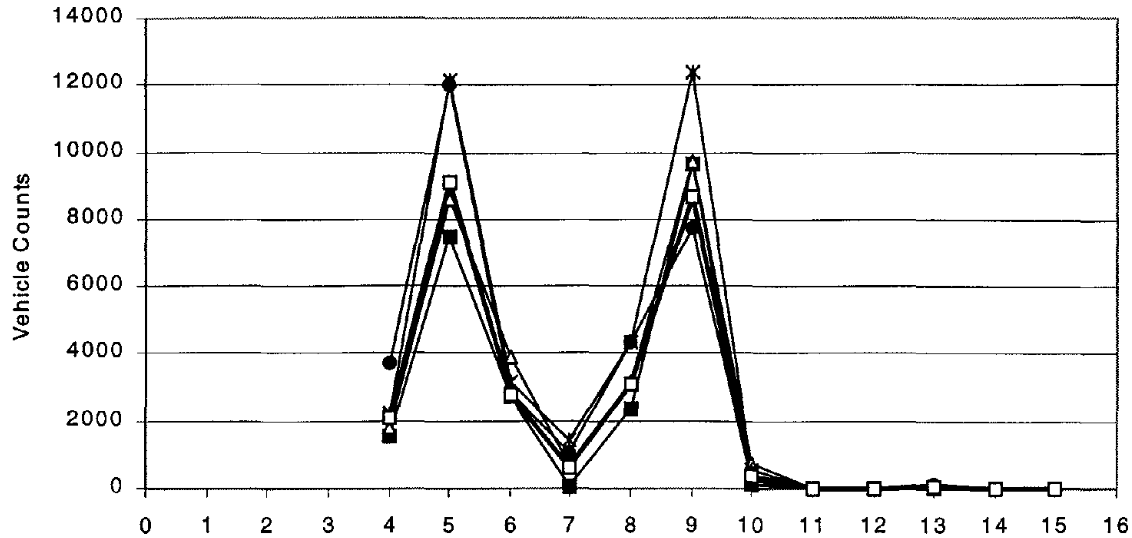


Figure 68. Comparison of truck AADT volumes for Site 55-3012.

Table 34. Comparison of truck AADT volumes for Site 55-3012.

Year	Growth Factor, 4.9%	Projected Truck Volume, 4.9% Growth	Monitoring Truck Volume	Historical Truck Volume
1977	0.53	44		72
1978	0.56	46		49
1979	0.58	48		76
1980	0.61	51		104
1981	0.64	53		70
1982	0.66	55		83
1983	0.69	57		118
1984	0.71	59		72
1985	0.74	61		111
1986	0.77	64		129
1987	0.79	66		89
1988	0.82	68		74
1989	0.84	70		110
1990	0.87	72		80
1991	0.90	74		
1992	0.92	76		
1993	0.95	79	66	
1994	0.97	81	79	
1995	1.00	83	0	
1996	1.03	85	99	
1997	1.05	87	88	



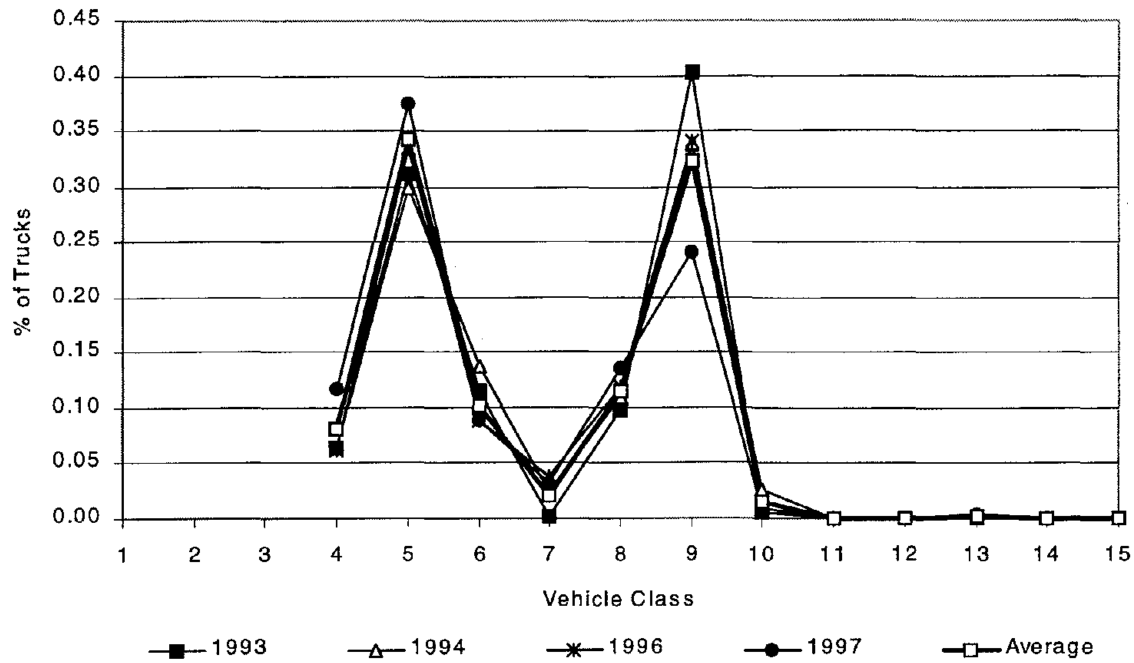
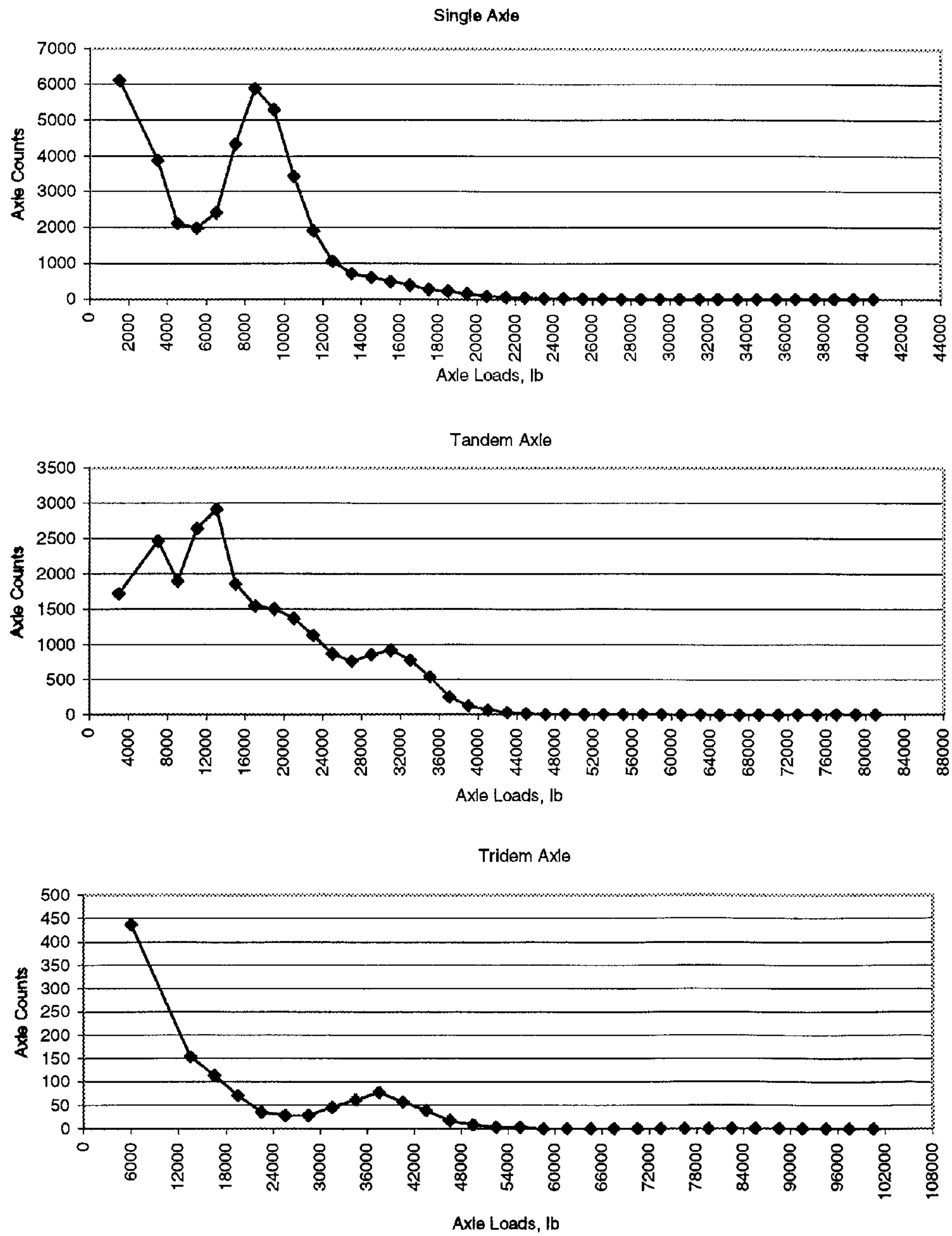


Figure 69. Truck distribution by class for Site 55-3012.



1 lb = 0.00445 kN

Figure 70. Base load spectra for Site 55-3012.

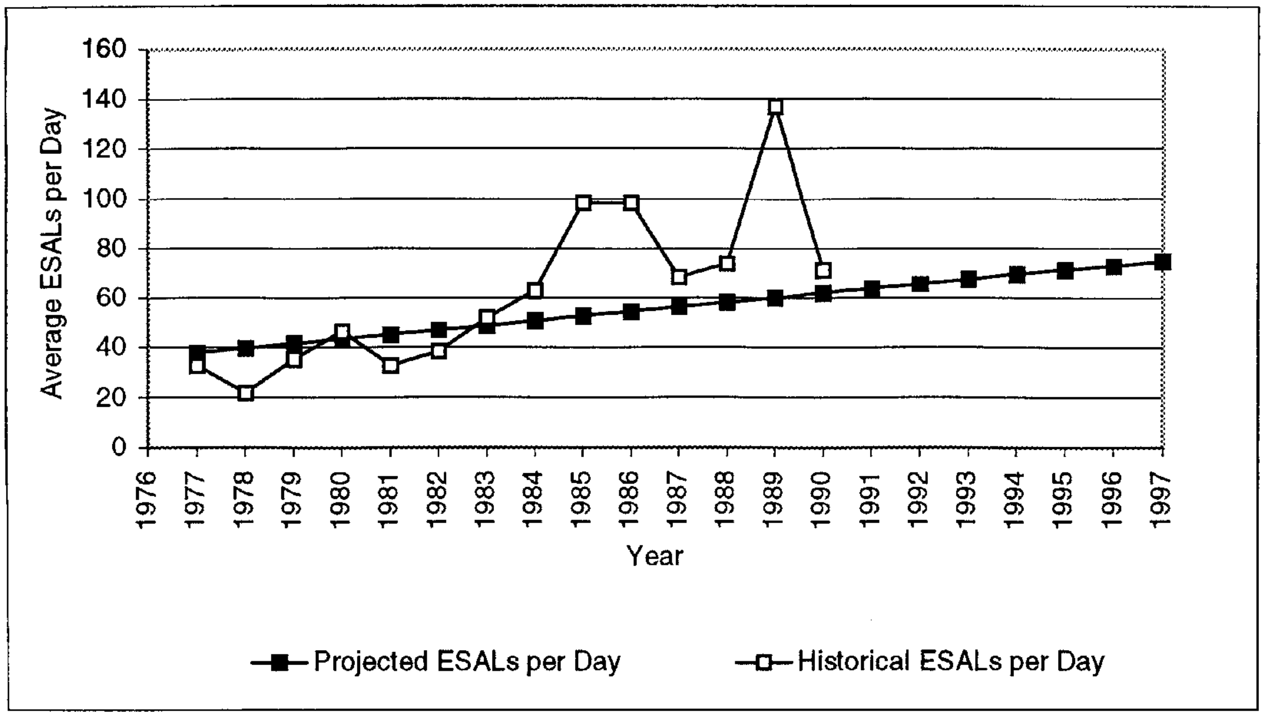


Figure 71. Projected and historical ESALs for Site 55-3012.

Table 35. Cumulative ESALs computation sheet for Site 55-3012.

Year	Projected ESALs per Day	Historical ESALs per Day
1977	38	33
1978	40	22
1979	42	36
1980	43	47
1981	45	33
1982	47	38
1983	49	52
1984	51	63
1985	53	99
1986	55	99
1987	56	68
1988	58	74
1989	60	137
1990	62	71
1991	64	
1992	66	
1993	67	
1994	69	
1995	71	
1996	73	
1997	75	

Cumulative ESALs = 432,146

Figure 69 shows that the truck volume distribution contains a high percentage of Class 5 vehicles (2-axle, 6-tire trucks), as would be expected on this type of highway (see table 4). The base annual load spectra are given in figure 70. The projected and historical ESALs are compared in figure 71 and table 35. According to figure 71, there is a good agreement between the historical and projected ESALs. This result is not surprising, considering that the axle load spectra used for this site were obtained from a rural principal arterial site in Minnesota (site 27-0501).

DESCRIPTION OF CASE STUDIES FOR CATEGORY 4

Category 4 represents LTPP sections with virtually no reliable monitoring measured AVC and WIM data, but with historical and monitoring estimated truck volume data. Base load annual spectra for Category 4 sites were obtained by combining site-related base truck distributions with typical load spectra for the individual truck classes. Typical load spectra for individual truck classes are given in appendix B; the spectra for Site 27-0501 were used for Category 4 predictions.

Site 01-6019

Site 01-6019 is located on a rural Interstate in Alabama. There was no record of the number of AVC days in the monitoring data summary table. However, there were data showing truck volume distribution by class for 1995, but the reported volume was so low that it was disregarded. The projection of truck volumes is documented in table 36 and figures 72 and 73. The total truck volume in 1997 was estimated to be 1950 and was used as the starting point for the projection. A linear regression line was fitted through historical truck AADT volumes.

The base normalized truck volume distribution shown in figure 74 was obtained by averaging normalized truck distributions for sites located on rural Interstates in Alabama. Again, to carry out Category 4 projections, it is necessary to have a traffic loading guide or catalog. The base annual spectrum is shown in figure 75. Projected ESALs are summarized in figure 76 and table 37. The projected ESALs are considerably lower than their historical ESALs. It is clear that the selected base truck volume distribution (figure 74) and/or the typical load spectra for the individual vehicles may not be appropriate.

Site 04-1002

Projection of traffic loading for site 04-1002 was done previously as a Category 2 projection using surrogate WIM data from nearby LTPP sections. Without the benefit of data obtained from the nearby sites, this site may be considered suitable for Category 4 projections. However, the main reason for carrying out this Category 4 projection was to evaluate the consequences of using Category 4 projections rather than Category 2 projections. The Annual Traffic Data Projection Sheet (figure 43) and the projection of annual truck volumes, shown in figure 44 and table 25, were the same for both projection categories.

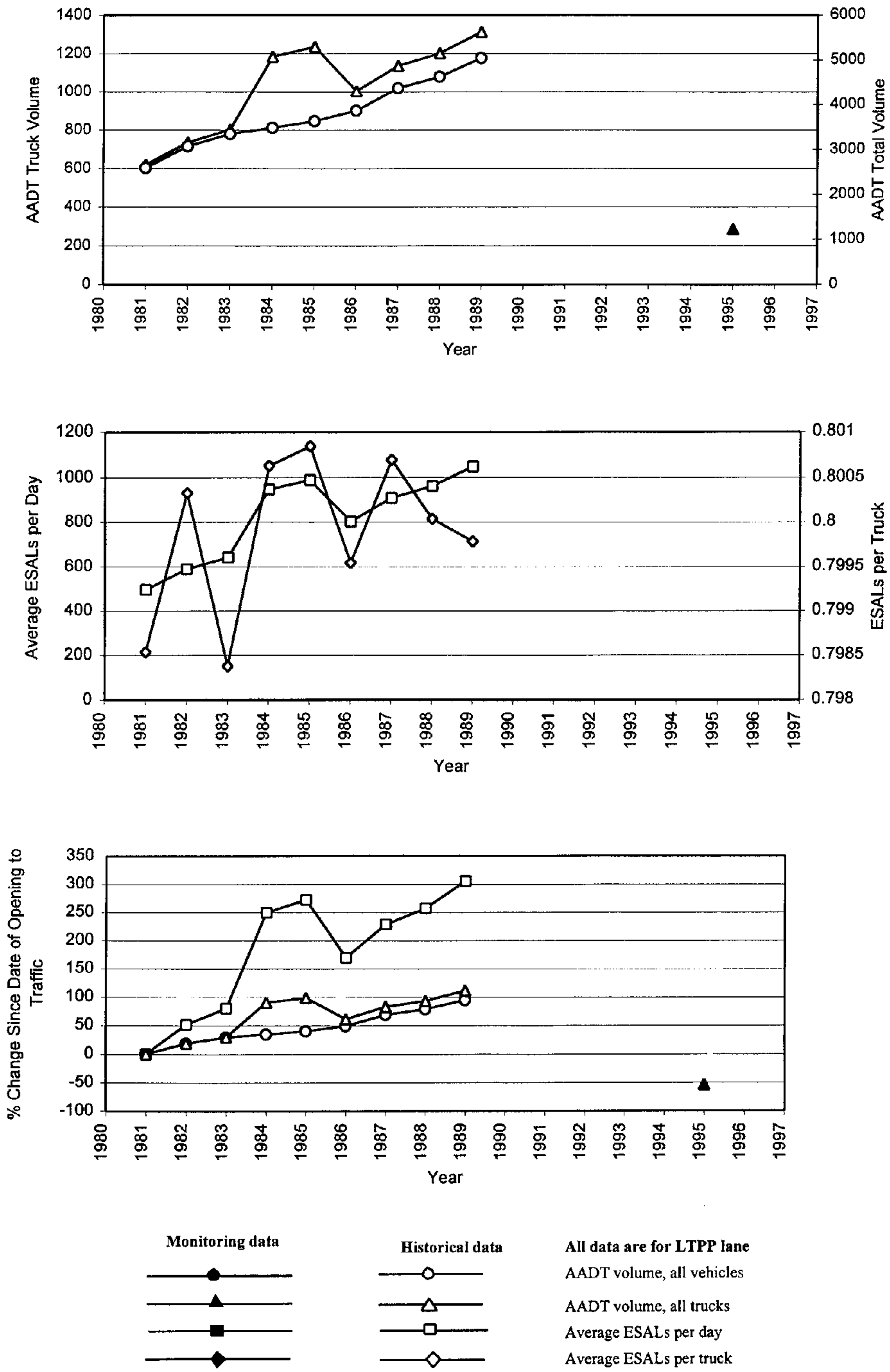


Figure 72. Annual Projection Data Sheet for Site 01-6019.

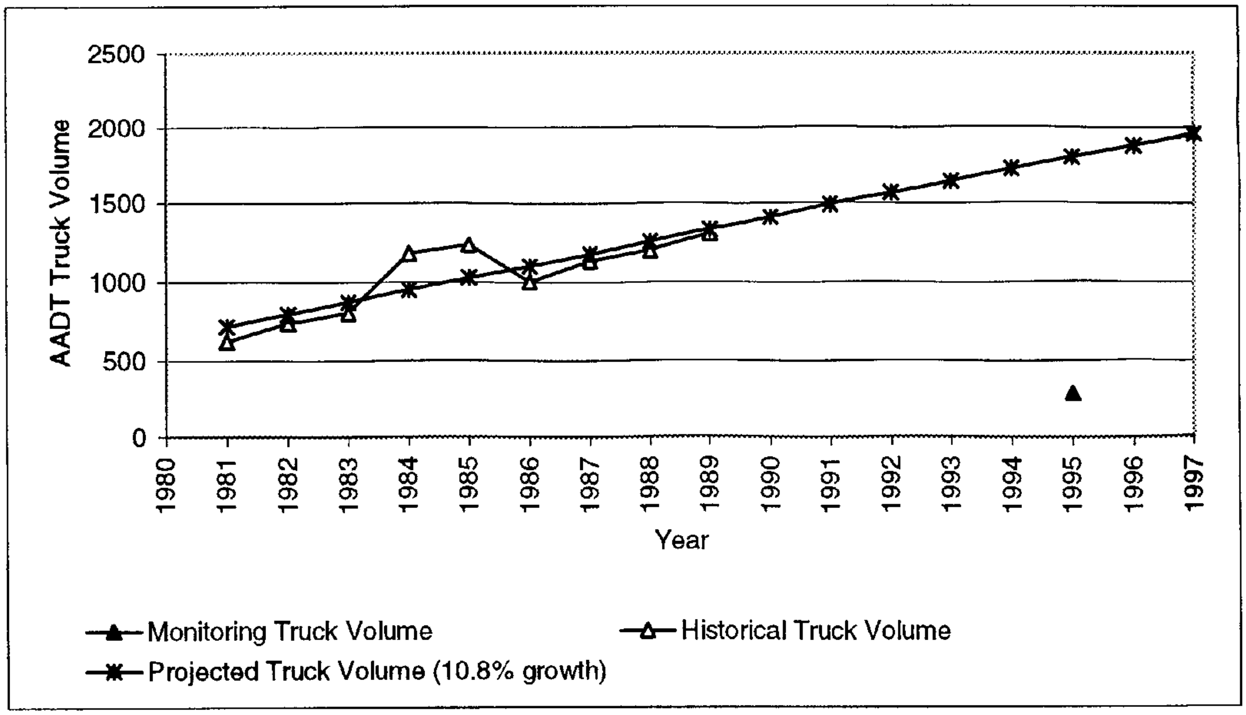


Figure 73. Comparison of truck AADT volumes for Site 01-6019.

Table 36. Comparison of truck AADT volumes for Site 01-6019.

Year	Growth Factor, 10.8%	Projected Truck Volume, 10.8% Growth	Monitoring Truck Volume	Historical Truck Volume
1981	0.37	717		621
1982	0.41	795		736
1983	0.45	872		803
1984	0.49	950		1184
1985	0.52	1027		1235
1986	0.56	1104		1004
1987	0.60	1182		1136
1988	0.64	1259		1202
1989	0.68	1337		1312
1990	0.72	1414		
1991	0.76	1492		
1992	0.80	1569		
1993	0.84	1647		
1994	0.88	1724		
1995	0.92	1802	285	
1996	0.96	1879		
1997	1.00	1957		

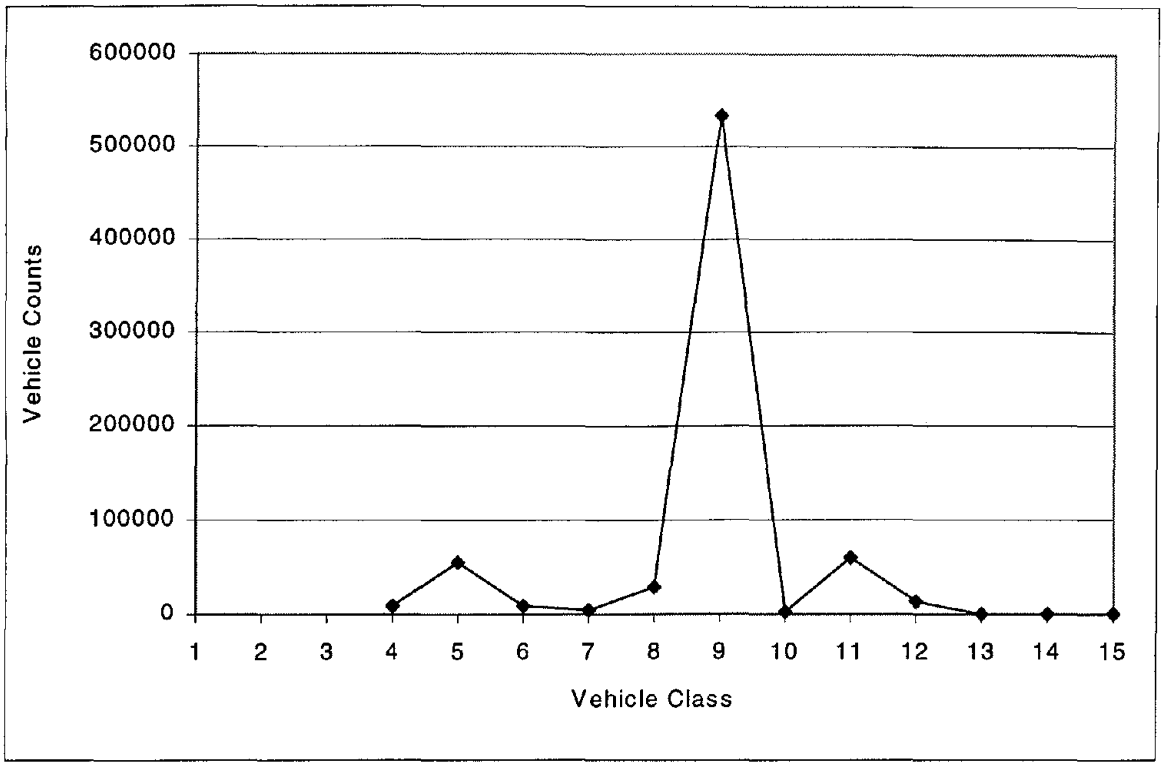
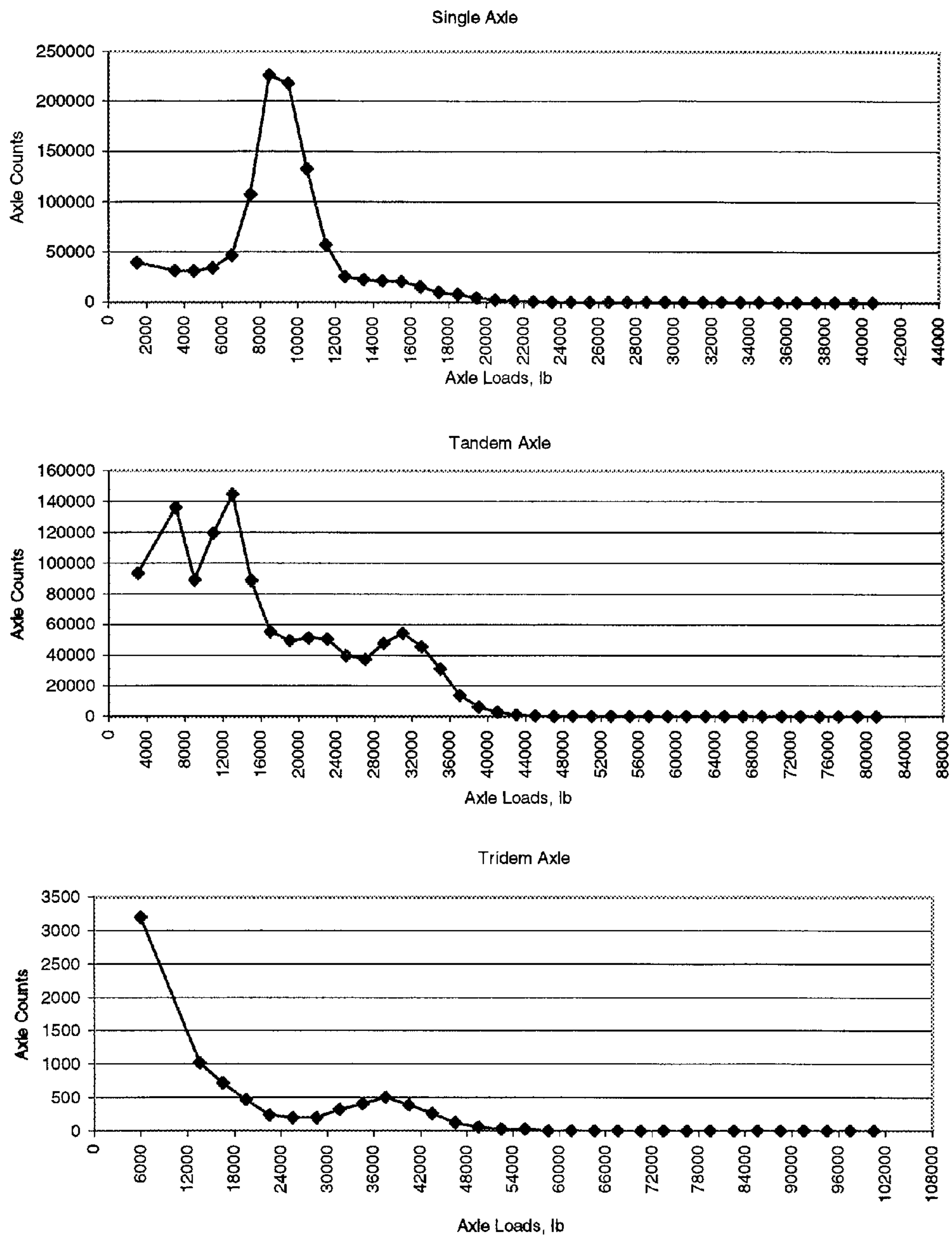


Figure 74. Base truck volume distribution by class for Site 01-6019.



1 lb = 0.00445 kN

Figure 75. Base load spectra for Site 01-6019.

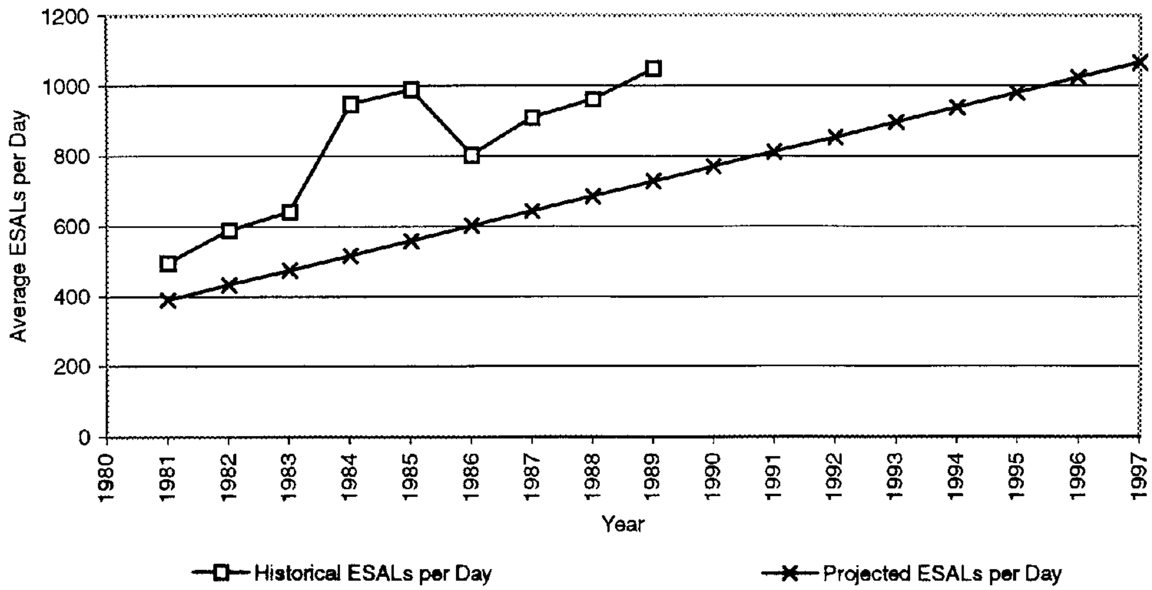


Figure 76. Comparison of projected and historical ESALs for Site 01-6019.

Table 37. Cumulative ESALs computation sheet for Site 01-6019.

Year	Historical ESALs per Day	Projected ESALs per Day
1981	496	390
1982	589	433
1983	641	475
1984	948	517
1985	989	559
1986	803	601
1987	910	644
1988	962	686
1989	1049	728
1990		770
1991		812
1992		854
1993		897
1994		939
1995		981
1996		1023
1997		1065

Cumulative ESALs = 4,516,353

The base truck volume distribution used for the Category 4 projection was the average of the 1993 and 1994 truck volume distributions (of the nearby sites located on the same stretch of highway) shown in figure 47. The vehicle class-specific load spectra used were obtained from Minnesota Site 27-0501. A comparison of base spectra used for Category 2 and 4 projections carried out for this site is shown in figure 77. The resulting ESALs are compared with the ESALs obtained previously using the Category 2 projection (in figure 48 and table 26). The Category 4 ESALs are only a third of the Category 2 ESALs, as well as a third of the historical ESALs. These results underscore the importance of utilizing surrogate or site-related data rather than Category 4 projections.

Site 17-5423

Site 17-5423 is located on a rural Interstate in Illinois. This site was used to illustrate the procedure for carrying out step 7 (see chapter 4) for Category 4 projections. The material already provided in chapter 4 is supplemented by figure 78, which shows the Annual Traffic Data Projection Sheet, and by figure 79 and table 38, which show the predicted truck volumes.

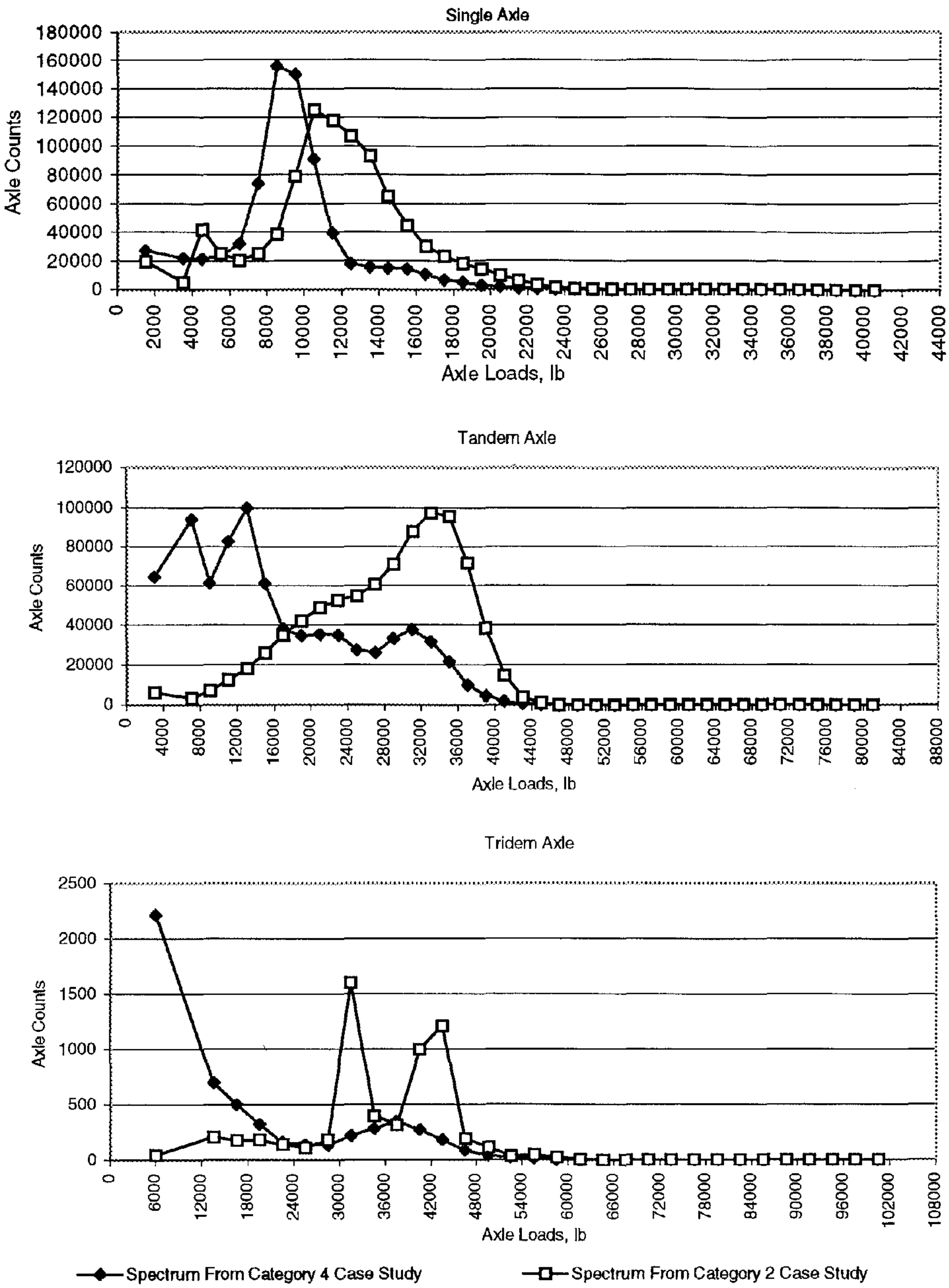
As part of the sensitivity analysis, the effect of using two alternative base truck volume distributions was evaluated for this site. Both distributions are for rural Interstate sites, one in Arizona and the other in Illinois. As shown in figure 80, both distributions are very similar. However, the Arizona distribution has a higher proportion of Class 11 and 12 trucks, which is translated into somewhat larger ESALs obtained for the Arizona alternative (table 39 and figure 81). It should be noted that the same axle load spectra were used for the calculation of base annual load spectra and, thus, also for the calculation of ESALs for both alternatives. Overall, the projected ESALs are less than half of the historical ESALs.

In summary, Category 4 projections require judicious selection of both base truck volume distributions and base axle load spectra for individual truck classes. The base axle load spectra used for Category 3 and 4 predictions have an overall ratio of ESALs per truck of less than 0.5 (figure 31). Thus, the use of this spectra has resulted in lower-than-expected loads.

EFFECT OF QUANTITY OF MONITORING DATA

Site 29-4036 was used to assess the effect of the amount of monitoring data on the precision of the protected traffic loads. This site was already used as a case study to illustrate Category 1 projections. The available AVC and WIM monitoring data for Site 29-4036 were progressively reduced to fit Category 3 and 4. The reduced data were then used to carry out Category 3 and 4 projections for this site.

It is important to note that this work should be viewed as a proof-of-concept study done within the framework of the traffic projection methodology developed in this report. Much more realistic and comprehensive assessment of the influence of the amount of monitoring data on traffic loads is described in reference 6.



1 lb = 0.00445 kN

Figure 77. Base load spectra for Site 04-1002.

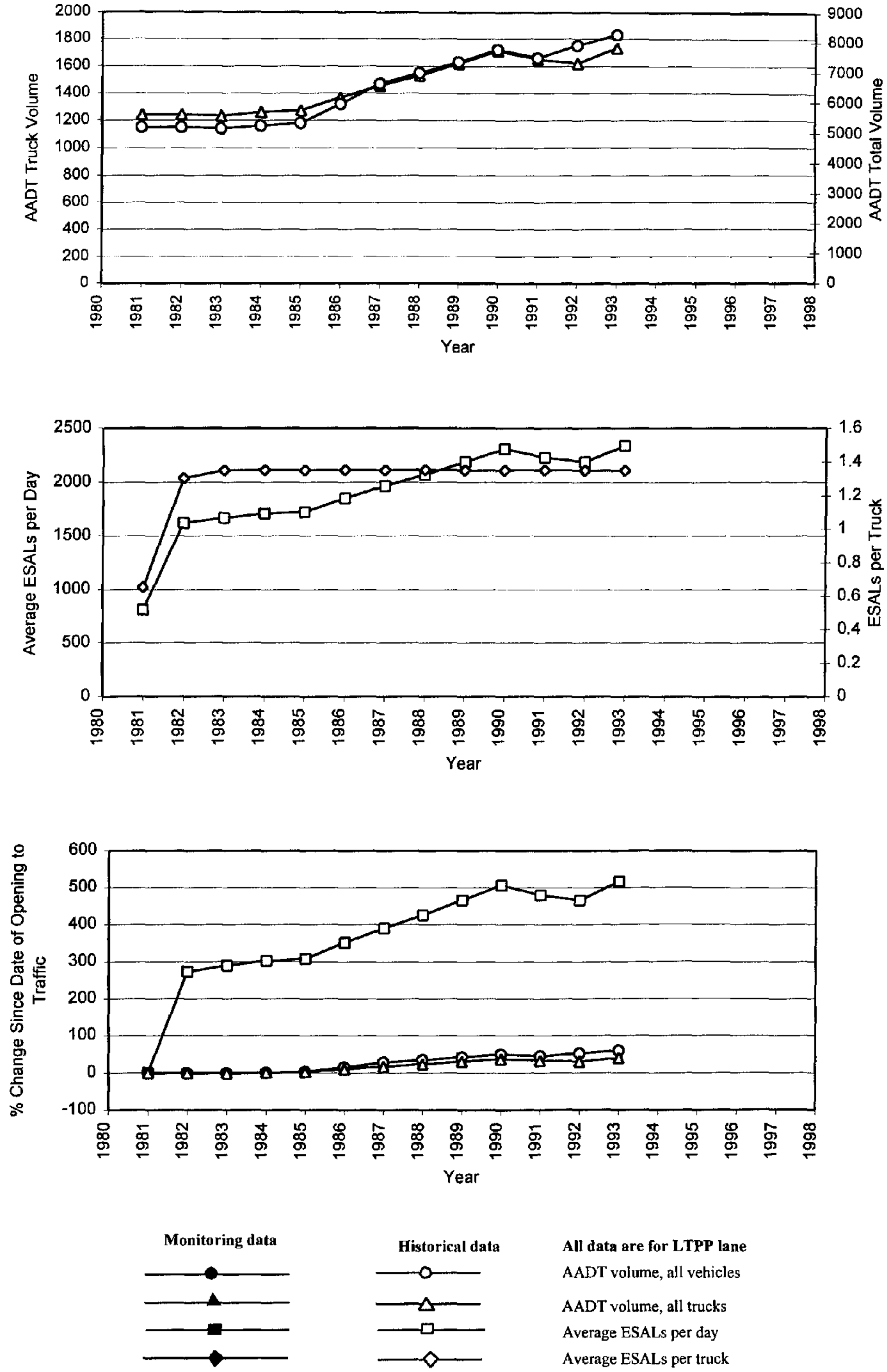


Figure 78. Annual Projection Data Sheet for Site 17-5423.

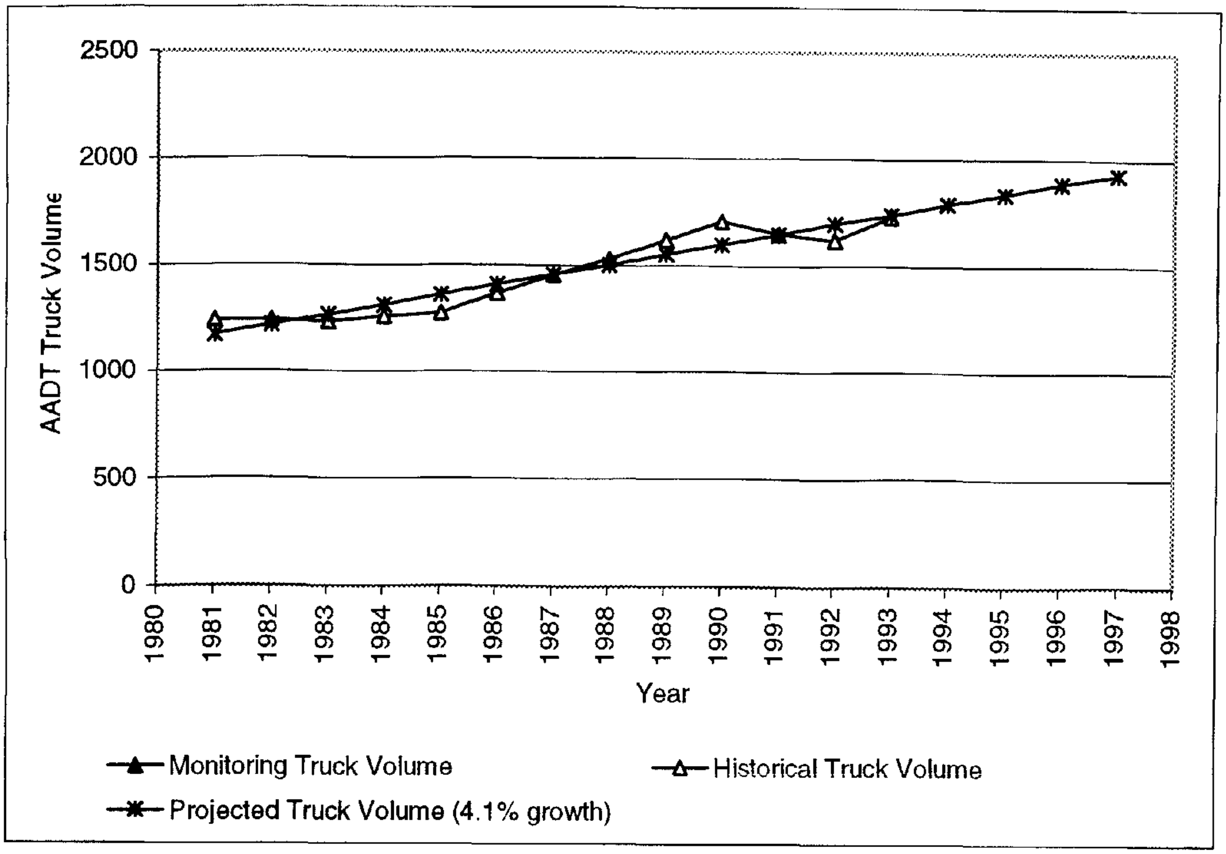


Figure 79. Comparison of truck AADT volumes for Site 17-5423.

Table 38. Comparison of truck AADT volumes for Site 17-5423.

Year	Growth Factor, 4.1%	Projected Truck Volume, 4.1% Growth	Historical Truck Volume
1981	0.60	1169	1242
1982	0.63	1217	1242
1983	0.65	1265	1233
1984	0.68	1312	1260
1985	0.70	1360	1274
1986	0.73	1408	1368
1987	0.75	1456	1454
1988	0.78	1504	1530
1989	0.80	1552	1620
1990	0.83	1600	1710
1991	0.85	1647	1650
1992	0.88	1695	1620
1993	0.90	1743	1733
1994	0.93	1791	
1995	0.95	1839	
1996	0.98	1887	
1997	1.00	1934	

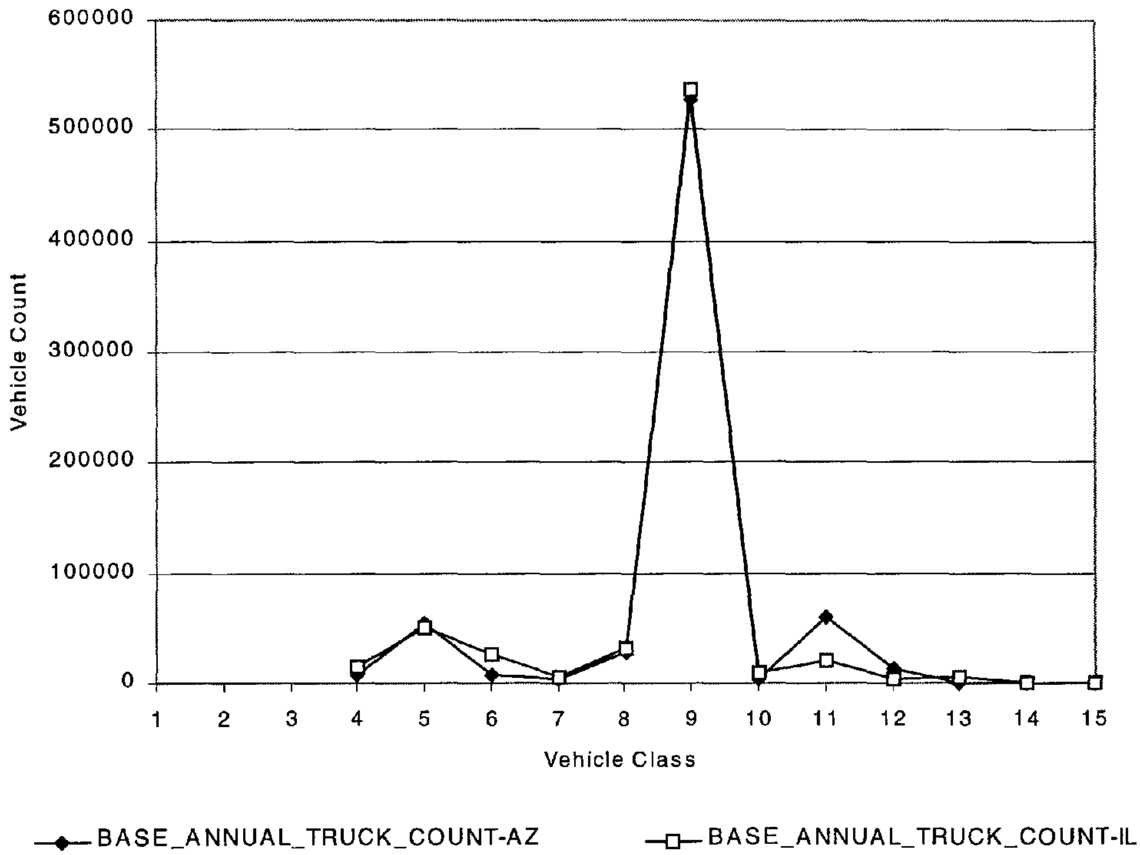


Figure 80. Comparison of truck distribution curves for Arizona and Illinois rural Interstates.

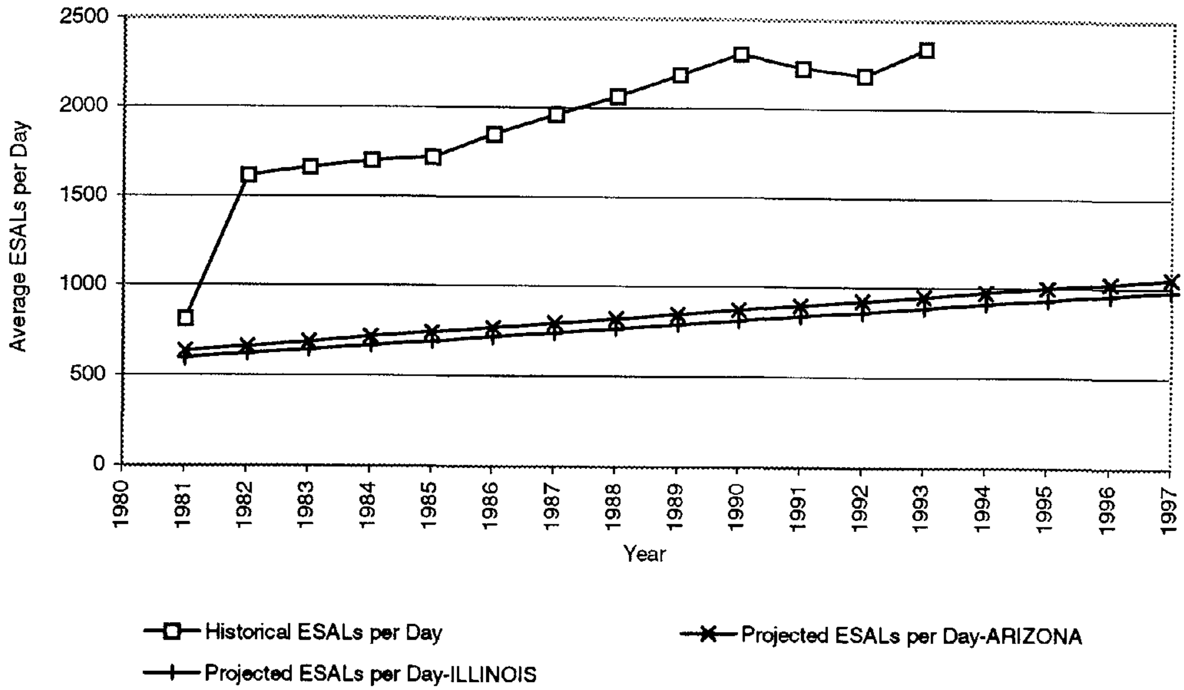


Figure 81. Comparison of projected and historical ESALs for Site 17-5423.

Table 39. Cumulative ESALs computation sheet for Site 17-5423.

Year	Historical ESALs per Day	Projected ESALs per Day—Arizona	Projected ESALs per Day—Illinois
1981	811	636	594
1982	1619	662	619
1983	1666	689	643
1984	1704	715	667
1985	1721	741	692
1986	1849	767	716
1987	1964	793	740
1988	2068	819	765
1989	2189	845	789
1990	2310	871	813
1991	2230	897	838
1992	2189	923	862
1993	2340	949	886
1994		975	911
1995		1001	935
1996		1027	959
1997		1053	984

Cumulative ESALs for Arizona = 5,242,121
Cumulative ESALs for Illinois = 4,895,220

The results of Category 1 predictions for Site 29-4036 are summarized in tables 21 and 22 and figures 36 through 42. Figure 82 shows the projection of truck volumes using only historical truck volumes, as would be expected for Category 4 predictions. Table 40 provides a comparison of truck volumes projected for Categories 1, 3, and 4. Figures 83 and 84 compare the projected annual axle load spectra for 1983 and 1995, respectively. The results, in terms of cumulative ESALs, are given in table 41 and figure 85. The ESALs for Category 3 and 4 projections are less than half of those for Category 1 projections. However, as discussed previously, this was caused by the "light" base load spectra used for Category 3 and 4 projections.

BRIEF SUMMARY

The following observations are based on the 12 case studies described in this chapter:

- The proposed methodology can be used to project annual axle load spectra for all LTPP sites.
- The involvement of SHAs in the predictive process is crucial. Many data problems cannot be resolved without local involvement.
- Base axle load spectra for individual trucks, and base truck volume distribution, required for Category 3 and 4 projections, must be selected judiciously, and this selection must be supported by a sound, well-organized, and well-documented knowledge base. Therefore, the development of an LTPP Pavement Loading Guide or a catalog is proposed.
- Sensitivity analysis can be used to quantify the effect of key assumptions made during the prediction process.
- The majority of the data processing and engineering effort involved in the projection process was spent on quality assurance issues.
- The quality assurance process would greatly benefit from developing a knowledge base or a catalog documenting values and ranges of traffic variables. The process would also benefit from the availability of summary measures for traffic loads that are independent of pavement variables.
- Several data inconsistencies exist in the CTDB. For example, data in several traffic monitoring tables are conflicting or missing; calculated ESALs reported in the IMS appeared to conflict with ESALs calculated in the course of conducting the case study for Site 29-5483.

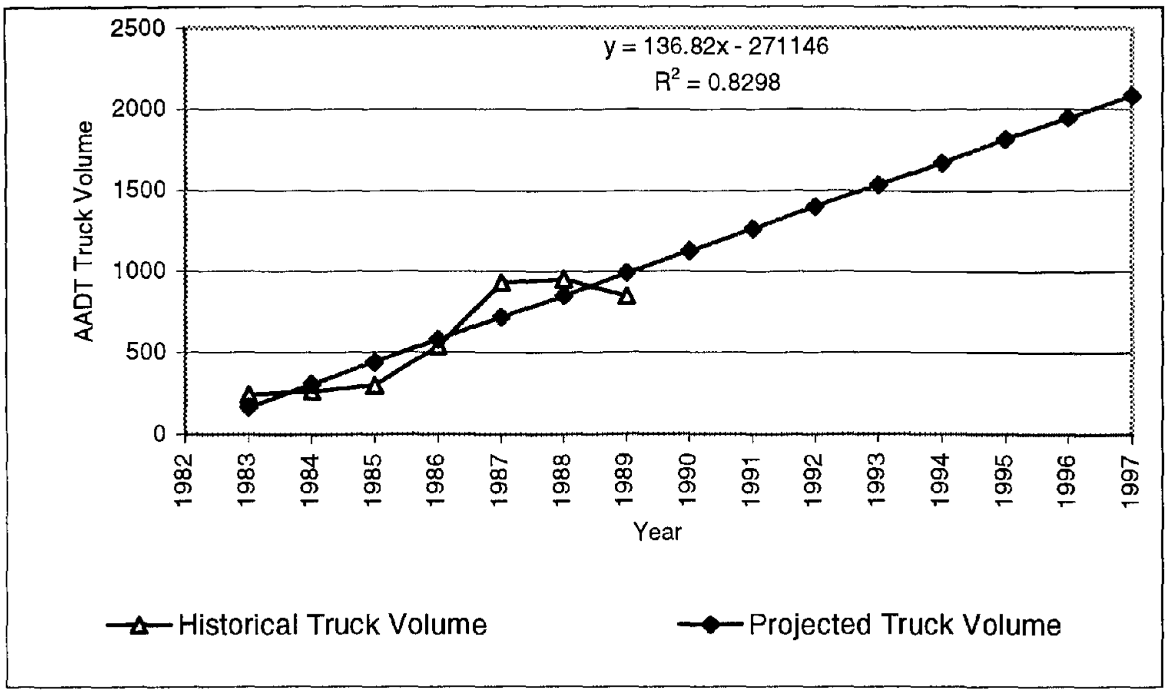
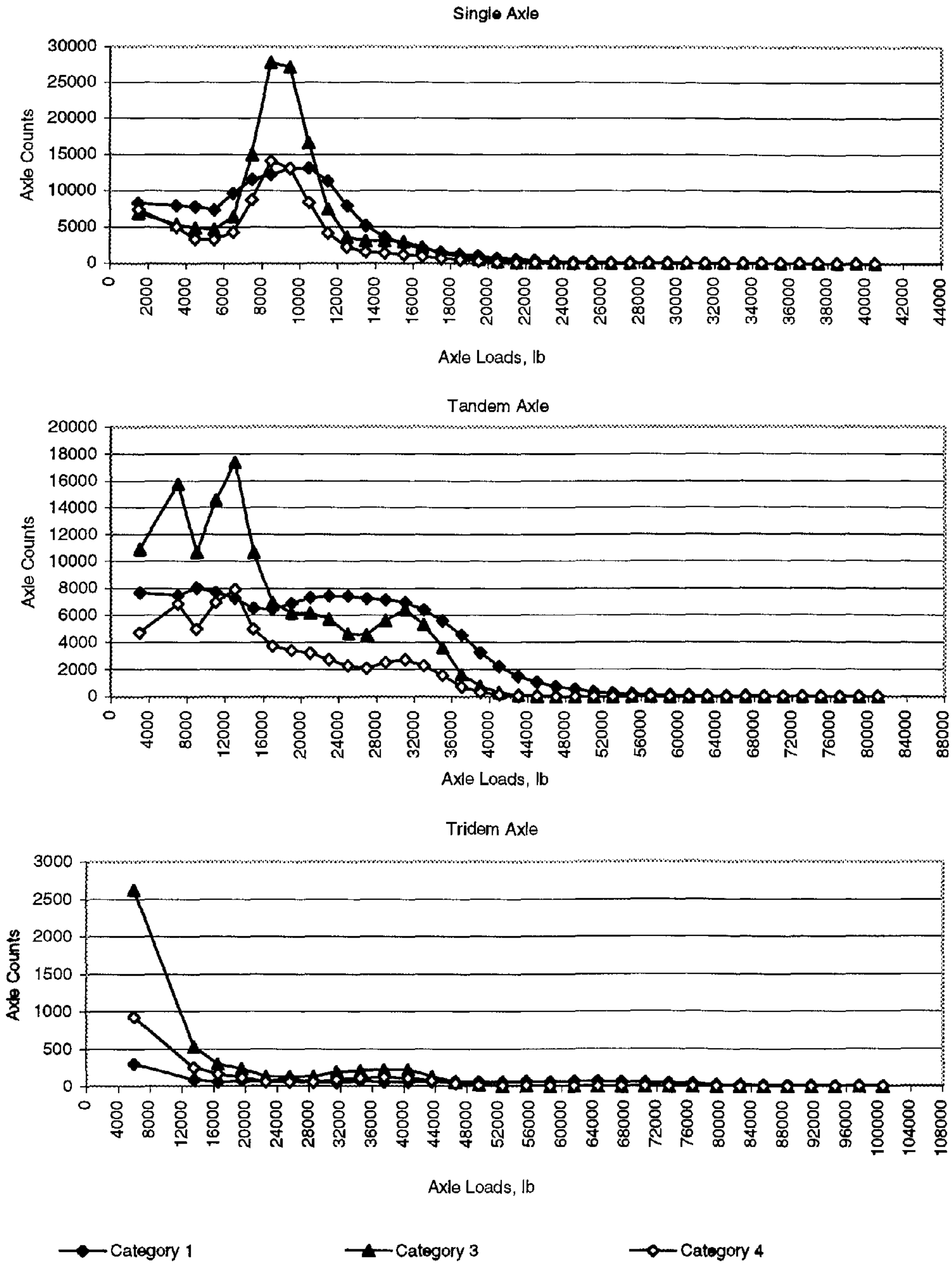


Figure 82. Historical and projected truck AADT volumes for Site 29-4036 for Category 4.

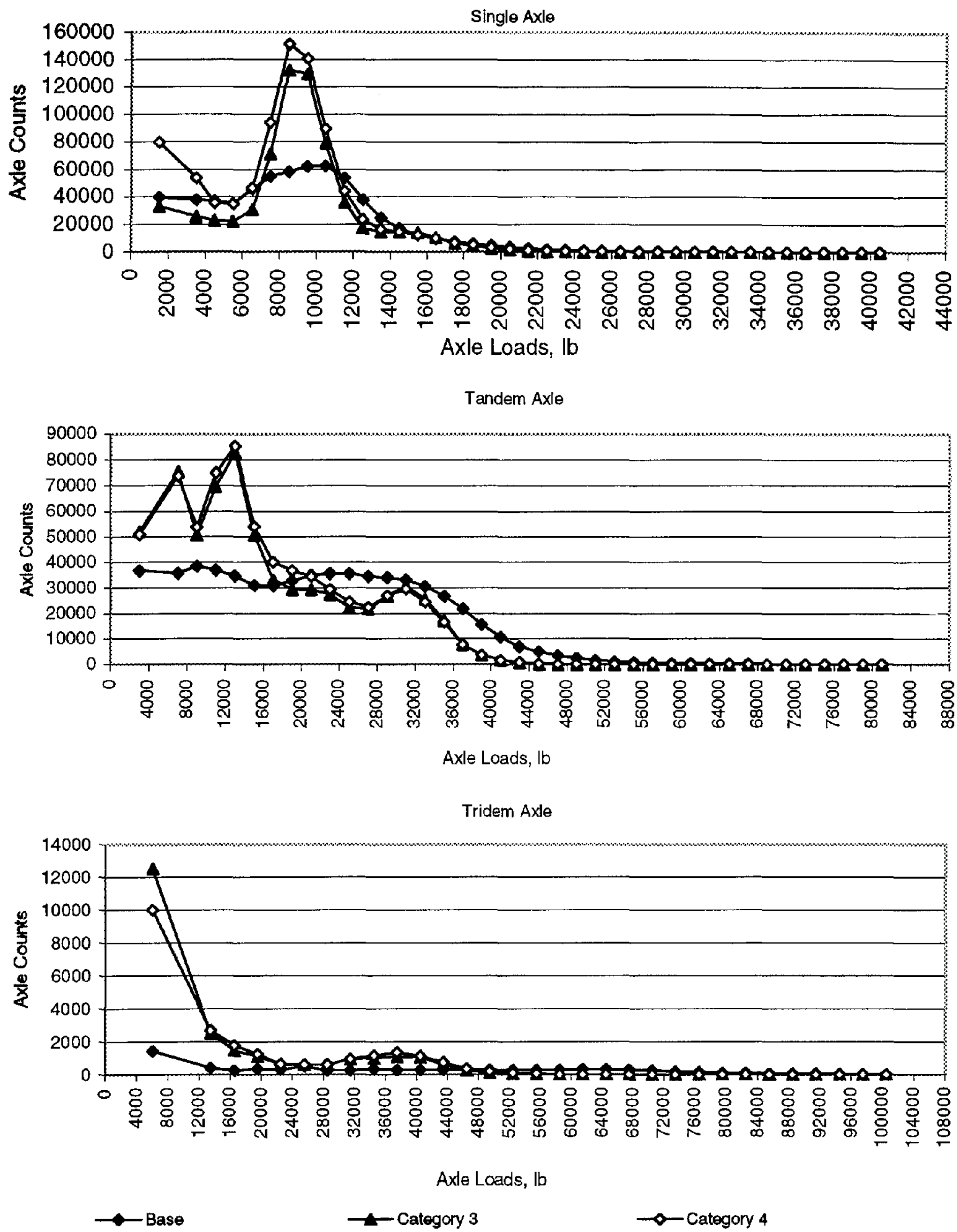
Table 40. Monitored and historical truck AADT volumes for Site 29-4036 for Categories 1, 3, and 4.

Year	Monitored Truck AADT	Historical Truck AADT	Category 1 & 3 Truck Volume	Category 4 Truck Volume
1983		242	289	168
1984		266	330	305
1985		295	375	442
1986		535	428	579
1987		932	487	715
1988		954	555	852
1989		848	632	989
1990	826		720	1126
1991	831		820	1263
1992	868		934	1399
1993	919		1064	1536
1994	1430		1212	1673
1995	1317		1380	1810
1996	1700		1572	1947
1997	1856		1791	2084



1 lb = 0.00445 kN

Figure 83. Comparison of 1983 load spectra for Site 29-4036.



1 lb = 0.00445 kN

Figure 84. Comparison of 1995 load spectra for Site 29-4036.

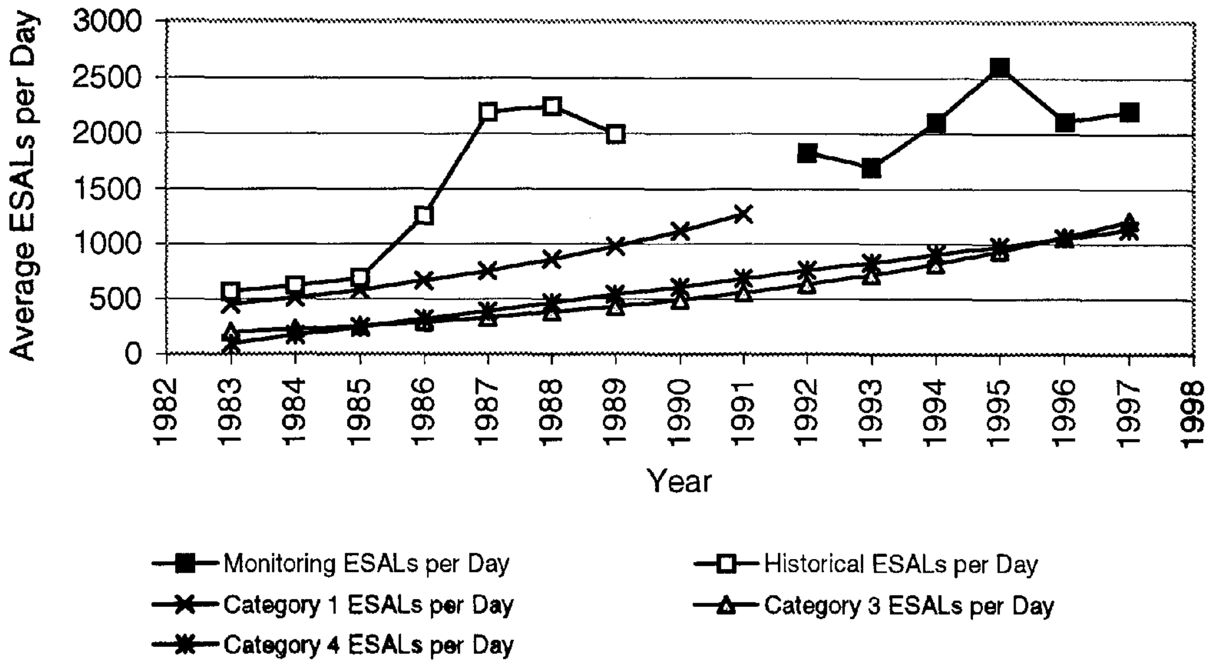


Figure 85. Comparison of ESAL volumes for Site 29-4036.

Table 41. Comparison of ESAL volumes for Site 29-4036.

Year	Monitoring ESALs per Day	Historical ESALs per Day	Category 1 ESALs per Day	Category 3 ESALs per Day	Category 4 ESALs per Day
1983		570	449	196	91
1984		625	511	223	165
1985		693	582	254	240
1986		1258	663	290	314
1987		2192	756	330	388
1988		2244	861	376	462
1989		1995	980	428	536
1990			1117	487	611
1991			1272	555	685
1992	1824			632	759
1993	1698			720	833
1994	2102			821	908
1995	2603			935	982
1996	2109			1065	1056
1997	2203			1213	1130

Note: Categories 1 and 3 have the same truck volume growth curve, but different base spectra.

Cumulative ESALs for Category 1 = 7,201,762
Cumulative ESALs for Category 3 = 3,111,247
Cumulative ESALs for Category 4 = 3,343,464

CHAPTER 6. STATISTICAL MEASURES AND TOOLS FOR MANAGING TRAFFIC LOADS

THE NEED FOR SUMMARY TRAFFIC LOAD STATISTICS

Pavement traffic loads consist of a large number of car and truck axles passing over the pavement. Current vehicle monitoring equipment, such as WIM scales, can measure and record axle weights and axle spacings for the majority of truck axles that pass over the pavement during its lifespan and can produce millions of records. Consequently, the management of traffic loads, including quality assurance, data storage, routine use of traffic load data, and forecasting of traffic loads, requires the use of summary statistical measures. Traditionally, a summary measure used was the number of ESALs as defined in the *AASHTO Guide for the Design of Pavement Structures* [18].

It can be argued that, because we are moving toward mechanistic pavement design, we do not need ESALs, but rather load spectra. The argument presented here is not against using load spectra, but rather for the development of summary measures to facilitate working with load spectra, and to support the use of spectra by providing tools for summarizing and comparing them.

Working with load spectra is not an easy task. Considering the existence of just 3 axle configurations (single, tandem, and tridem) and about 30 weight categories for each axle configuration, the resulting load spectrum is represented by a matrix with 4 columns (a load-range column and 3 axle configurations) and 30 rows (for the 30 weight categories). The 30 x 4 load spectrum matrix is difficult to assess in terms of overall size. Just for quality assurance purposes, we need to summarize load spectra to ascertain the overall dimensions of the traffic load. It should also be realized that the effect of traffic loads on pavement damage increases exponentially with the size of the load. Consequently, conventional statistical measures, such as a mean or a variance, are not related to the influence that these measures have on load-associated pavement damage. For example, two spectra with the same mean may have a different effect on pavement damage.

The AASHTO Guide mentioned above defines axle load equivalency factors (LEF), which can be used to obtain ESALs. A LEF can be viewed as a pavement damage factor (or index) assigned to each specific axle load. The size of the index is related to a standard load of 80 kN (18,000 lb). When the specific load occurs, its corresponding index materializes and results in ESALs. In other words, the relationship between LEF and ESALs is similar to that between a price list and a shopping bill. For example, if a single axle weighing 89 kN (20,000 lb) has a LEF of 1.5, the passage of 10 such axles (each weighing 89 kN [20,000 lb]) results in ESALs equal to 15.0. By repeating this procedure for other axle loads and summing the results, it is possible to convert millions of different axle loads into one number—the number of ESALs.

Over the years, several different authors and agencies have proposed and used many different LEFs. Even though the definition of LEF differs, the vast majority of the definitions are based on a rational engineering basis. The most widely used LEFs are the AASHTO factors, which depend on the following variables:

- Pavement type (flexible or rigid).
- Pavement thickness (structural number for flexible pavements, slab thickness for rigid pavements).
- Axle configuration (single, tandem, or tridem). No LEFs are provided by AASHTO for quadruple or higher axle groups.
- Pavement serviceability, initial serviceability, and serviceability at the end of the pavement's lifespan in terms of present serviceability index.

Because ESALs based on AASHTO LEFs depend on pavement type, thickness, and pavement serviceability, the comparison of traffic loads for different sections based on ESALs (e.g., in terms of ESALs per truck or the total number of ESALs per year) is only approximate and may lead to misunderstanding. For example, ESALs can change even though the traffic stream does not change (e.g., between two intersections) just because of the change in the pavement type or because the pavement was rehabilitated. The main practical advantage of ESALs is their well-recognized relationship to pavement damage.

There is a need for a traffic load statistic (such as ESALs) that is independent of pavement variables in the same way that AADT volumes are. Such a statistic would be particularly useful for the management of traffic loads for the LTPP experiment because LTPP sites encompass pavements of different types and thicknesses, and there is a need for a common benchmark to evaluate, assess, and compare traffic loads across all sites.

To illustrate the advantages of developing and using LEFs that are independent of pavement type and thickness, figure 86 is presented [19]. This figure shows average AASHTO ESALs for five-axle tractor-semitrailers (vehicle class 9) on rural Interstates in several States. The data suggest that there are considerable differences in ESALs for these vehicles between States. However, it is uncertain to what degree these differences can also be attributed to the influence of pavement-related variables (pavement type, thickness, and serviceability).

The influence of some of the pavement-related variables is illustrated using data taken from reference 20 and presented in table 42. Data in table 42 show the variations in the average AASHTO ESALs for five-axle tractor-semitrailers based on WIM data from Florida. Comparing these variations with the ESAL variations given in figure 86, it appears that the variations in ESALs per truck reported for different States are roughly equivalent to that for different pavements.

Table 42. Average ESALs per FHWA vehicle class 9 (predominantly five-axle tractor-semitrailer), urban Interstates.

Pavement Type	**Flexible Pavement**		**Rigid Pavement**	
Thickness	SN = 3	SN = 5	D = 9	D = 12
ESALs/Class 9	1.05	0.99	1.53	1.62

Notes: SN = Structural number (a number related to the thickness of pavement layers and their materials).
D = Thickness of the PCC slab in inches.

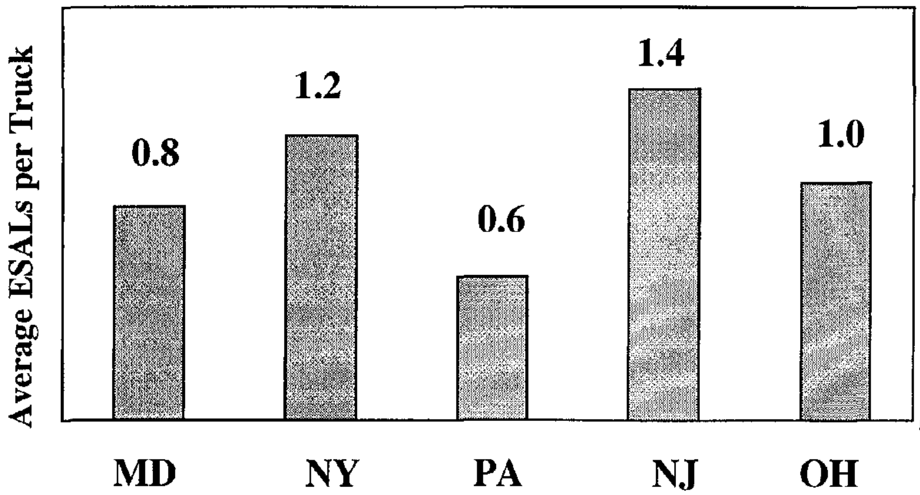


Figure 86. Number of average ESALs per five-axle tractor-semitrailer on rural Interstates.

A typical variation in ESALs due to pavement-related variables, expressed as the percentage of the ESAL value, is shown in table 43.

Table 43. Influence of pavement-related variables on AASHTO LEFs.

Parameter	Percent Change in LEFs	
	Flexible Pavement	**Rigid Pavement**
Initial Serviceability	± 2 to 4%	less than 1%
SN or D	± 5 to 10%	± 5%
Terminal Serviceability	10 to 20%	4 to 8%
Pavement Type	0% for single axles, 40% for tandem axles, and 140% for tridem axles	

Note: Some of the entries in the table are based on reference 21. LEFs also depend on pavement distress used to define serviceability. For AASHTO LEFs, serviceability is defined mainly in terms of roughness.

Because different pavement-related variables could have been used for the calculation of ESALs presented in figure 86, it is not possible to attribute the differences in ESALs between the States to traffic conditions only. This is a significant loss of information because, for quality assurance and forecasting purposes, the knowledge of variation in the average ESALs for different truck types is useful.

What is required is a summary traffic load statistic that: (1) is independent of pavement variables, (2) is related to pavement damage, and (3) has a familiar meaning and magnitude. With these needs in mind, two statistical measures are proposed in this chapter:

- Load Spectra Coefficients (LSCs) to summarize individual load spectra.
- General LEFs to summarize the load spectra of traffic streams.

LOAD SPECTRA COEFFICIENTS

The need to compare, assess, or evaluate axle load spectra is well recognized. Several approaches have been proposed to do so, ranging from plotting the load distributions to using non-parametric statistical tests. Some of these approaches are discussed below.

In addition to plotting the spectra, values of load spectra at different percentile levels can also be calculated and compared. The Interim Report [5] describes the use of sigmoidal curve parameters to compare spectra. When the cumulative percentage of the number of axles within each weight group is plotted against the mid-range of the weight group, an S-shaped (sigmoidal) curve is obtained, as illustrated in figures 7 through 9 (chapter 2). Statistically, this relationship is called a *cumulative density function.* A sigmoidal curve is fitted to the data using non-linear regression, providing two parameters that characterize the load spectrum. The sigmoidal curve is of the form:

$$N = 100 * e^{-\left(\frac{\rho}{w}\right)^{\beta}} \quad \textbf{(6)}$$

where:	N	=	Cumulative percentage of the number of axles.
	e	=	Number such as that in e = 1.
	ρ, β	=	Curve parameters.
	w	=	Mid-value of load range.

Each cumulative density function can be characterized by parameters ρ and β. The two parameters are then evaluated to observe whether there are patterns in their change over time. It was observed that these parameters provide a convenient way of describing the percentage breakdown of the load spectra over time. This technique was used to assess load spectra in the Interim Report [5]. However, a uniform increase in the spectra (or the uniform growth in the number of axles) cannot be examined by using the two parameters.

Kim et al. [8] used the Kruskal-Wallis test to evaluate whether the differences in the axle load distributions (single, tandem, and tridem axle distributions obtained as Statewide averages for LTPP sections in the North Central Region) were statistically significant. Kim et al. also used polynomial forms of regression equations to model the cumulative distribution of axle loads.

Cunagin and Goff [12] used the Kolmogorov-Smirnov test to compare cumulative axle load distribution functions obtained for several non-LTPP sites. They concluded that even the sites that had similarly shaped gross vehicle weight distributions had significantly different load spectra, in part due to the large data samples provided by WIM scales. This result highlights the problem of comparing load spectra using parameters that are not related to pavement performance prediction or pavement damage. For example, a statistically significant difference between two cumulative load distributions ascertained using the Kolmogorov-Smirnov test (or the t-test comparing 85th-percentile differences between the two spectra) does not mean that the two spectra have a significantly, or even practically, different influence on pavement performance. It should be stressed that the tests of statistical significance depend largely on the number of observations. Given high traffic volumes and the capabilities of WIM scales, the number of observations available for the comparisons can be quite large, making the statistical assertions of significance relatively frequent—but without any practical significance, such as the linkage to pavement performance.

In conclusion, we need statistical measures that are related to the concept of pavement damage and are independent of pavement-related variables. The LSC, introduced in chapter 4, can fulfill this need. The LSCs for normalized load spectra were defined by equation 7:

$$LSC = \sum_{i=1}^{i=l} \left(\frac{\left(\frac{mid\text{-}load\ range_i}{L} \right)}{18{,}000} \right)^{3.8} * \frac{load\text{-}range\ count_i}{total\ count} * L \quad \textbf{(7)}$$

where: *LSC* = Load spectrum coefficient used to compare normalized load spectra.
l = Number of load ranges (the numbers may differ for single, tandem, and tridem axles).
mid-load range$_i$ = Average load range in pounds for load range i, e.g., if the load range is 6,000 to 6,999, use 6,500.
load-range count$_i$ = Number of axles in load range i.
L = 1 for single axles, 2 for tandem, and 3 for tridem. (L converts the effect of tandem and tridem axles into that for single axles.)

Before discussing the features of the LSC, it is useful to define a companion summary measure—a general axle load equivalency factor—and then discuss the two measures together.

GENERAL AXLE LOAD EQUIVALENCY FACTORS

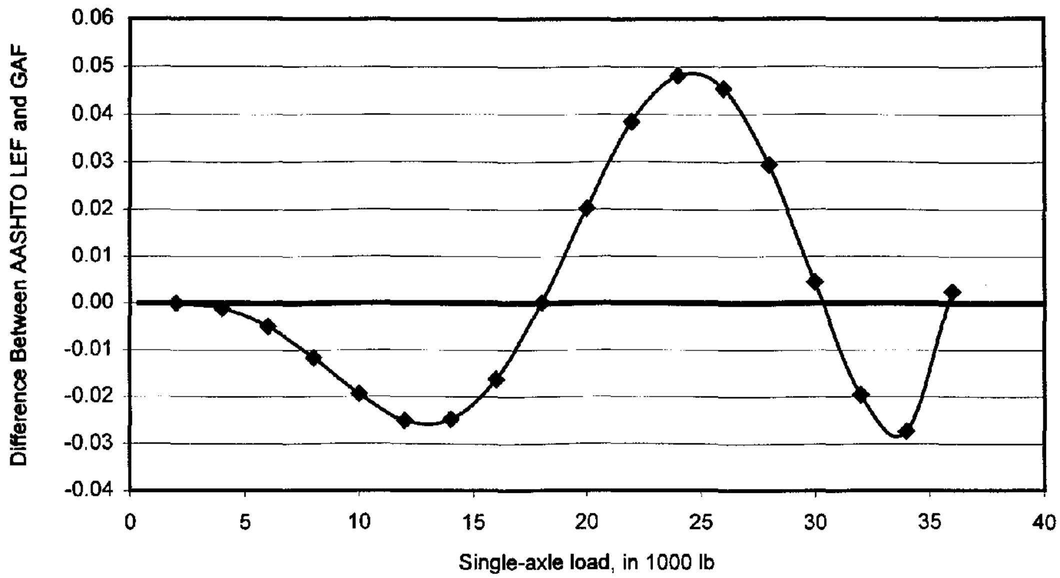
The general axle load equivalency factors, or general axle factors (GAF), are defined by equation 8:

$$GAF = \left(\frac{W}{18{,}000} \right)^{3.8} \quad \textbf{(8)}$$

where: *W* = Axle load of any type or spacing in pounds.

GAFs have a similar meaning and roughly the same magnitude as the AASHTO LEFs. In fact, GAFs are virtually identical to AASHTO LEFs for single-axle loads for flexible pavements with the structural number equal to 5 and the terminal serviceability index equal to 2.5. This is illustrated in figure 87, which shows that the biggest difference between the

AASHTO LEF and the GAF for the practical range of single-axle loads (4 to 160 kN [1,000 to 36,000 lb]) is about 0.05, or about 2 percent of the LEF value.



1 lb = 0.00445 kN

Figure 87. Comparison of differences between AASHTO LEF and GAF for single axles.

The sum of the GAFs for all axles of a truck equals a general truck factor (GTF). If the GTF were used in figure 86 (instead of the AASHTO-based truck factors), the differences between States could have been attributed directly to loading conditions. The use of the GAF for the calculation of the ESAL will yield the general ESAL (GESAL).

Like LSCs and GAFs, GESALs are also independent of pavement type and thickness, level and type of pavement distress, and axle type. Any changes in LSCs and GAFs can be attributed directly to changes in traffic loads.

LSCs and GAFs have the same exponent of 3.8. This results in a unique relationship between LSCs and GAFs. For example, the following two calculations will yield identical GESALs for an axle load spectrum:

Calculation 1 Using LSC:

- Transform the load spectrum into a normalized spectrum (by expressing the actual axle counts as percentages of the total counts) and the corresponding total number of axles. Note that a load spectrum is equal to its normalized form multiplied by the total number of axles.

- Calculate the LSC for the normalized spectrum (using equation 7).

- Multiply the LSC by the corresponding number of axles to obtain the GESAL for the spectrum.

Calculation 2 Using GAF (this calculation is identical to the ESAL calculation):

- Calculate the GAF for each load range of the axle load spectrum using equation 8.

- Multiply the GAF obtained for each load range by the number of axles for the load range.

- Sum the results obtained for each load range to obtain the GESAL for the spectrum.

In summary, the management of traffic loads can be greatly simplified using the proposed LSCs and GAFs. The simplification would be particularly useful for quality assurance activities and for projecting traffic loads for LTPP sections. Some of the consequences of using GAF for pavement design are described in reference 22.

LTPP TRAFFIC LOADING GUIDE

As documented extensively in chapters 4 and 5, many traffic projection activities, such as decisions regarding the acceptance of data (as part of quality assurance) and the selection of traffic growth factors, require judgment. In particular, base axle load spectra for individual trucks and base truck volume distribution, required for Category 3 and 4 projections, must be selected judiciously. However, in the absence of guidelines for what is acceptable or expected, and without the support and reliance on a well-organized and well-documented knowledge base, the exercise of judgment is difficult. The lack of benchmark values can be overcome by the development of a catalog of benchmark values of normalized load spectra, truck factors, vehicle-type distributions, and so on.

Such a catalog or guide can be produced through an iterative process during the course of Phase 2 work. As sites are assessed, applicable information can be assessed and synthesized for inclusion into the Traffic Loading Guide. As work progresses, the collected information will start to fulfill its quality assurance and traffic projection guiding roles. Subsequently, data can be refined, presented in a user-friendly format, and supplemented by instructions for use.

A Pavement Traffic Loading Guide should include information on the following factors:

- Typical truck volume distributions for common highway functional types.

- Typical normalized axle load spectra (for vehicle classes 4 through 13) for common highway function types. The normalized axle load spectra should be accompanied by the corresponding number of axles and by the LSC.

- Typical ESALs (preferably GESALs) for the combination of vehicle classes and functional types.

- Typical traffic load spectra, and the corresponding LSC, for common highway functional types.

Table 44. Factors considered for inclusion in the proposed LTPP Traffic Loading Guide.

FHWA Highway Functional Type	FHWA Vehicle Classes 4 Through 13		Classes 4 Through 13 Combined
	Class 4	Classes 5, 6, 7 → 13	
Rural Interstates	• Normalized Axle Load Spectra • Axle per Vehicle Class • Load Spectra Coefficients • Typical ESAL/Truck	→ → → Same for the other vehicle classes →	• Normalized Truck Volume Distribution • Normalized Annual Load Spectra
• • •	• • • Repeat for other functional types		
Urban Collector	• • • • •	• • • • •	• • • • •

Even though the Guide has been conceived as an internal LTPP traffic projection tool, and to a certain degree as a byproduct and the synthesis of traffic projections that will be done in the course of Phase 2, it has the potential to become a useful product for pavement design engineers.

CHAPTER 7. COMPUTATION AND STORAGE OF PROJECTED TRAFFIC DATA

The projection of traffic loads requires a systematic approach to the process of analysis, computation, and storage of the projected data. This chapter describes computational procedures developed to generate projected annual axle load spectra for all in-service years of LTPP sections, and outlines how the projected data will be archived within the IMS Traffic Module.

In addition to generating the projected annual axle load spectra, the projection process will also yield a set of intermediate variables that are necessary to compute the projected load spectra. It is proposed that both the projected annual axle load spectra and the intermediate variables are stored in the IMS Traffic Module.

Figure 88 presents an overview of the existing IMS Traffic Module, consisting of historical and monitoring traffic data, and the proposed addition of the projected traffic data to the Traffic Module. Figure 88 also shows that the projected data will consist of the projected axle load spectra and the intermediate data elements. The intermediate data elements carry important information documenting how the projected axle load spectra were calculated. In addition to the structured traffic data elements stored in the IMS, additional site-specific documentation summarizing supporting data and underlying assumptions will be organized and maintained in separate files. The intermediate data elements and the additional site-specific documentation will enable future auditing of the projection process and/or the enhancement of the projections, e.g., if additional data become available.

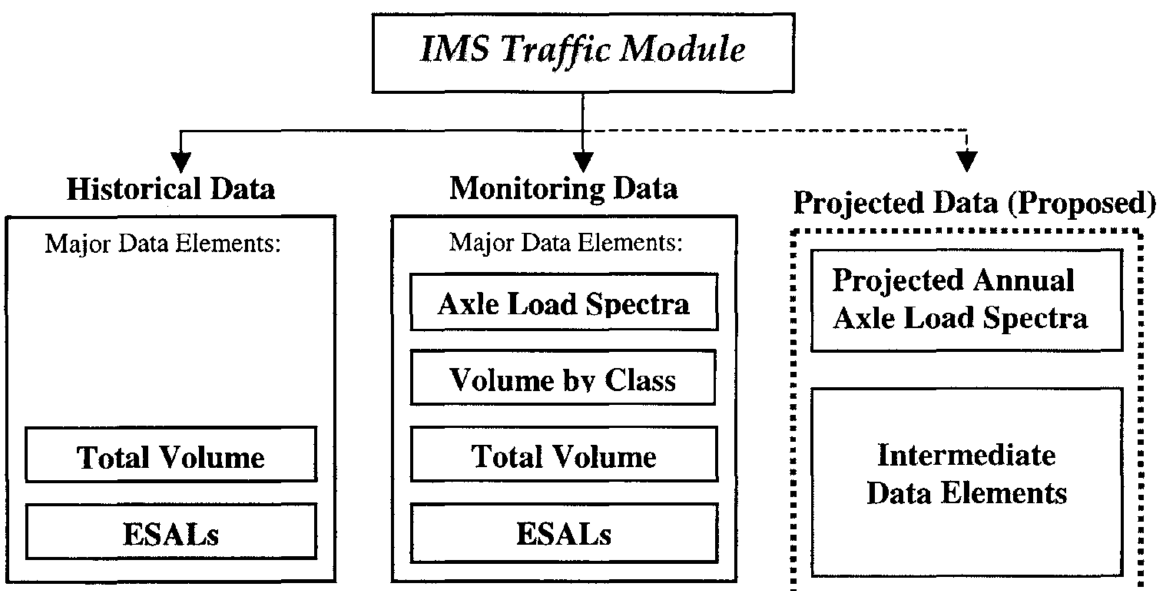


Figure 88. Overview of the IMS Traffic Module showing the proposed addition of projected data.

As a result of the projection methodology that was developed in chapter 4 and applied to case studies in chapter 5, a set of computed parameters tables was created to guide the computation and storage of the projected axle load spectra data and the intermediate supporting traffic projection data. This chapter also contains the description of the computed parameters tables and the relationships between the variables in the tables. The following list represents a set of the proposed computed parameters tables.

- Main Table:
  - Projected Annual Axle Load Spectra

- Intermediate Tables:
  - Annual Growth Factors
  - Base Annual Axle Load Spectra
  - Base Annual Axle Load Spectra by Vehicle Class
  - Base Vehicle Distribution by Class
  - Axle per Vehicle Class Factors

Depending on the availability of monthly monitoring data in the IMS database, an additional intermediate table containing monthly distribution factors will be included in the set of the computed parameters tables. Based on the availability and the amount of monitoring and historical data, four different methods were developed and used to calculate projected load spectra, as described in chapter 3. The summary of traffic data requirements for each projection category is presented in table 45.

Table 45. Description of the projected categories.

Category No.	Category Description
1	Projection method is based on site-specific truck volume (monitoring and historical) and site-specific truck weight distribution (monitoring) data available on a monthly basis.
2	Projection method is based on site-specific truck volume (monitoring and historical) and site-specific truck weight distribution (monitoring) data available on an annual basis.
3	Projection method is based on site-specific truck volume distribution by vehicle class (monitoring and historical) and regional truck weight distribution data.
4	Projection method is based on site-specific total truck volume (AADT) data, regional truck volume distribution data by vehicle class, and regional truck weight distribution data.

Figure 89 shows the proposed computed parameters tables and the hierarchy among the tables. The basic computed parameters table is shown by heavy borderlines. A description of the tables, as well as a description of the computational procedures required to obtain the tables follows, and is structured under the following headings:

- Computation of Annual Growth Factors.
- Computation of Base Annual Axle Load Spectra.
- Computation of Base Annual Axle Load Spectra by Vehicle Class.
- Computation of Base Vehicle Distribution by Class.
- Computation of Axle per Vehicle Class Factors.
- Computation of Monthly Distribution Factors.
- Computation of Projected Annual Axle Load Spectra.
- Summary of the Traffic Projection Process.

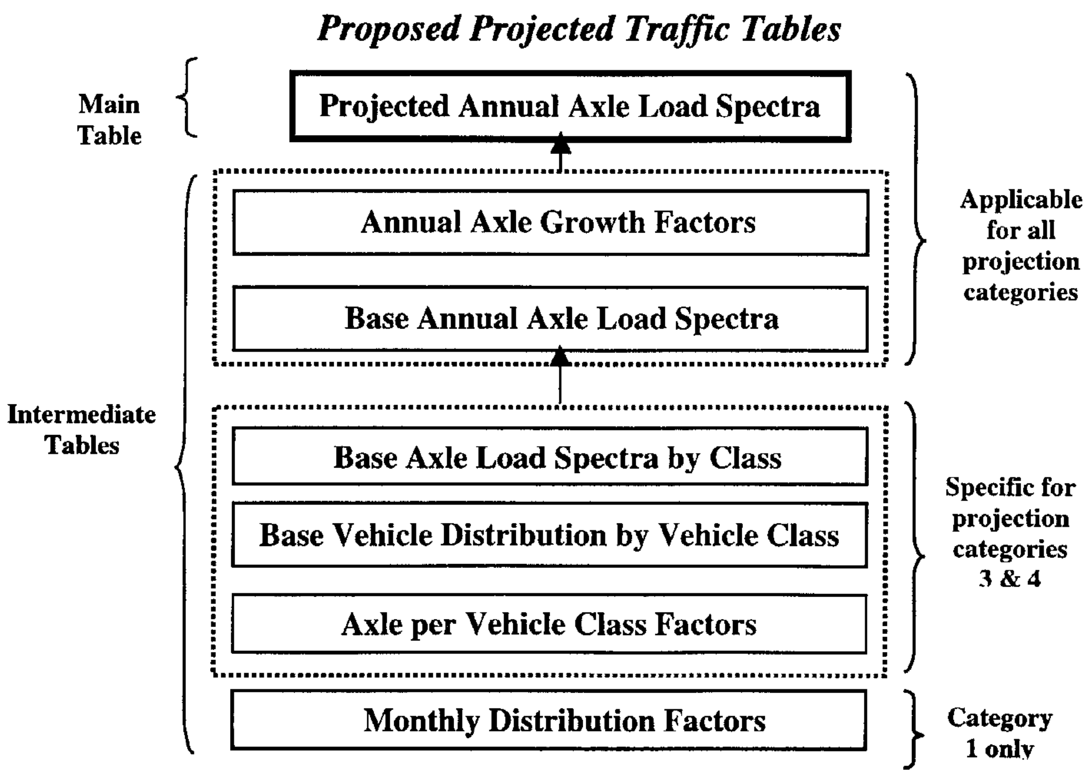


Figure 89. Summary of the proposed computed parameters tables.

COMPUTATION OF ANNUAL GROWTH FACTORS

The **Annual Growth Factors** table contains annual traffic growth factors calculated for each in-service year for the LTPP sites included in the table entitled, **Projected Annual Axle Load Spectra**. These factors are used to compute projected annual axle load spectra.

Annual traffic growth factors are determined as a result of a comprehensive analysis of all available site-specific monitoring and historical traffic data as outlined in chapter 4. The computational procedure for the annual growth factors is shown in figure 90.

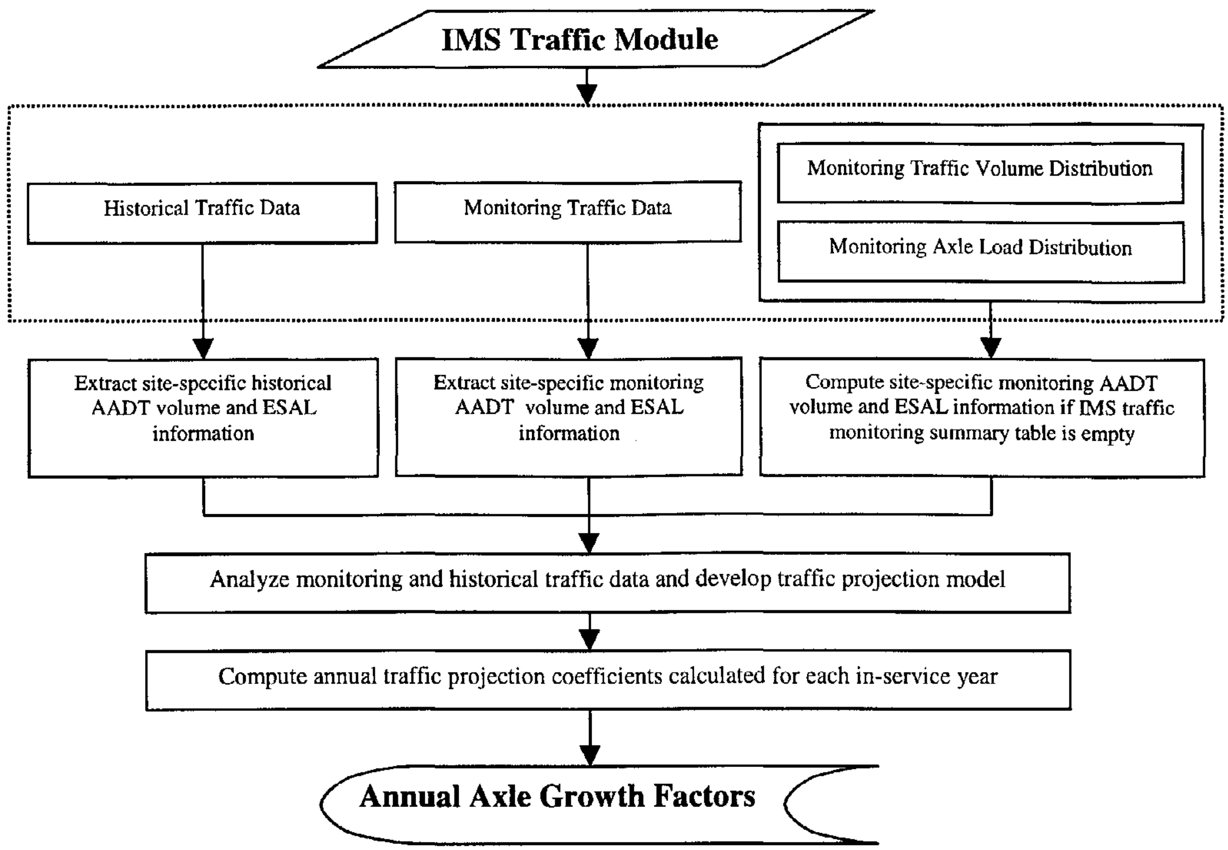


Figure 90. Flowchart for computation of the annual traffic growth factors.

COMPUTATION OF BASE ANNUAL AXLE LOAD SPECTRA

The table **Base Annual Axle Load Spectra** includes computed annual base load spectra for single, tandem, tridem, and quadruple axle groups. The base annual load spectrum is a typical load spectrum for each site that is included in the table **Projected Annual Axle Load Spectra**. The base annual load spectra are developed using guidelines given in chapter 4.

For the sites that fall into traffic projection Categories 1 and 2, the base axle load spectra are computed using available monitoring annual axle load spectra from the IMS traffic module. For the sites that fall into traffic projection Categories 3 and 4, the base spectra are computed using class-specific normalized regional base spectra from the new proposed table **Base Annual Axle Load Spectra by Vehicle Class.** In addition, knowledge of the base vehicle class distribution (from the table **Base Vehicle Distribution by Class**) and axles per truck coefficients (from the table **Axles per Vehicle Class Factors)** is required for the sites in traffic projection Categories 3 and 4. The computational procedure for the base annual axle load spectra is shown in figure 91.

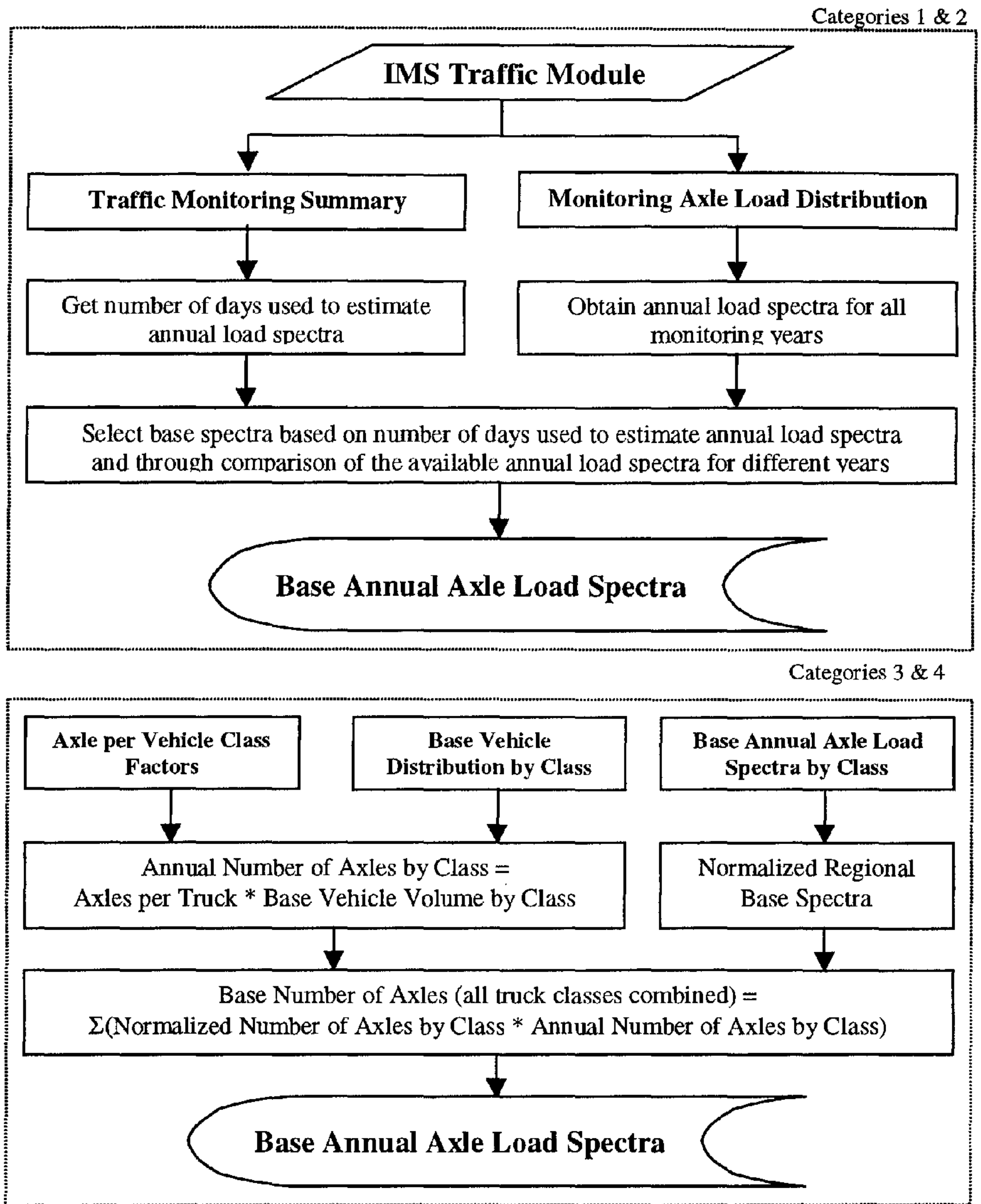


Figure 91. Flowchart for computation of the base annual axle load spectra.

COMPUTATION OF BASE ANNUAL AXLE LOAD SPECTRA BY VEHICLE CLASS

The **Base Annual Axle Load Spectra by Vehicle Class** table contains computed normalized and vehicle-class-specific base annual load spectra for LTPP sites falling under the requirements for traffic projection Categories 3 and 4. The normalized spectra are given for 10 FHWA vehicle classes (vehicle classes 4 through 13), and for each class, the spectra are given separately for single, tandem, tridem, and quadruple axle groups. The normalized vehicle-class-specific base spectra are computed using the vehicle-class-specific monitoring spectra for the sites that represent similar functional highway types and that are located in similar geographical regions as outlined in chapter 4. The data source for this table is vehicle-class-specific load spectra extracted from Level 2 LTPP CTDB data. The computational procedure for the normalized class-specific base spectra is shown in figure 92.

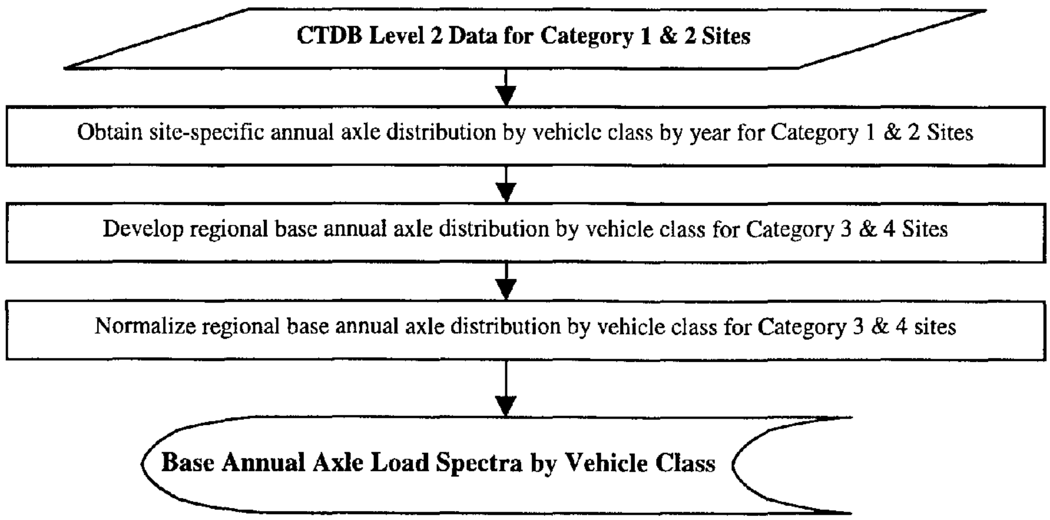


Figure 92. Flowchart for computation of the base annual load spectra by vehicle class.

COMPUTATION OF BASE VEHICLE DISTRIBUTION BY CLASS

The **Base Vehicle Distribution by Class** table contains base annual vehicle type distributions that were developed for the sections falling under the requirements for traffic projection Categories 3 and 4. For Category 3 sites, base annual vehicle type distributions are computed from site-specific monitoring annual vehicle type distributions stored in the IMS traffic module. For Category 4 sites, base annual vehicle distributions are computed using: (1) normalized monitoring annual vehicle type distributions for the sites that represent similar functional highway types and that are located in a similar geographical region, and (2) site-specific AADT truck values from the IMS traffic module. The computational procedure for the base annual vehicle type distributions is shown in figure 93.

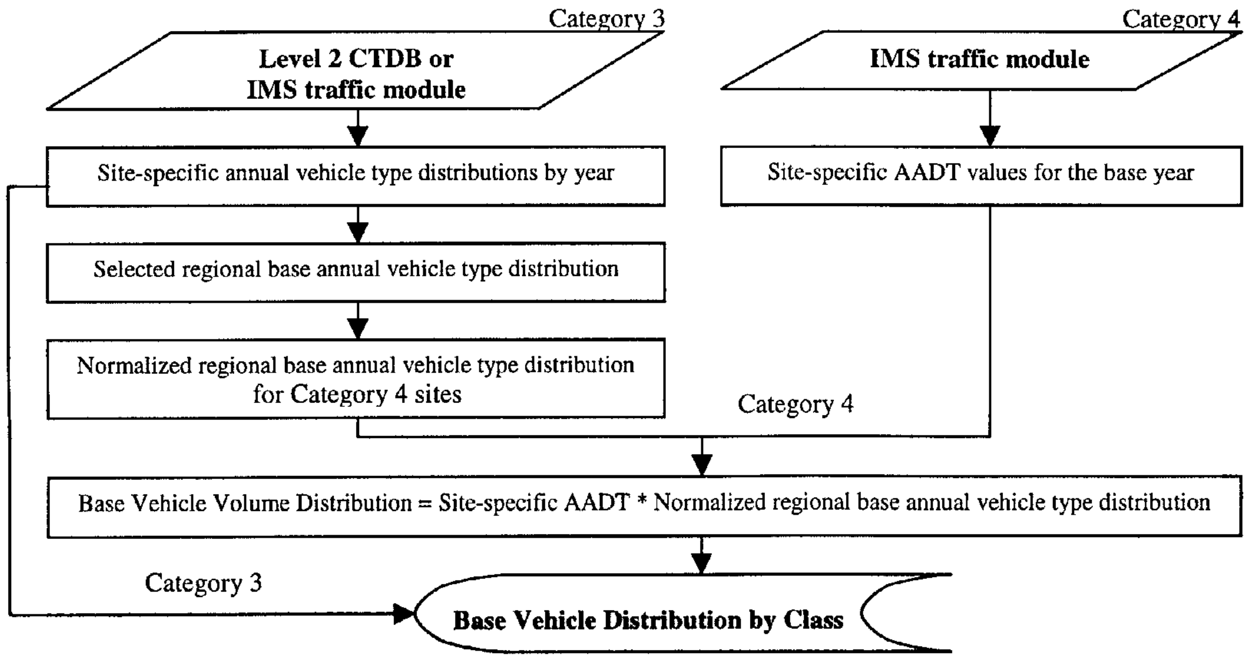


Figure 93. Flowchart for computation of the base annual vehicle distribution by class.

COMPUTATION OF AXLE PER VEHICLE CLASS FACTORS

The **Axle per Vehicle Class Factors** table contains a representative number of axles per vehicle for FHWA Classes 4 through 13 (trucks) for the sites in traffic projection Categories 3 and 4. This table is used in conjunction with **Base Vehicle Distribution by Class** and **Base Annual Axle Load Spectra by Class** tables to compute annual base spectra for the sites in the traffic projection Categories 3 and 4. The main data source for this table is class-specific axle counts and estimated vehicle counts extracted from Level 2 LTPP CTDB data. The computational procedure for the axles per truck factors is shown in figure 94.

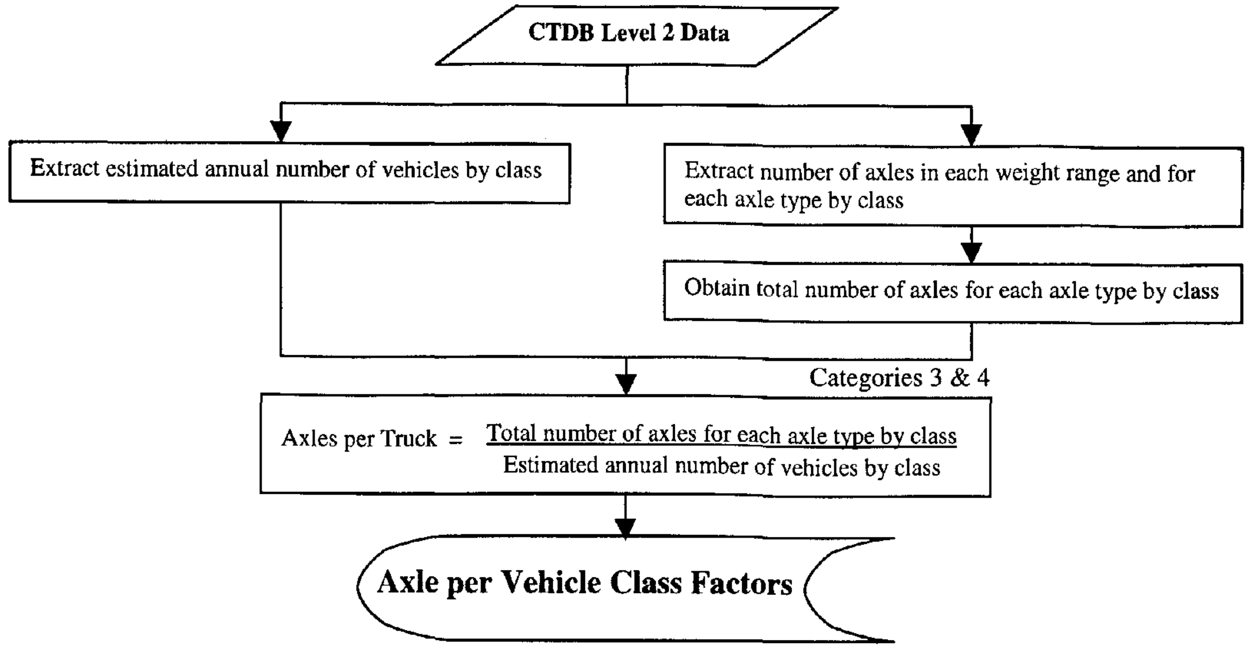


Figure 94. Flowchart for computation of the axle-per-truck factors.

COMPUTATION OF MONTHLY DISTRIBUTION FACTORS

Depending on the availability of the monthly monitoring data, the **Monthly Distribution Factors** table will be created. The proposed table contains a set of 12 representative monthly distribution factors, one for each month of the year. The monthly distribution factors are based on the average monthly ESAL distribution created using monthly monitoring data for all available monitoring years, as outlined in chapter 4. The monthly distribution factors are expressed as a percentage of the annual ESALs. These percentages serve as indicators of monthly fluctuation of the annual load spectra for all in-service years. For example, January load spectra may be 8 percent of the annual load spectra in terms of axle counts (in all individual load ranges), and July load spectra may be 13 percent of the annual spectra. Thus, the monthly distribution factors are used to compute monthly load spectra. The monthly load spectra are computed by multiplying the projected annual axle load spectra (from the **Projected Annual Axle Load Spectra** table) by the monthly distribution factors. Computed monthly load spectra could be further summed over the selected years to obtain cumulative monthly spectra for a desired time period.

COMPUTATION OF PROJECTED ANNUAL AXLE LOAD SPECTRA

The table **Projected Annual Axle Load Spectra** contains projected annual axle load distributions (load spectra) for single, tandem, tridem, and quadruple axle groups for LTPP sections computed for each in-service year. The projected annual load spectrum for each year is computed by multiplying the base annual load spectrum (from the table **Projected Annual Axle Load Spectra)** by the annual traffic projection factors (from the table **Annual Axle Growth Factors**). The summation of axle counts from the **Projected Annual Axle Load Spectra** table over a specified period of time yields cumulative axle loading for a given LTPP section. The computational procedure for the projected annual axle load spectra is shown in figure 95.

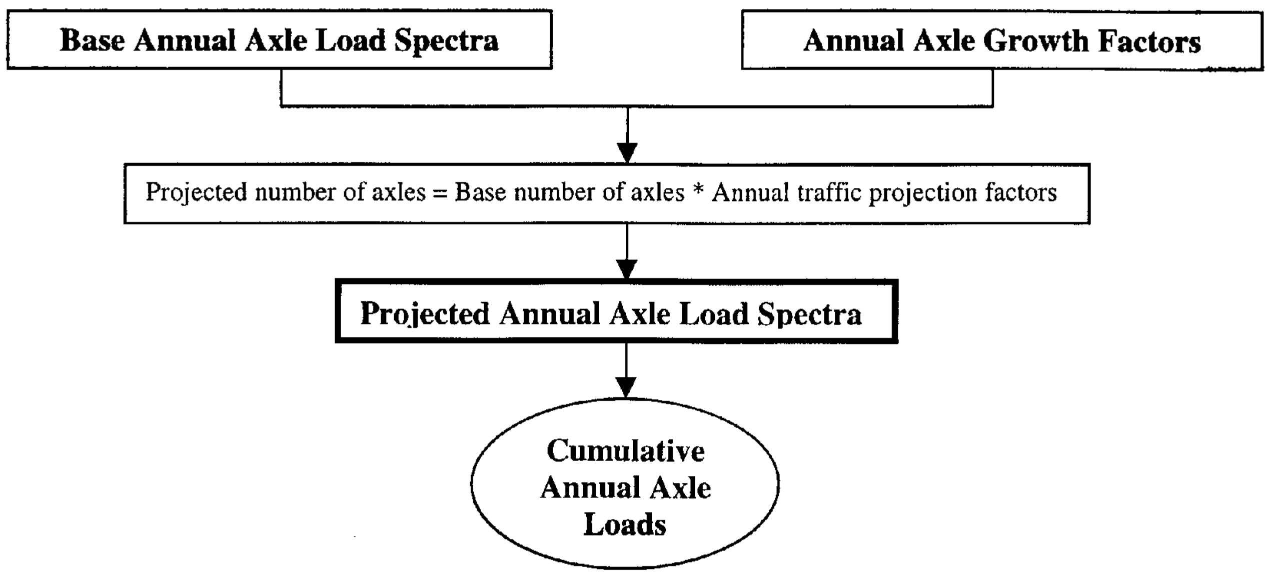


Figure 95. Flowchart for computation of projected annual axle load spectra.

SUMMARY OF TRAFFIC PROJECTION PROCESS

This section presents an overall summary of the traffic projection process, as illustrated in figure 95. This flowchart shows the relationships between the existing IMS Traffic Module and proposed computed parameters tables, and the way in which the tables are derived. The basic computed parameters table is highlighted by heavy border lines. Currently, there is no provision for the tables containing data elements shown in oval shapes (cumulative axle loads by year and by month). However, these tables can be easily computed from the projected axle load spectra.

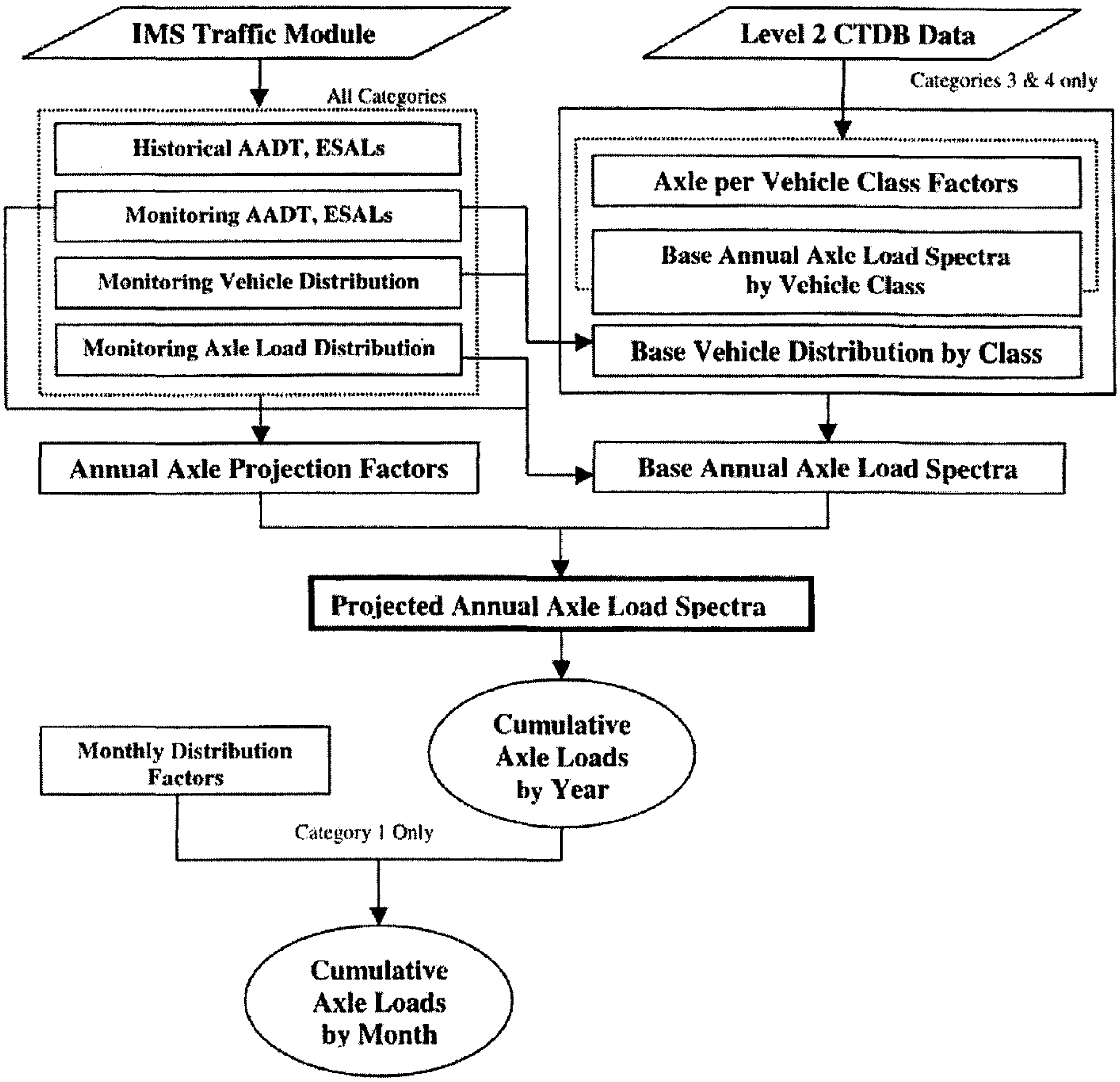


Figure 96. Overall outline of traffic projection process.

CHAPTER 8. SUMMARY AND RECOMMENDATIONS

SUMMARY

Knowledge of cumulative truck axle loads is a crucial part of the pavement performance analysis process. In order to obtain traffic loads for the entire in-service life of the LTPP pavement sections, monitoring axle loading data available in the LTPP database for a limited number of years have to be projected to cover the whole pavement service life. The process of traffic loading projection is not simple and requires considerable knowledge of traffic data and expertise. The loads should be projected in a systematic manner using a uniform approach. To unify the process of traffic projection, a comprehensive traffic load spectra projection methodology, applicable to all the LTPP sites, was developed and tested on case studies. Projected load spectra and intermediate variables computed using this methodology are proposed to be included in the IMS database.

This report describes a methodology developed for projecting axle load spectra for LTPP sections. An axle load spectrum is defined as the distribution of single, tandem, and tridem axles into load ranges. Typically, there are only a few years for which axle load spectra were collected for LTPP sections using automated equipment—AVC and WIM. Data collected by automated equipment are called *monitoring data*; data estimated by the SHAs before the installation of the automated equipment are called *historical data.*

To obtain axle load spectra for all in-service years of LTPP sections, the traffic loads have to be backcasted (for the years before the installation of traffic monitoring equipment) as well as forecasted (for the years after the automated equipment stopped functioning). In this report, this process of estimating traffic data both before and after the data collection period is called *projecting.*

Because of the large differences in the quantity and quality of traffic data available for the LTPP sites, four alternative traffic data projection procedures, called *projection categories*, were developed and used:

Category 1 is intended for LTPP sections that have sufficient AVC and WIM data to enable projection of monthly variation in traffic loads.

Category 2 is for LTPP sections with both AVC and WIM data; however, compared to Category 1, the amount of data is insufficient for projection of monthly variation in traffic loads.

Category 3 represents sections with adequate AVC data, but with virtually no site-specific WIM data.

Category 4 represents LTPP sections with virtually no reliable measured AVC and WIM monitoring data.

Regardless of the projection category, the basic procedure for projecting axle load spectra for the LTPP sections includes the following steps:

1. All available annual historical and monitoring data are used to establish annual growth factors.

2. A base annual axle load spectrum, representing a typical annual load spectrum, is established.

3. For the years with missing annual monitoring load spectra, the missing spectra are obtained by multiplying the base annual load spectrum by the growth factors.

4. As an option, a cumulative axle load spectrum can be obtained by summing the annual spectra for all in-service years.

The methodology for projecting axle load spectra was evaluated and demonstrated using case studies for specific LTPP sections. Altogether, 12 case studies were conducted (3 studies for each projection category). Case studies also included sensitivity analyses that addressed the following topics:

- Effect of key assumptions used in the traffic load projection process.

- Reliability of historical traffic loading estimates.

- Effect of quantity of monitoring traffic data.

Traffic loads are applied to pavements by way of the truck technology that has been evolving during the lifespan of the LTPP sections. It is important to understand the nature and significance of these changes. The report contains a review of the evolution of motor carrier technology in terms of economical and political changes, regulatory changes in vehicle weights and dimensions, and engineering changes, and explains the difference between projecting traffic loads and volumes and projecting truck technology.

To facilitate the management of axle load spectra, two summary statistical measures were developed: Load Spectra Coefficients and General Equivalency Factors. To obtain benchmarks for carrying out quality assurance and traffic data projections, a proposal to develop an LTPP Traffic Loading Guide or a catalog is also described in the report.

CONCLUSIONS

The following are major conclusions based on the Phase 1 study.

- Traffic load projections for the majority of LTPP sites are feasible. The proposed procedure yields axle load spectra for: (1) all in-service years of the LTPP sections; (2) single, tandem, and tridem axles; and (3) all trucks combined

(FHWA vehicle Classes 4 through 13). The cumulative axle load spectra can be obtained by summing the annual axle load spectra.

- To bestow confidence in traffic load projections, the projection procedure needs to be transparent and well documented.

- The accuracy and reliability of the traffic projections for many of the LTPP sites may not be as high as originally anticipated.

- The involvement of the SHAs in the predictive process is crucial. Many data problems cannot be resolved without local involvement. Specific issues requiring input from local agencies include:

  - Relationship between historical and monitoring data.
  - Reasons for inconsistencies in historical and monitoring data.
  - Vehicle weight and dimension regulations.
  - Access to quality assurance/quality control information, such as WIM and AVC calibration data.
  - Changes in local traffic patterns (e.g., because of closing and opening of parallel highways, changes in the location and operation of major truck destinations or generators).
  - Availability of AVC and WIM data from nearby traffic monitoring installations that are not part of the LTPP study.

- The traffic projection process is very challenging and labor-intensive. The main reason for the labor-intensive process is the need to carry out the extensive quality assurance activities required to resolve inconsistencies in the reported data and to address differences between the historical and monitoring traffic data, as well as the differences between monitoring data obtained for different years.

- Based on the experience with the case studies, the majority of the traffic projection effort was actually spent on quality assurance issues. There is a natural tendency to believe that the data collected by traffic monitoring equipment are correct. To prove otherwise requires careful assessment of all available data, engineering judgment supported by extensive knowledge of traffic load characteristics, and the involvement of the SHAs.

- It would help if the basic quality assurance activities were done previously. However, it is difficult to separate quality assurance from traffic projections because of the synergy between these two activities. Also, some data problems are revealed only during the traffic projection process.

- Base axle load spectra for individual trucks and base truck volume distributions, required for Category 3 and 4 projections, must be selected judiciously, and this selection must be supported by a sound, well-organized, and well-documented knowledge base. In this connection, the development of an LTPP Pavement Loading Guide or a catalog is proposed.

- The quality assurance process would greatly benefit from the development of a knowledge base or a catalog documenting a typical range of traffic load variables. The process would also benefit from the availability of summary measures for traffic loads that are independent of pavement variables.

- Sensitivity analyses are useful to quantify the effect of key assumptions made during the prediction process.

- Several data inconsistencies exist in the CTDB. For example, data in several traffic monitoring tables are conflicting or missing; calculated ESALs reported in the IMS appear to conflict with ESALs calculated in the course of conducting a case study for Site 29-5483.

- The traffic prediction process triggers and requires a comprehensive quality assurance process of underlying traffic data, particularly the comparison of annual trends. The result of the quality assurance process is an essential and valuable product. Without this process, the results of many studies using traffic data that have been done or will be done are suspect and questionable.

- Traffic modeling is a highly cost-effective way to extend limited sampling data and to compensate for the lack of data. The collection of traffic data in the field, which requires the purchasing, installation, maintenance, and operation of AVC and WIM equipment, and the processing of data, is expensive (with an approximate annualized cost of $20,000 or more per site). To obtain a payback on this investment and to preserve the integrity of the LTPP program, it is necessary to allocate sufficient effort to fully utilize the available traffic data through the projection process.

RECOMMENDATIONS

- Proceed with launching the Phase 2 study. The objective of the Phase 2 Traffic Backcasting Study will be to produce and archive traffic load spectra for selected LTPP sites using the methodology developed in Phase 1.

- Involve the representatives of the SHAs in any future traffic projection process.

- Carry out fundamental quality assurance by systematically comparing the correspondence between the annual historical and monitoring traffic data and the relationship between the annual monitoring traffic data obtained for different years. It is important to note that the most efficient way to do so is within the framework of, and simultaneously with, the traffic projection process.

- Seek input from those responsible for LTPP pavement performance modeling regarding the importance of providing:

  - Separate projections of single-axle loads with single tires (steering axles) versus double tires. At present, this distinction is not made in the CTDB. However, it is possible to make it through the traffic projection process and modeling.

  - Projections of total traffic volumes. Only the truck volumes were projected in Phase 1.

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20. Florida Department of Transportation, Transportation Statistics Office, *Comparison of Pavement Damage Factors Derived From Weigh-In-Motion Data Measured by Portable vs. Permanent Systems*, Final Report, December 1993, p. 33.

21. Witczak, M.W., *Equivalent Wheel Load Factors*, Report prepared for the Association of American Railroads, February 1981.

22. Hajek, J.J., "General Axle Load Equivalency Factors," *Transportation Research Board Record 1482*, Transportation Research Board, National Research Council, Washington, DC, 1995, pp. 57-68.

APPENDIX A - COMPUTATIONAL PROCEDURE FOR AGGREGATION OF MONTHLY TRAFFIC DATA

The proposed traffic projection procedure for Category 1 sites requires the monitoring of monthly spectra. Currently, there are no monthly spectra available in the IMS database or CTDB. To obtain monthly monitoring spectra, CTDB Level 3 daily AVC and WIM data need to be utilized. A procedure was developed in this study to aggregate partial AVC and WIM daily data to obtain monthly counts. This procedure is applicable to LTPP sites that satisfy the following criteria:

- At least 210 days of AVC.
- At least one weekday and one weekend of WIM per quarter (preferably one week per quarter as a minimum).
- Availability of the above data items for at least 2 years in a 5-year period.

To better account for seasonal variations, monitored AVC data should be available for at least one week for every calendar month for at least one year (for example, out of 5 years of part-time monitoring, there should be data for at least one week for January, February, etc.).

The following steps outline the procedure for the aggregation of monthly data. This procedure needs to be executed for each site individually.

STEP 1 - OBTAIN AND PROCESS RAW LEVEL 3 AVC AND WIM DATA

In order to predict seasonality effects inherent in traffic data, traffic data collected on a daily basis are needed. These data are stored in binary file form as Level 3 data in the CTDB. AVC and WIM data are stored separately. To view the data, the traffic extractor program needs to be used to create a report that can be saved in DOS text format. The report is created separately for each LTPP section for each year. Each report needs to be manipulated further so that relevant information can be extracted and put in a manageable table form that will contain daily AVC or WIM data for all monitored years for a given section. The processed AVC and WIM tables will then be imported to a relational database for further processing.

STEP 2 - USE PROCESSED LEVEL 3 DAILY WIM DATA TO CREATE A TABLE OF ESTIMATED MONTHLY AXLE COUNTS FOR EACH MONTH, YEAR, LOAD RANGE, AXLE TYPE, AND TRUCK CLASS (ESTIMATED_MONTHLY_WIM)

1. Export processed Level 3 daily WIM data table to Access database (WIM_raw).

2. Export calendar table to Access database (calendar table includes year, month, day of the week, counts for every day of the week per month).

3. Create a query to separate WIM axle counts data by workdays and weekends.

4. For each load range, axle type, truck class, month, and year, obtain a sum of all axle counts collected during workdays (*Monitored_Workdays_Axles*) and a sum of all axle counts collected during monitored weekends (*Monitored_Weekends_Axles*), then obtain counts of monitored workdays (*Monitored_Workdays*) and monitored weekends (*Monitored_Weekends*).

5. For each load range, axle type, truck class, month, and year, compute estimated monthly axle counts by obtaining average workday and weekend axle counts and by multiplying the averages by the number of workdays (*workday*) and weekends (*weekend*), respectively, for a given month of a given year and by summing the products.

$$Estimated\_Monthly\_Axle\_Count=(Monitored\_Weekends\_Axles/Monitored\_Weekends)*weekend$$
$$+(Monitored\_Workdays\_Axles/Monitored\_Workdays)*workday$$

STEP 3 – USE PROCESSED LEVEL 3 DAILY AVC DATA TO CREATE A TABLE OF ESTIMATED TOTAL MONTHLY TRUCK COUNTS FOR EACH MONTH, YEAR, AND TRUCK CLASS

1. Export processed Level 3 daily AVC data table to Access database (AVC_raw).

2. Create a query to separate AVC truck counts data by workdays and weekends.

3. For each class, month, and year, obtain a sum of all truck counts collected during workdays (*Monitored_Workdays_CLASS*) and a sum of all truck counts collected during monitored weekends (*Monitored_Weekends_CLASS*), then obtain counts of monitored workdays (*Monitored_Workdays*) and monitored weekends (*Monitored_Weekends*).

4. For each truck class, month, and year, compute estimated monthly truck counts by obtaining average workday and weekend truck counts and by multiplying the averages by the number of workdays (*workday*) and weekends (*weekend*), respectively, for a given month of a given year and by summing the products.

$$Estimated\_Monthly\_CLASS=(Monitored\_Weekends\_CLASS/Monitored\_Weekends)*weekend$$
$$+(Monitored\_Workdays\_CLASS/Monitored\_Workdays)*workday$$

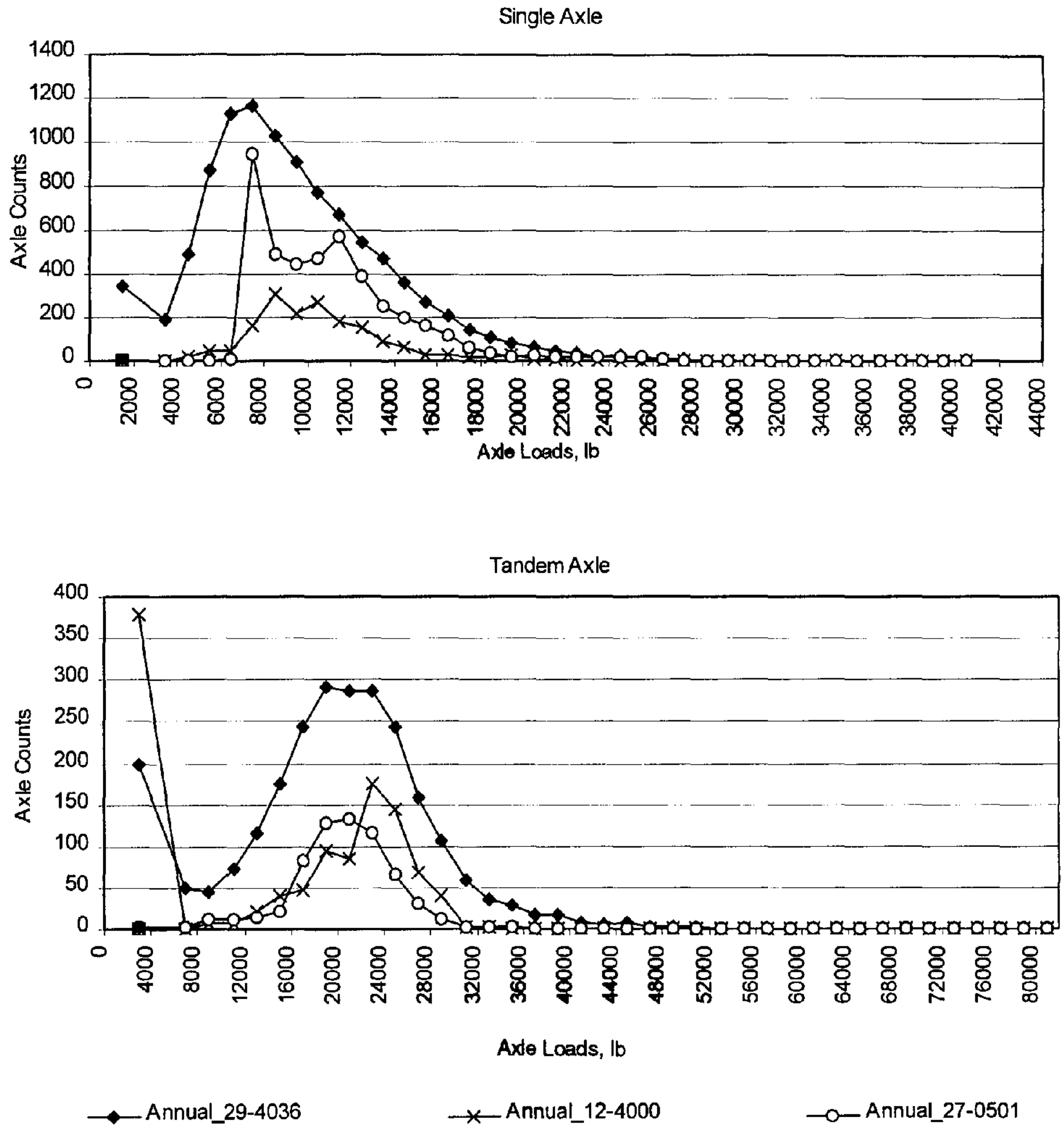
APPENDIX B - TYPICAL AXLE LOAD SPECTRA USED FOR CATEGORY 3 AND 4 PREDICTIONS

Appendix B contains the following:

- Figures 97 through 106 – These figures compare axle load spectra for individual truck types (vehicle classes 4 through 13) obtained for three LTPP sites (12-4000, 27-0501, and 29-4036). The axle load spectra in figures 97 through 105 are the average spectra obtained by averaging all annual acceptable axle load spectra available for the three sites.

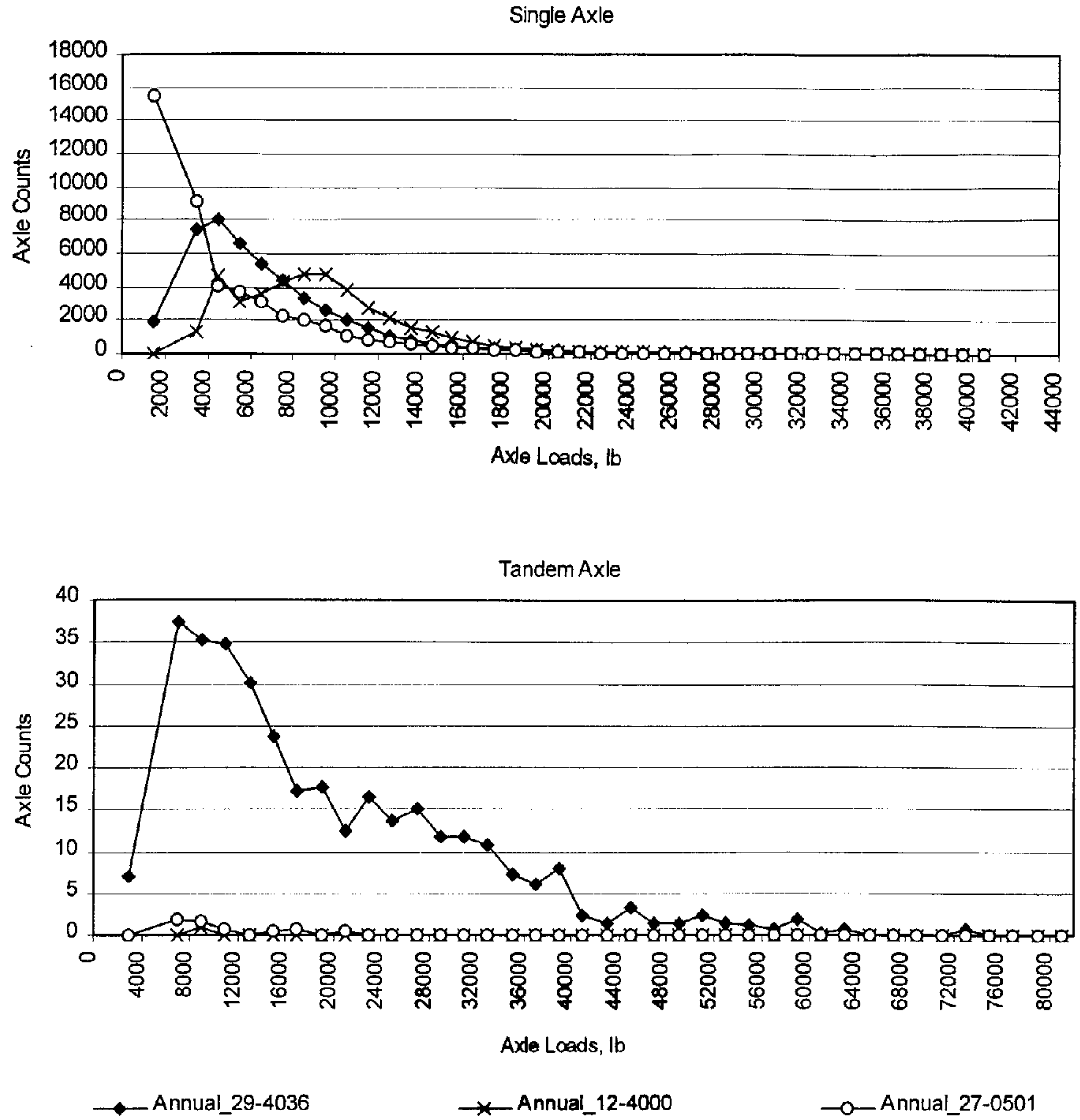
- Figures 107 through 109 – These figures compare axle load spectra for vehicle classes 6, 9, and 10 obtained for two LTPP sites (12-4000 and 27-0501). The axle load spectra are the average spectra of all acceptable annual axle load spectra available for the two sites.

- Figures 110 through 119 – These figures compare normalized axle load spectra for individual truck types (vehicle classes 4 through 13) obtained for three LTPP sites (12-4000, 27-0501, and 29-4036). The normalized axle load spectra in figures 110 through 119 are the average spectra obtained by averaging all annual acceptable normalized axle load spectra available for the three sites.



1 lb = 0.00445 kN

Figure 97. Load spectra for Class 4 vehicles.



1 lb = 0.00445 kN

Figure 98. Load spectra for Class 5 vehicles.

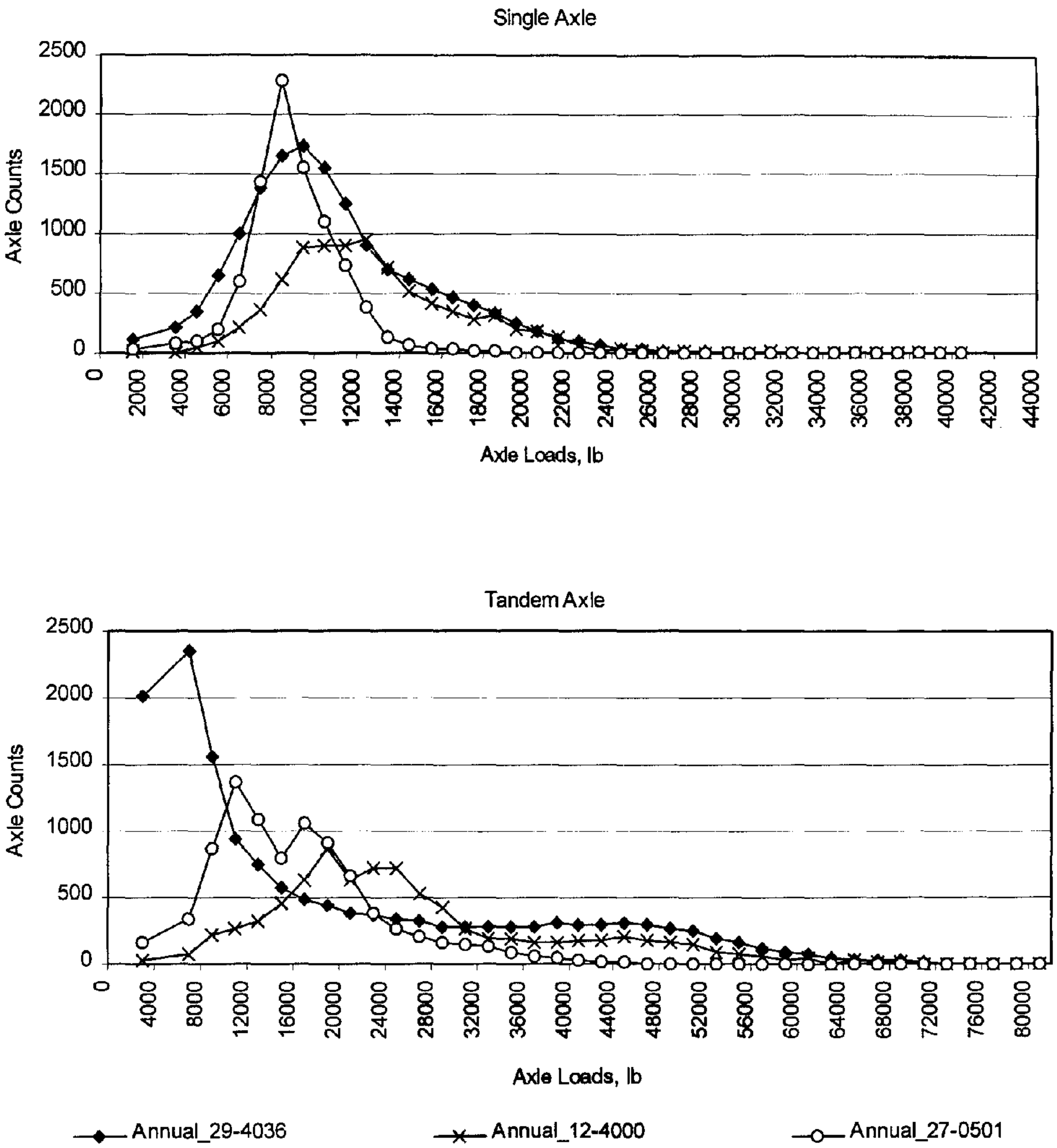


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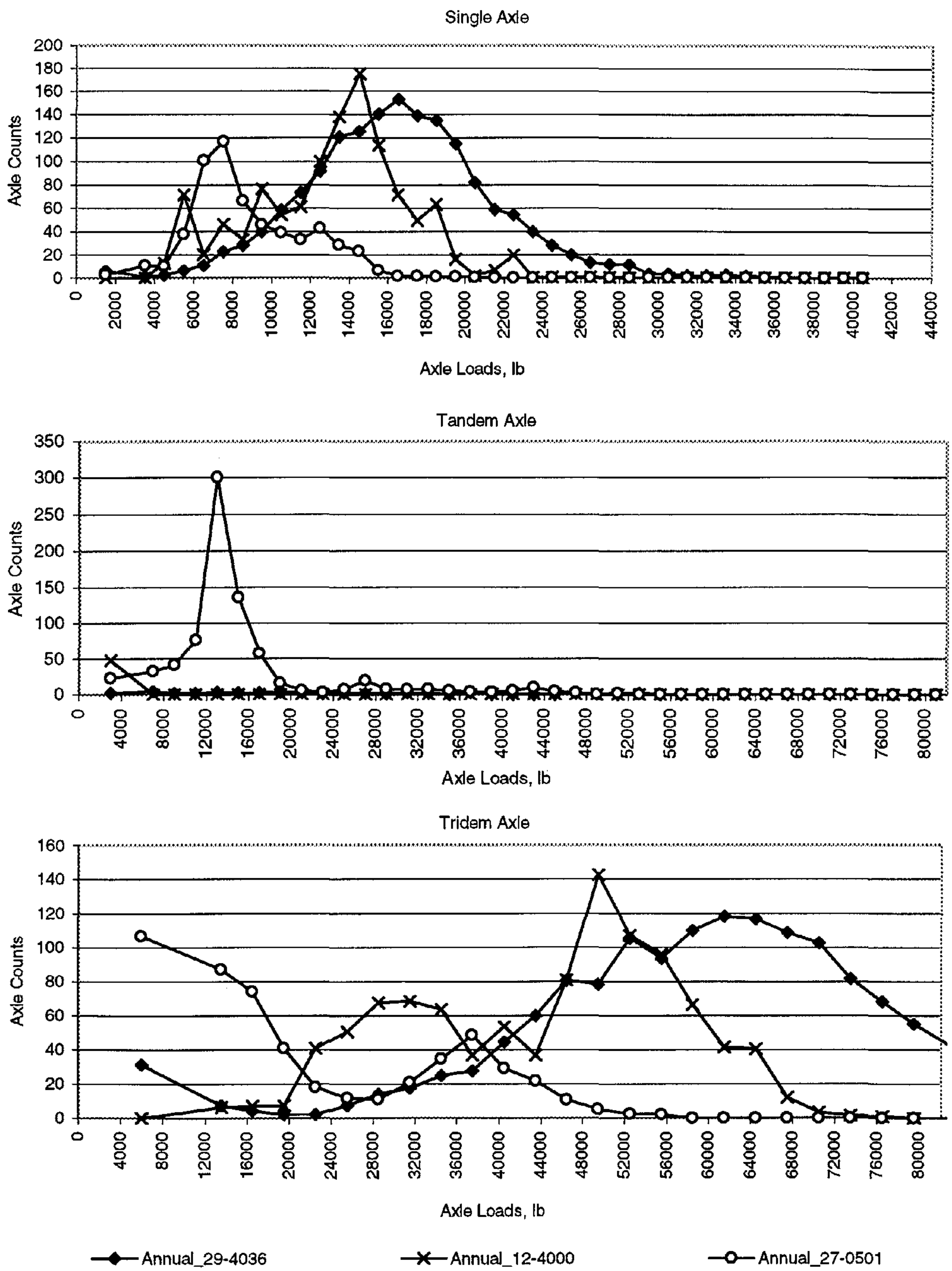
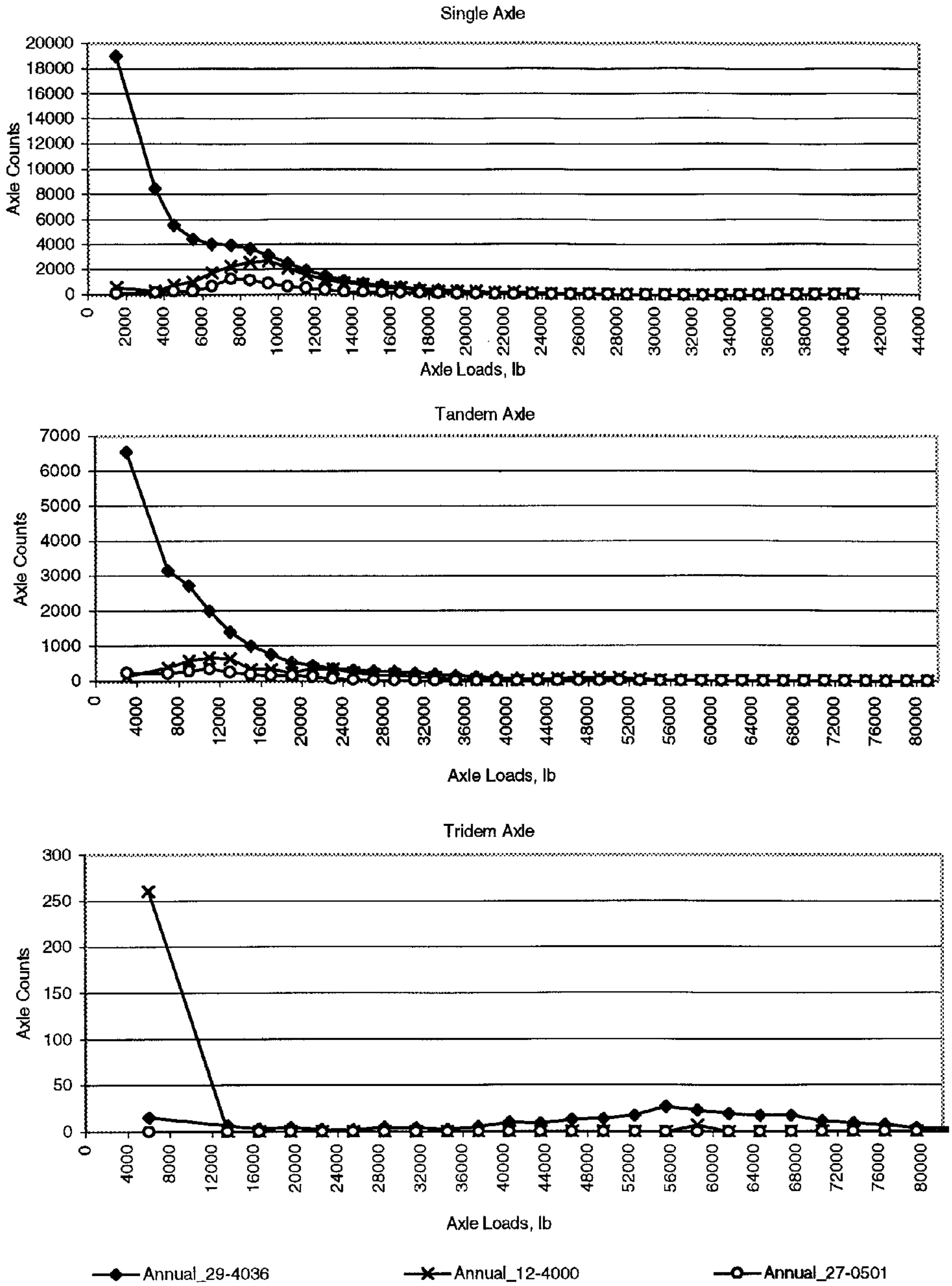
Figure 99. Load spectra for Class 6 vehicles.



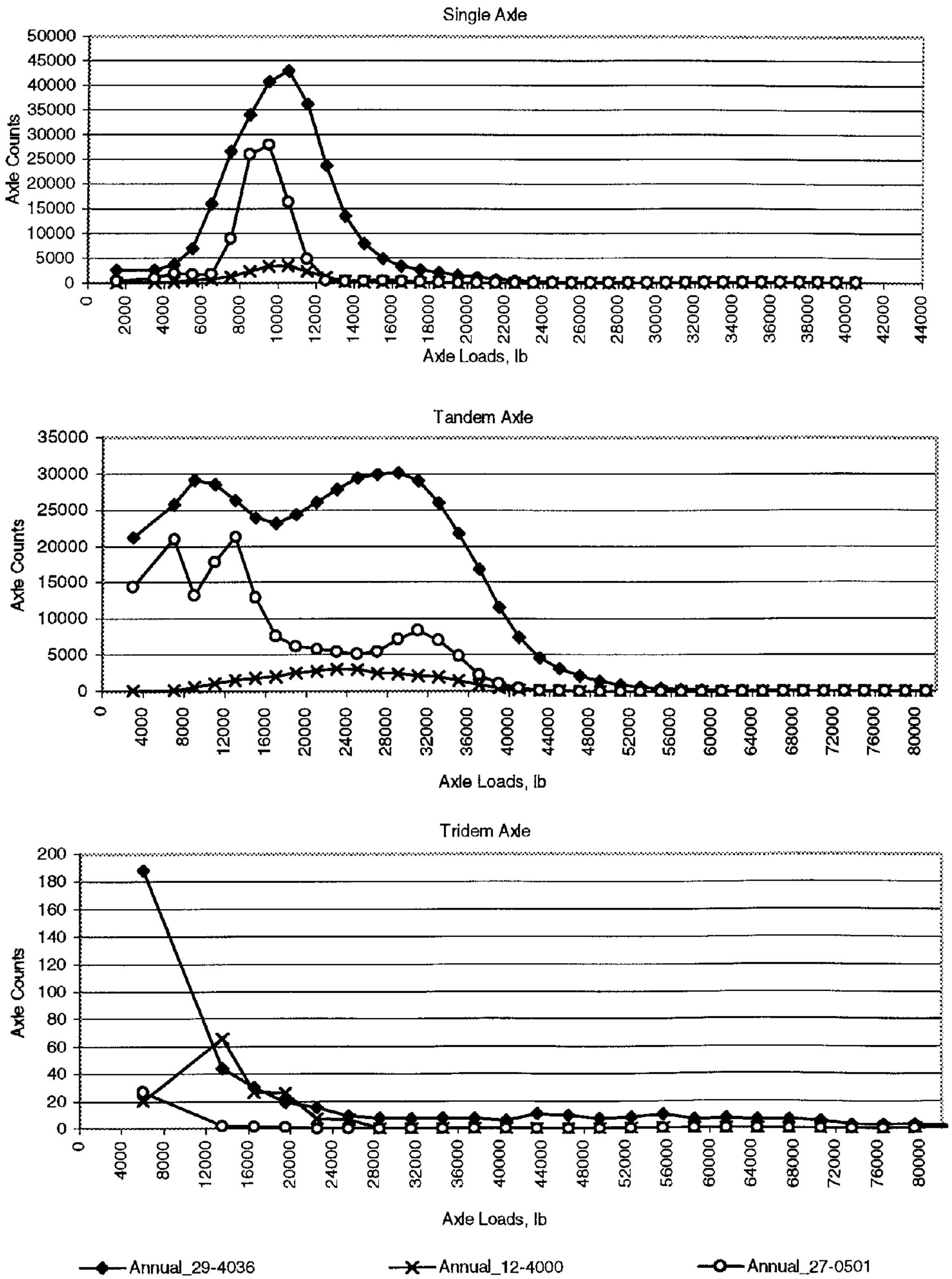
1 lb = 0.00445 kN

Figure 100. Load spectra for Class 7 vehicles.



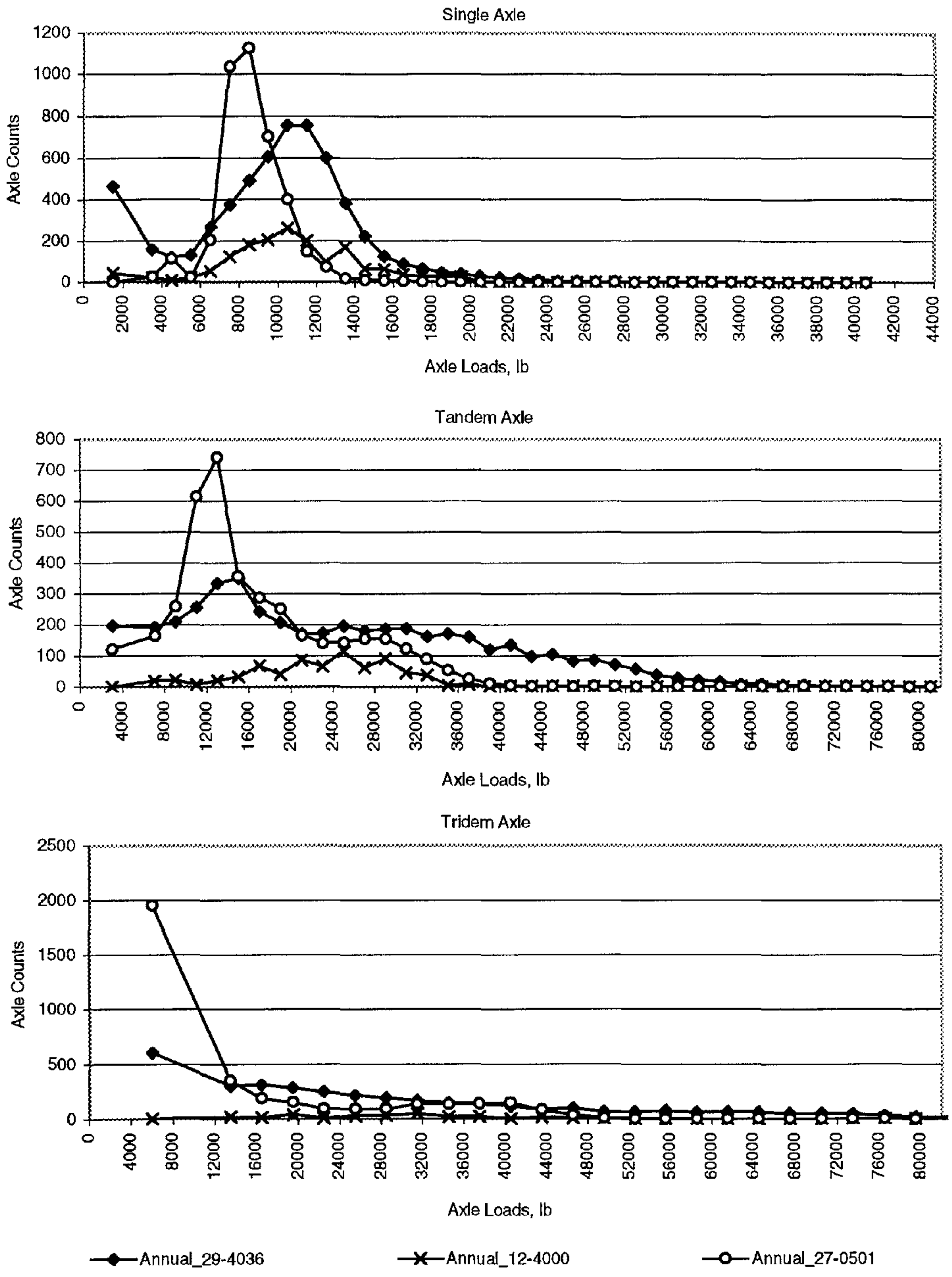
1 lb = 0.00445 kN

Figure 101. Load spectra for Class 8 vehicles.



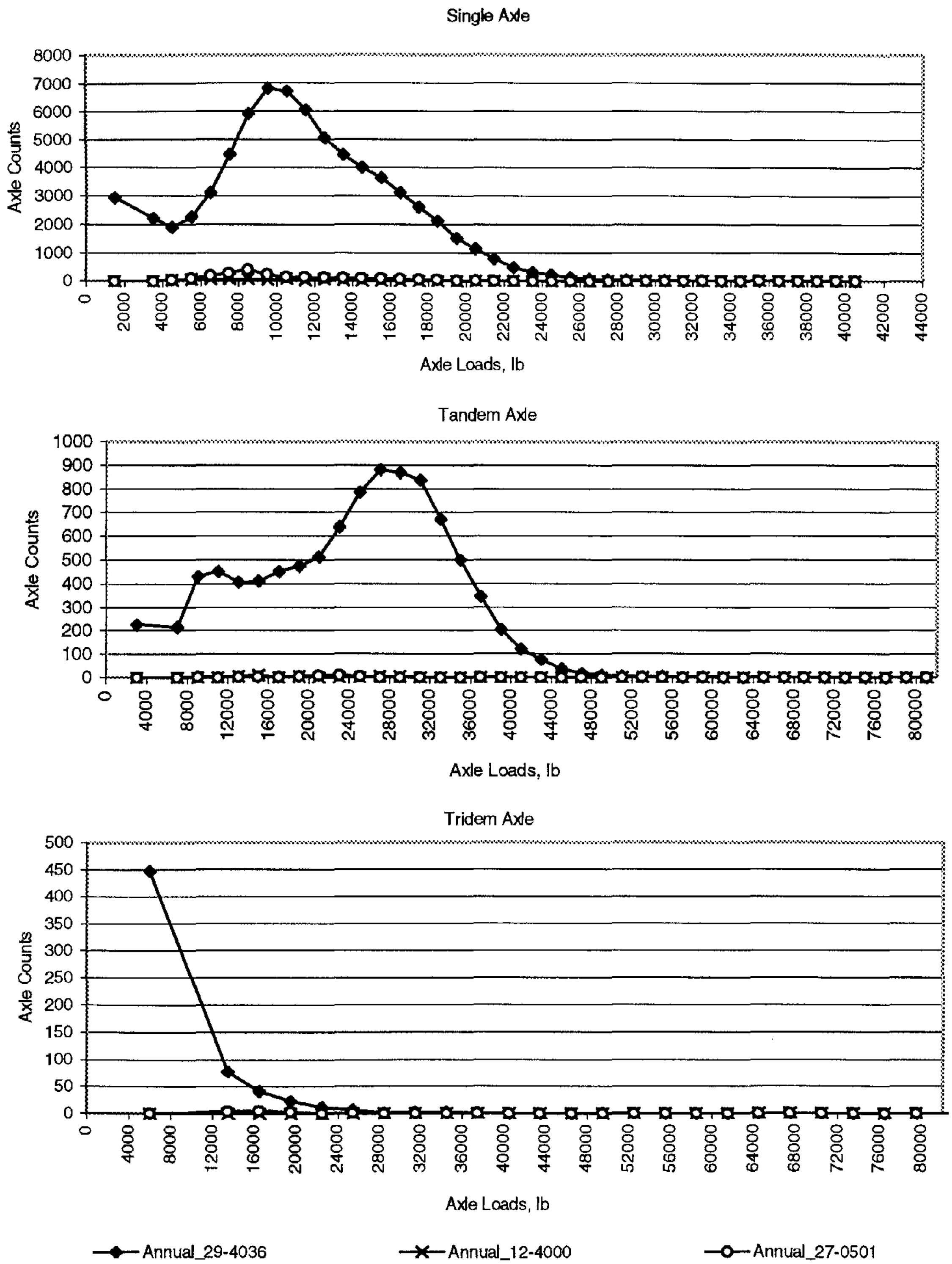
1 lb = 0.00445 kN

Figure 102. Load spectra for Class 9 vehicles.



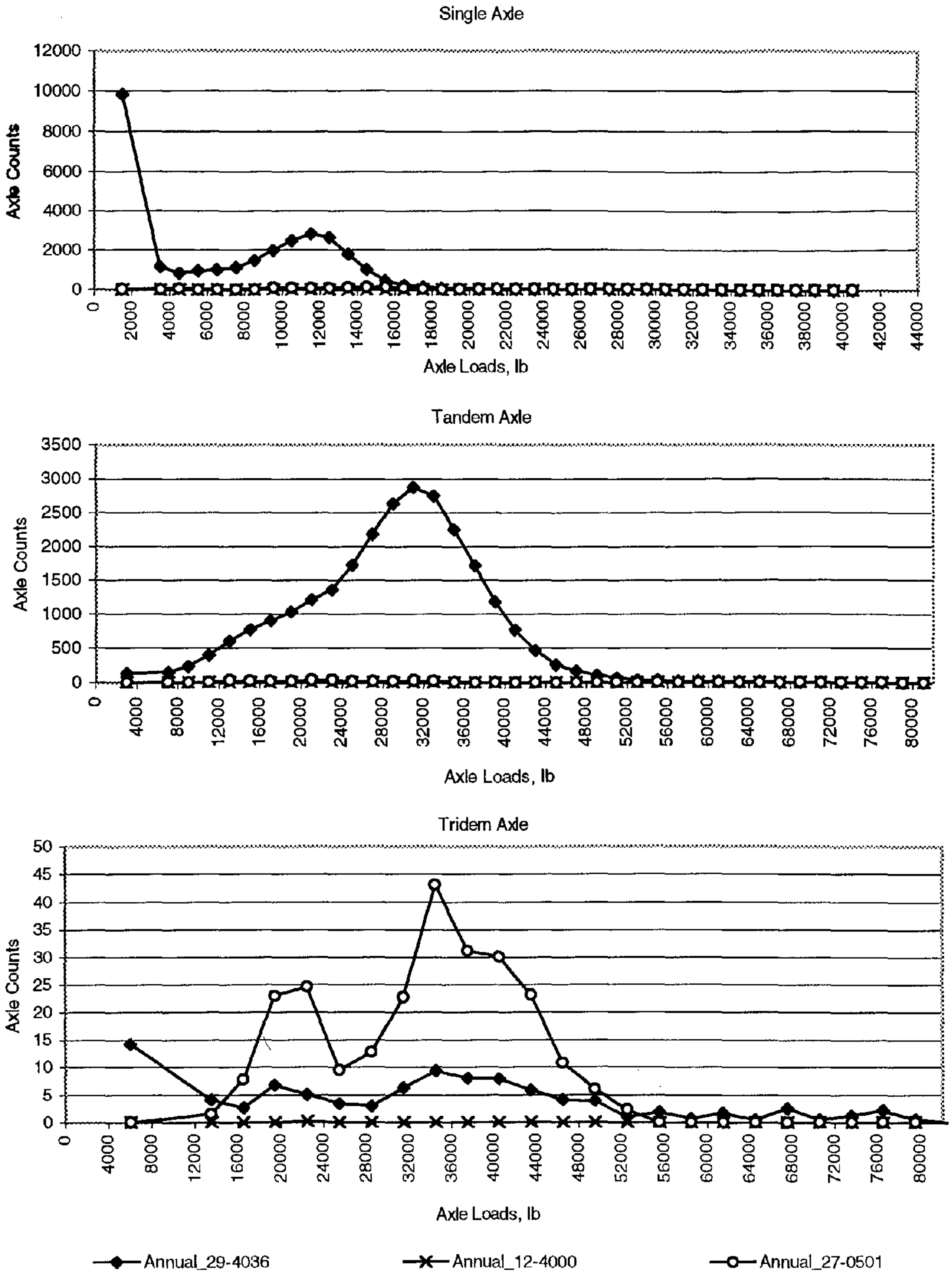
1 lb = 0.00445 kN

Figure 103. Load spectra for Class 10 vehicles.



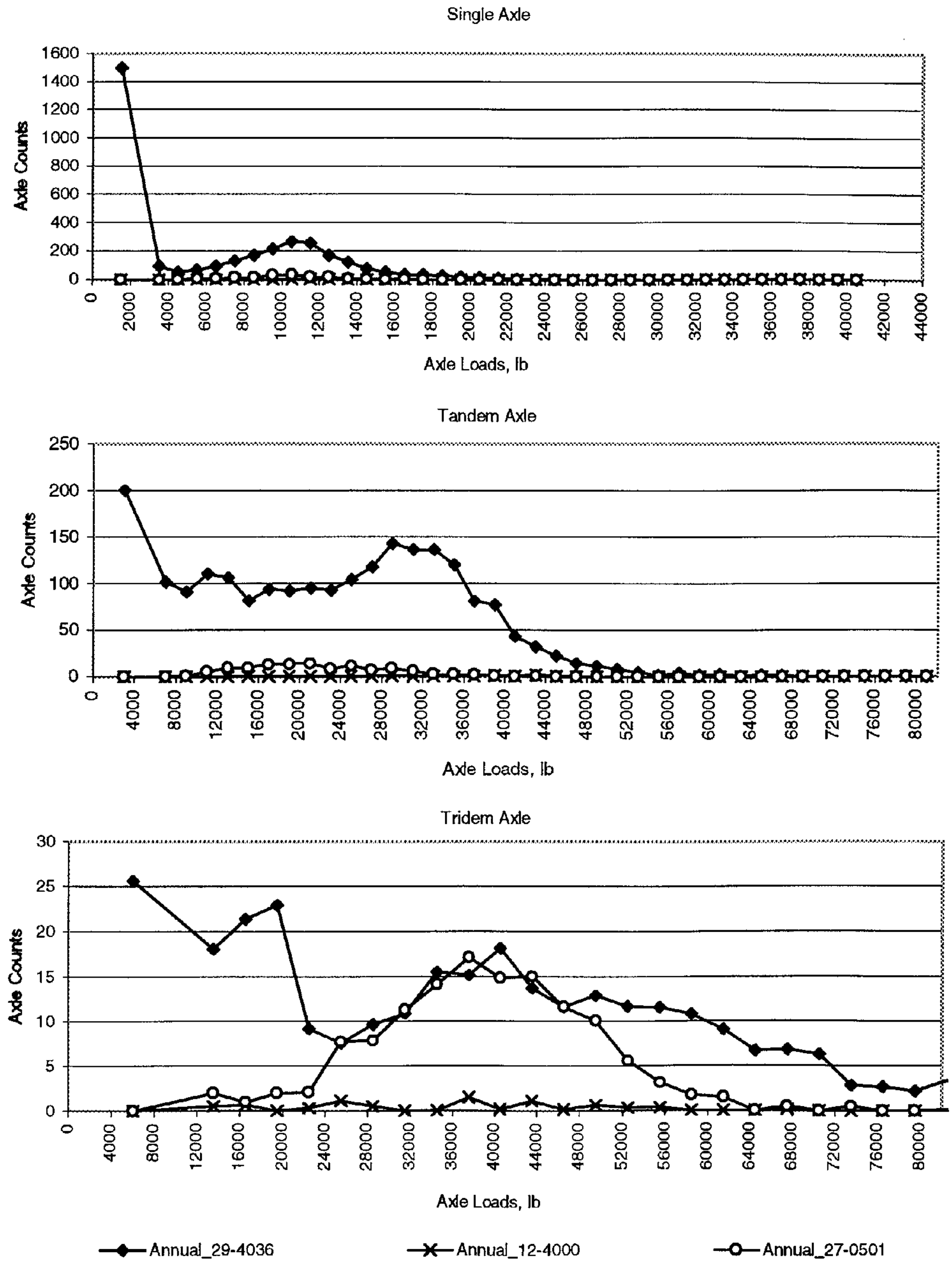
1 lb = 0.00445 kN

Figure 104. Load spectra for Class 11 vehicles.



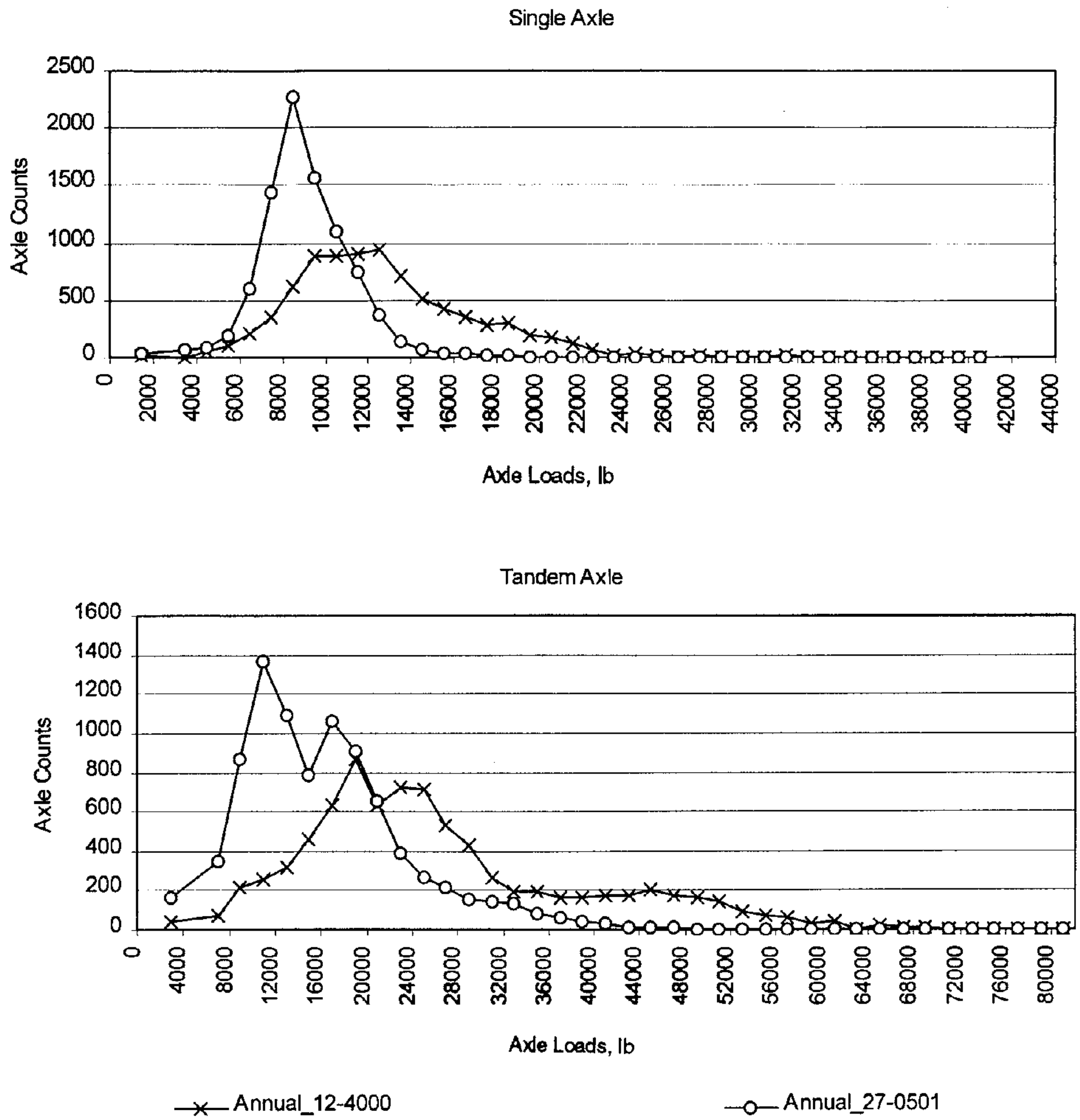
1 lb = 0.00445 kN

Figure 105. Load spectra for Class 12 vehicles.



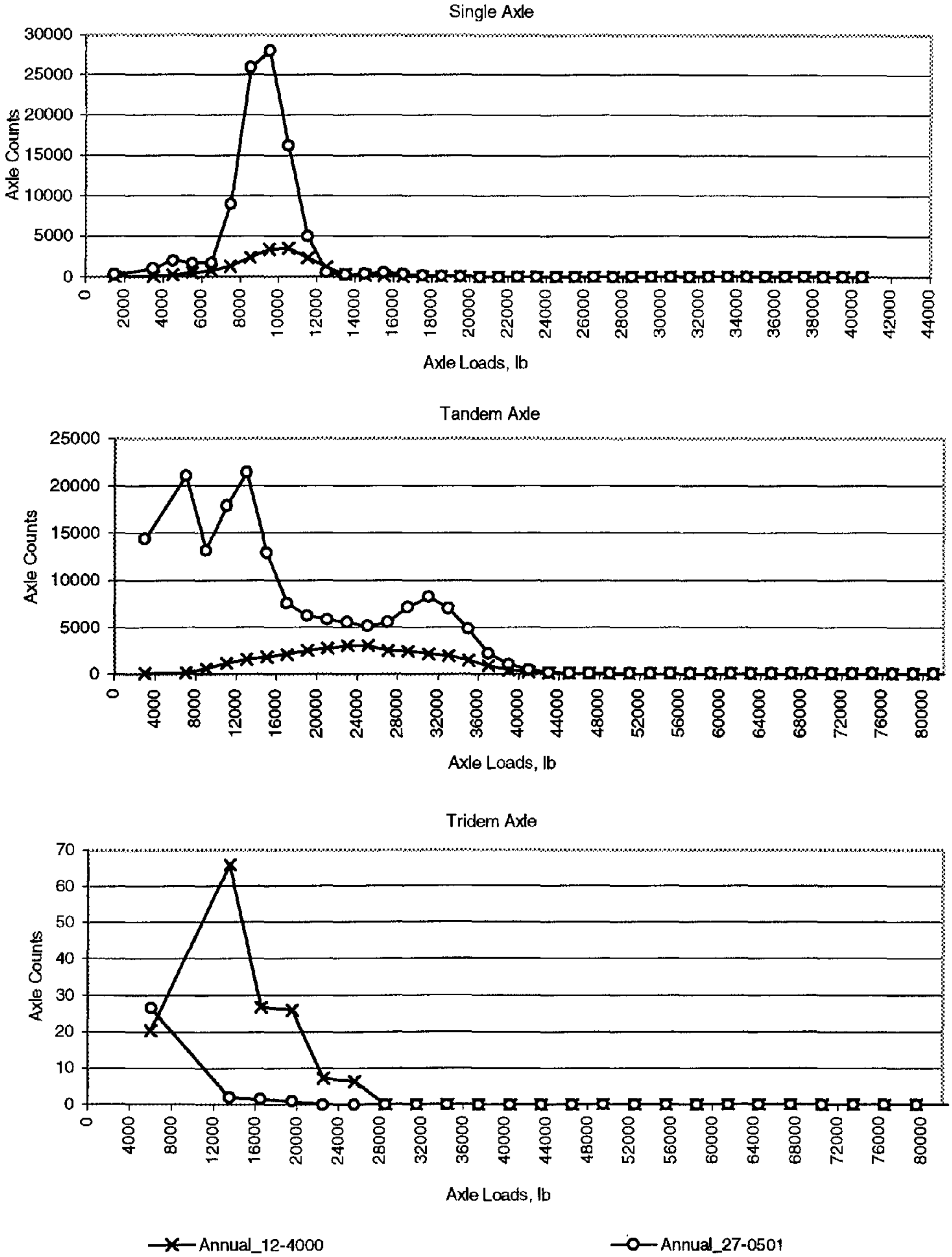
1 lb = 0.00445 kN

Figure 106. Load spectra for Class 13 vehicles.



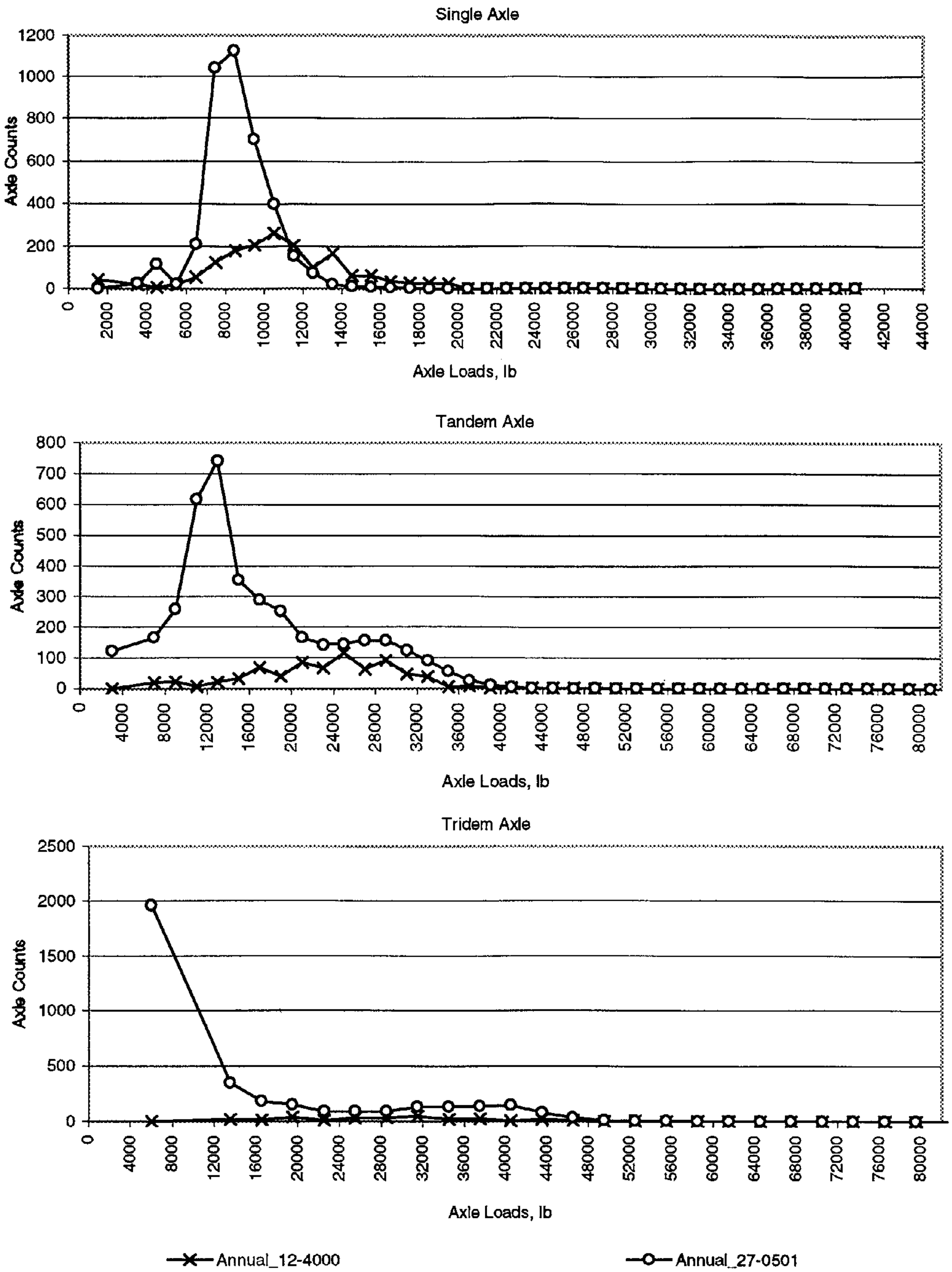
1 lb = 0.00445 kN

Figure 107. Comparison of axle load spectra for Class 6 vehicles.



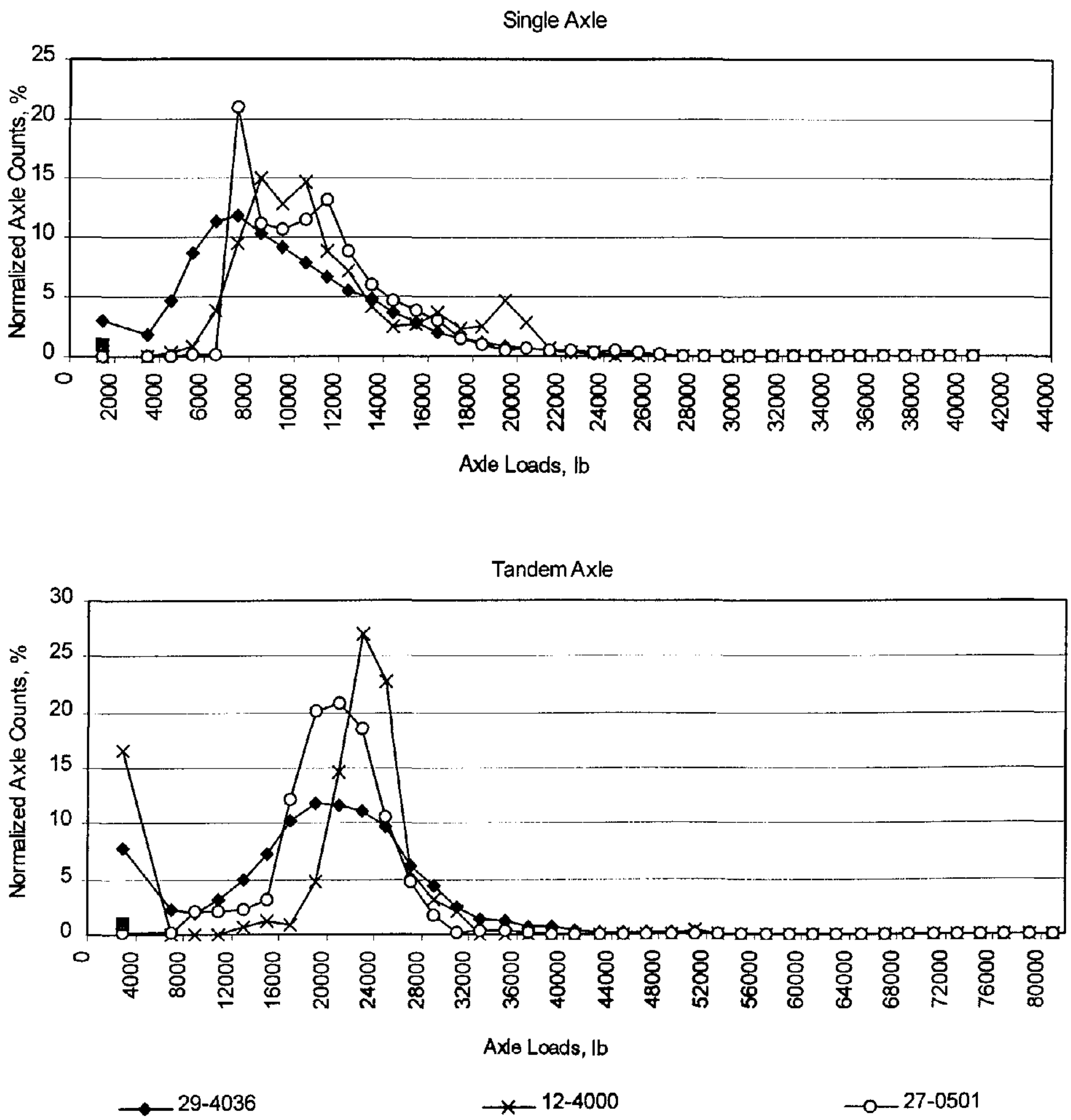
1 lb = 0.00445 kN

Figure 108. Comparison of axle load spectra for Class 9 vehicles.



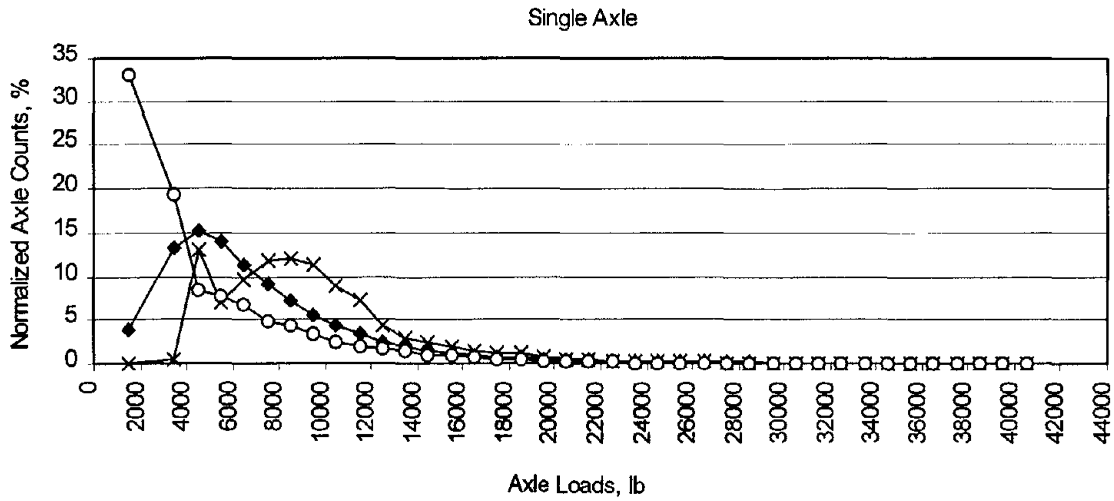
1 lb = 0.00445 kN

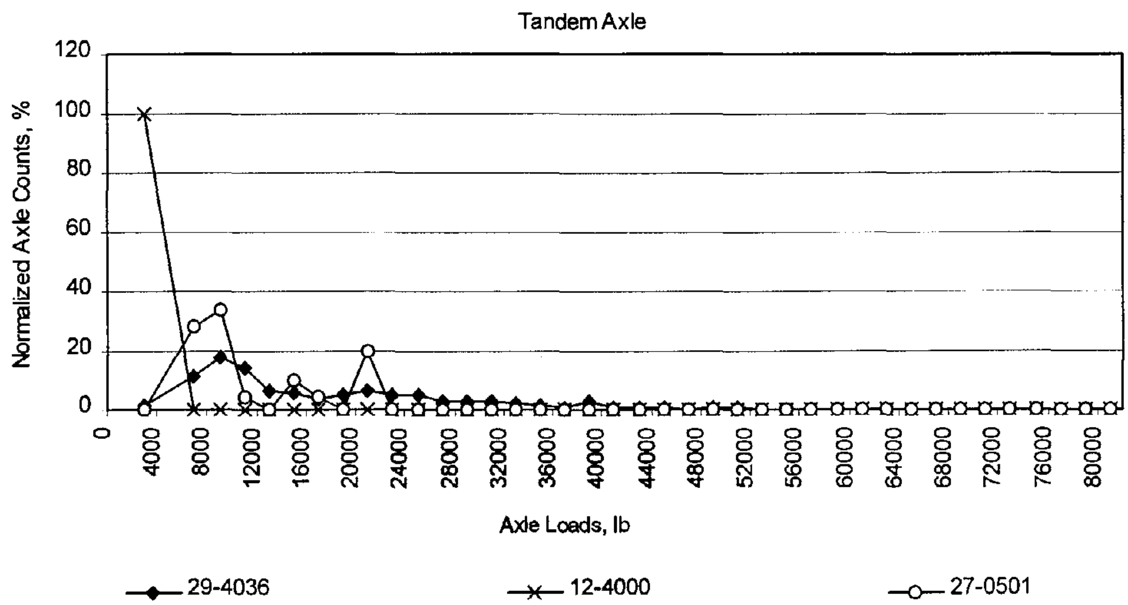
Figure 109. Comparison of axle load spectra for Class 10 vehicles.



1 lb = 0.00445 kN

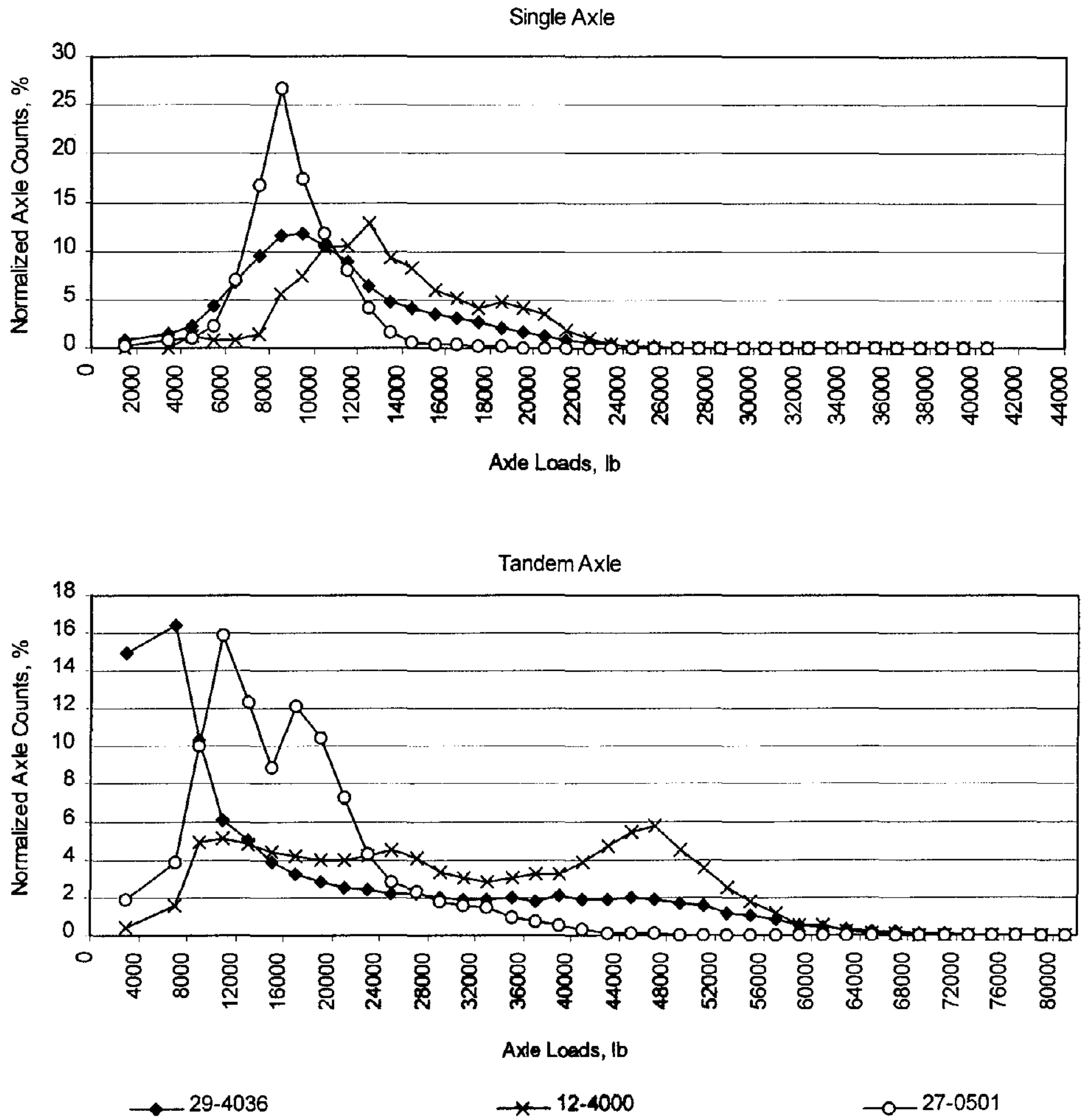
Figure 110. Normalized load spectra for Class 4 vehicles.





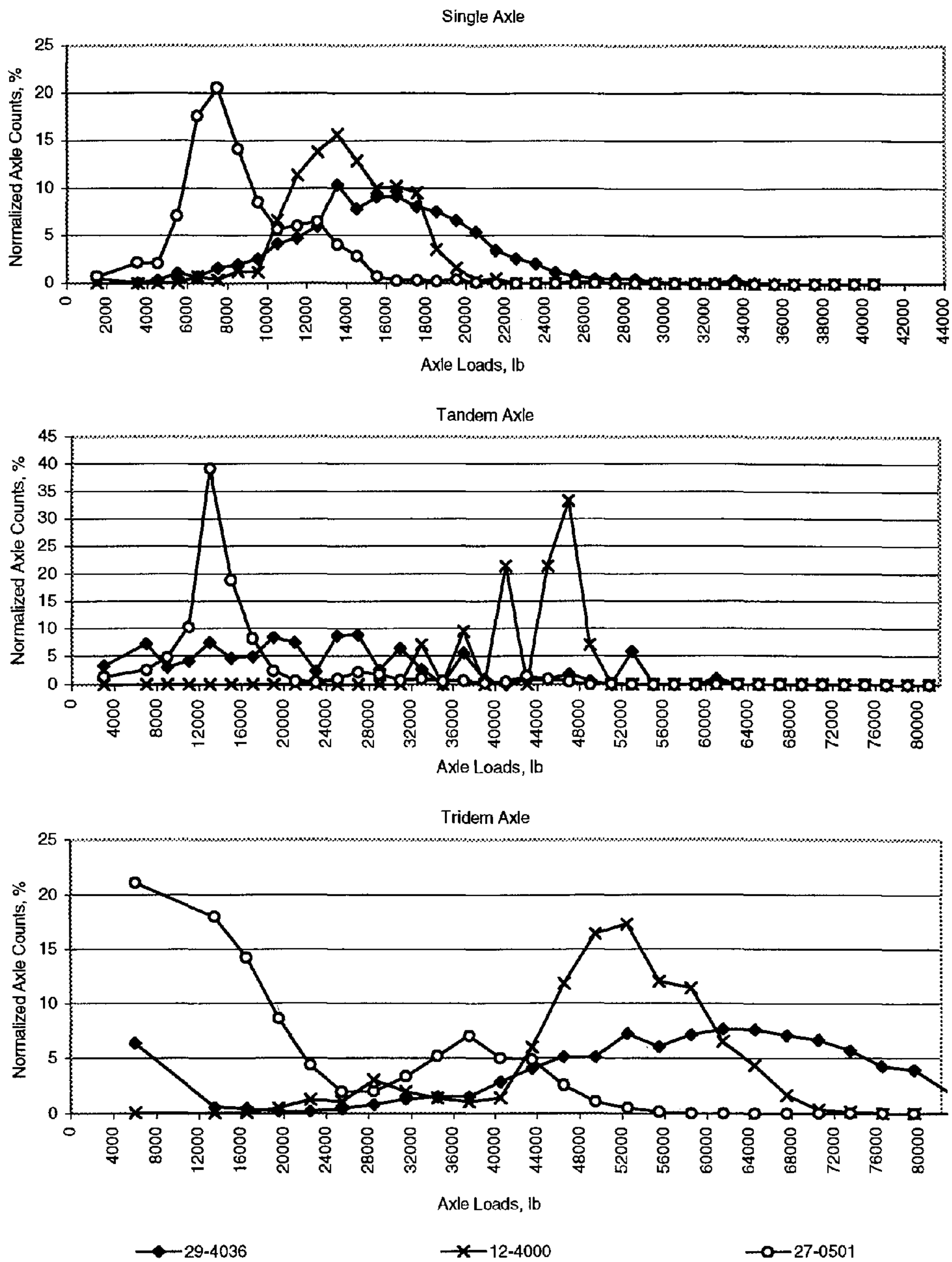
1 lb = 0.00445 kN

Figure 111. Normalized load spectra for Class 5 vehicles.



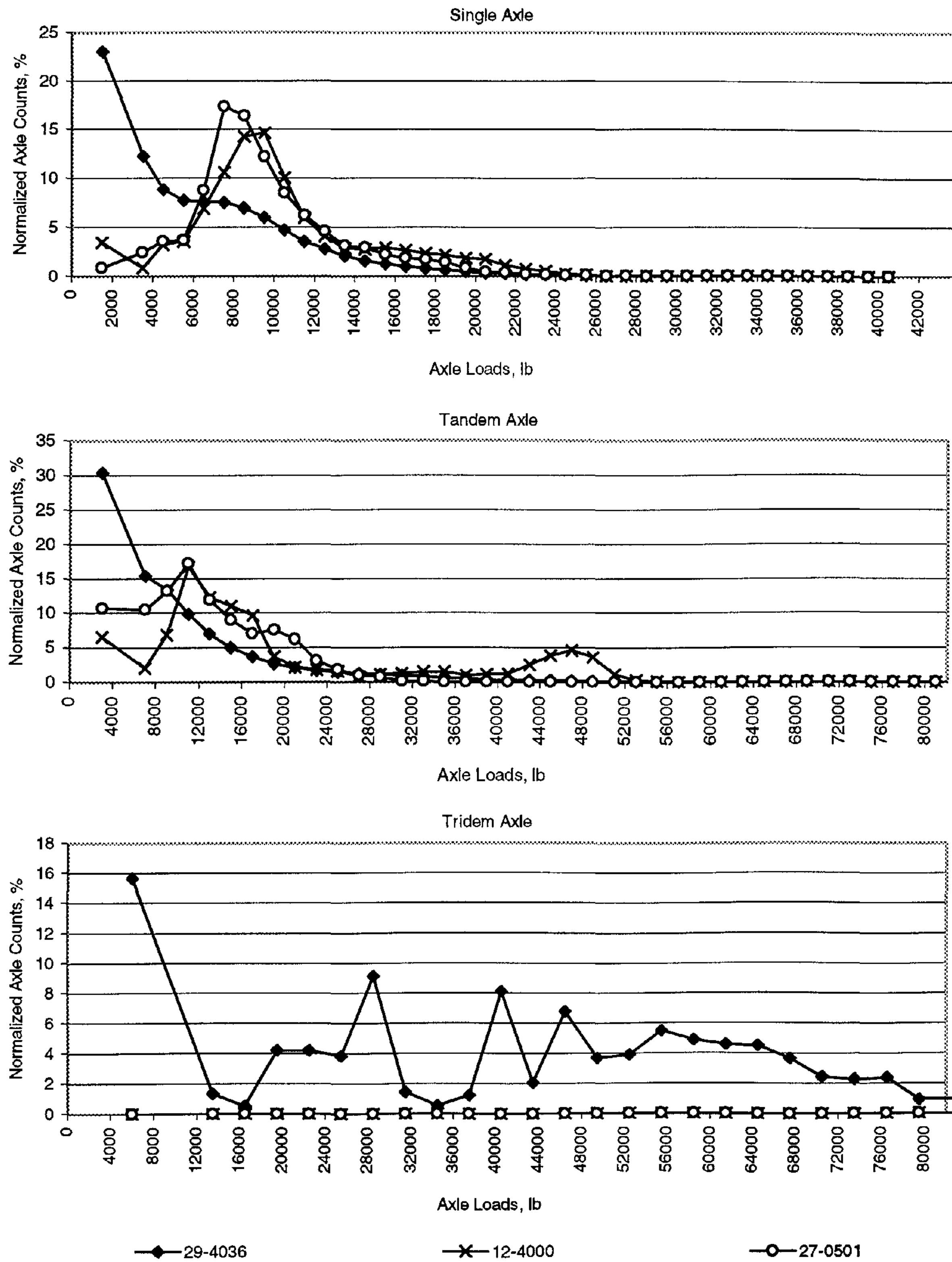
1 lb = 0.00445 kN

Figure 112. Normalized load spectra for Class 6 vehicles.



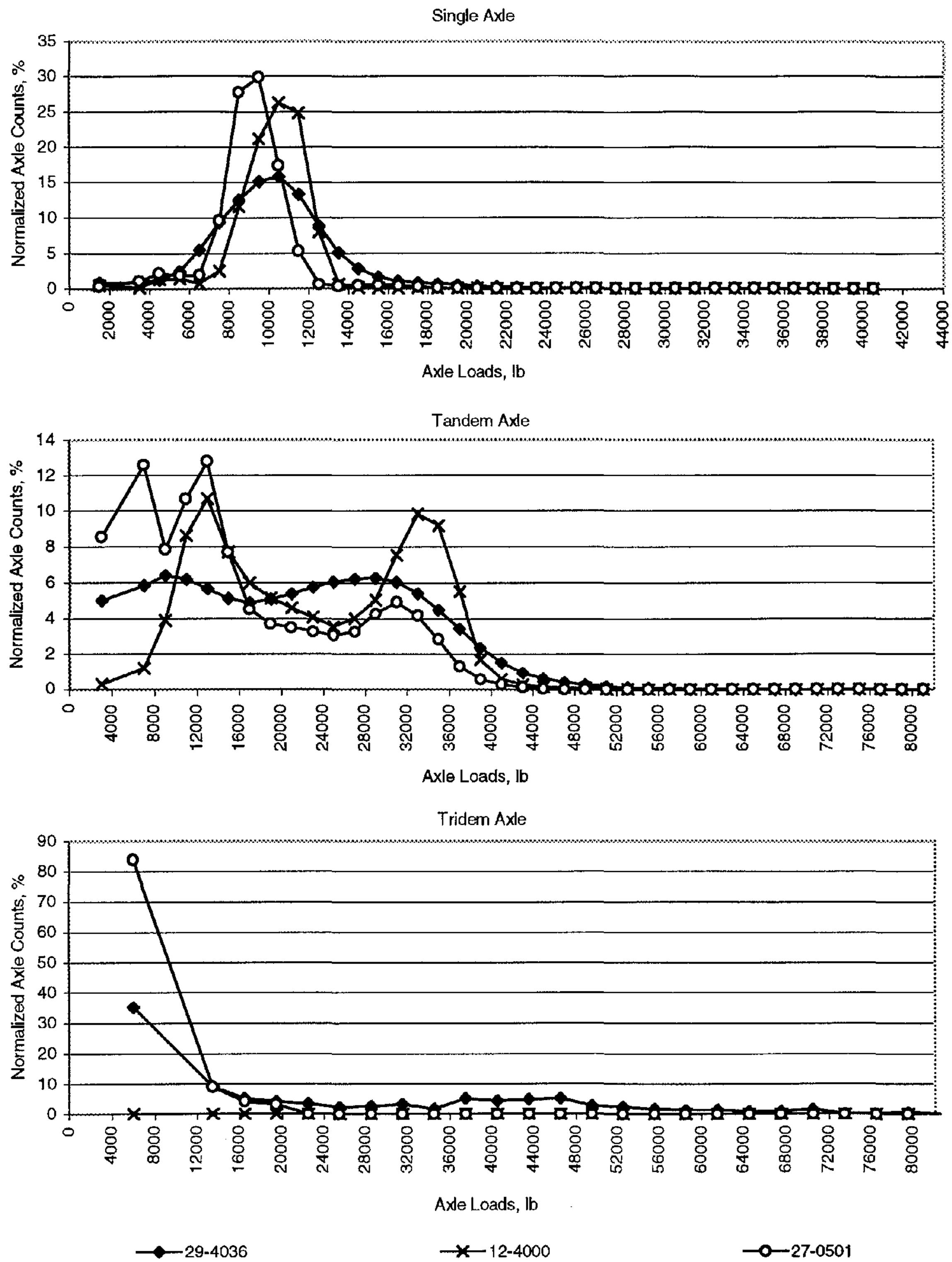
1 lb = 0.00445 kN

Figure 113. Normalized load spectra for Class 7 vehicles.



1 lb = 0.00445 kN

Figure 114. Normalized load spectra for Class 8 vehicles.



1 lb = 0.00445 kN

Figure 115. Normalized load spectra for Class 9 vehicles.

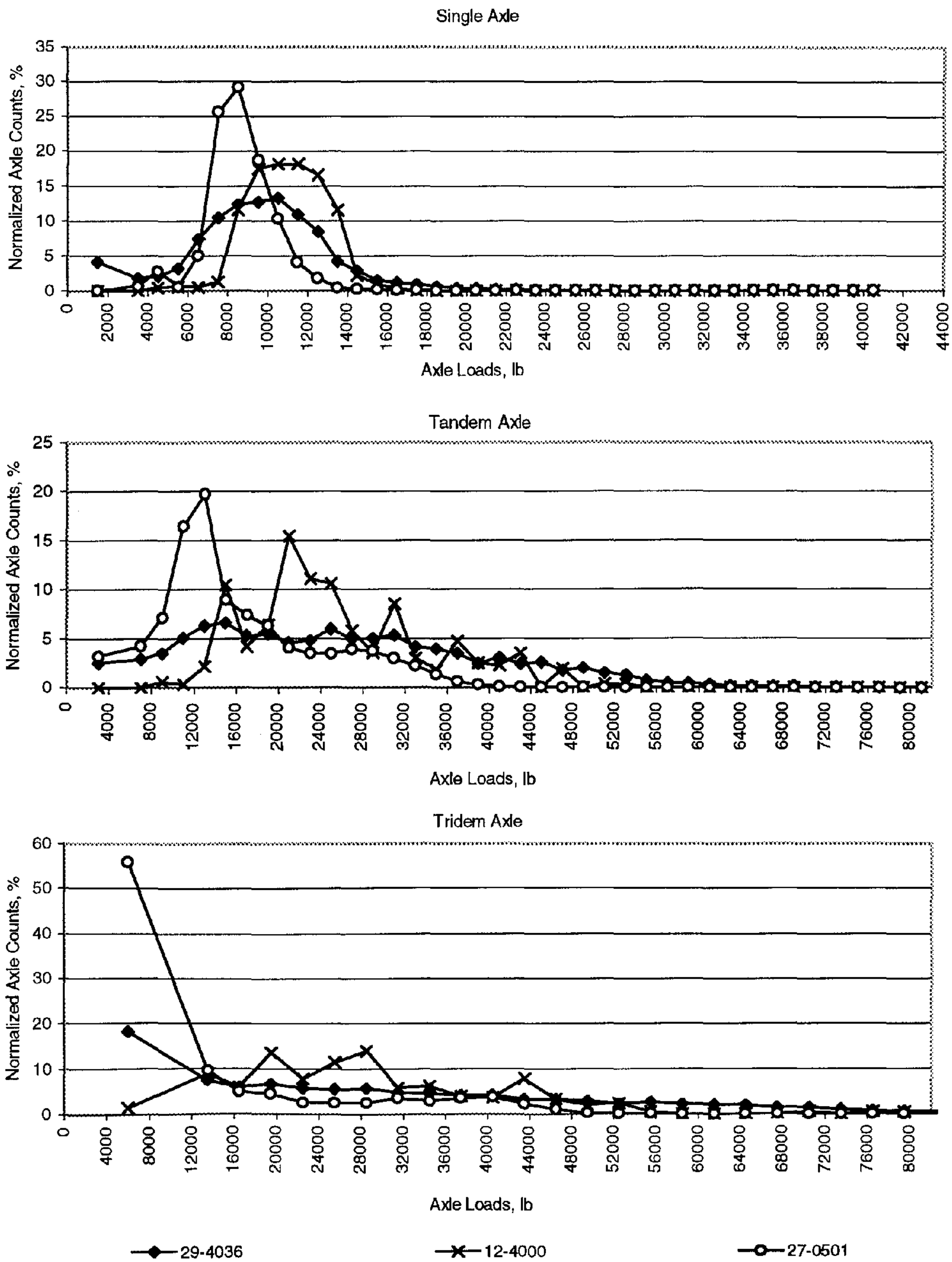


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Figure 116. Normalized load spectra for Class 10 vehicles.

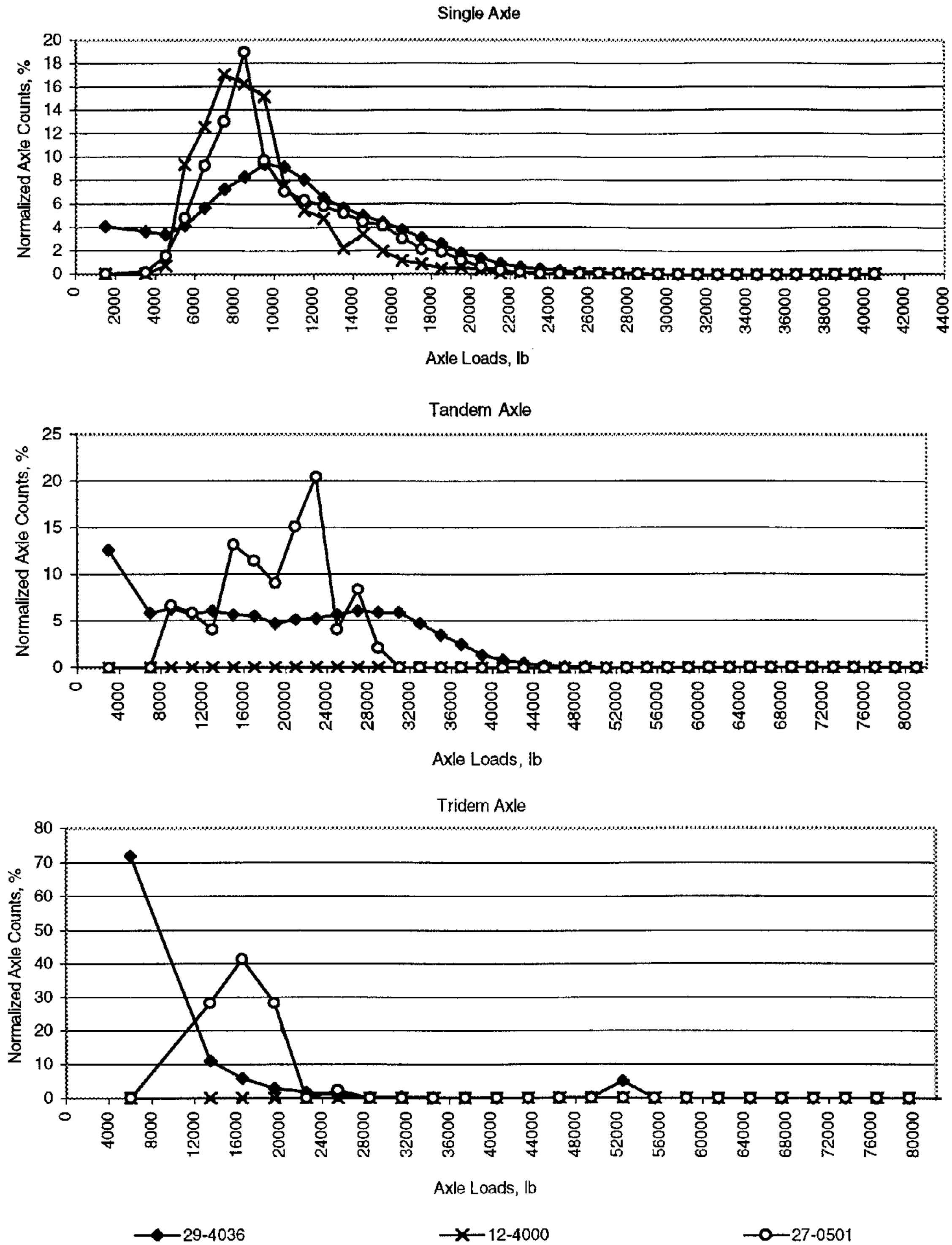

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Figure 117. Normalized load spectra for Class 11 vehicles.

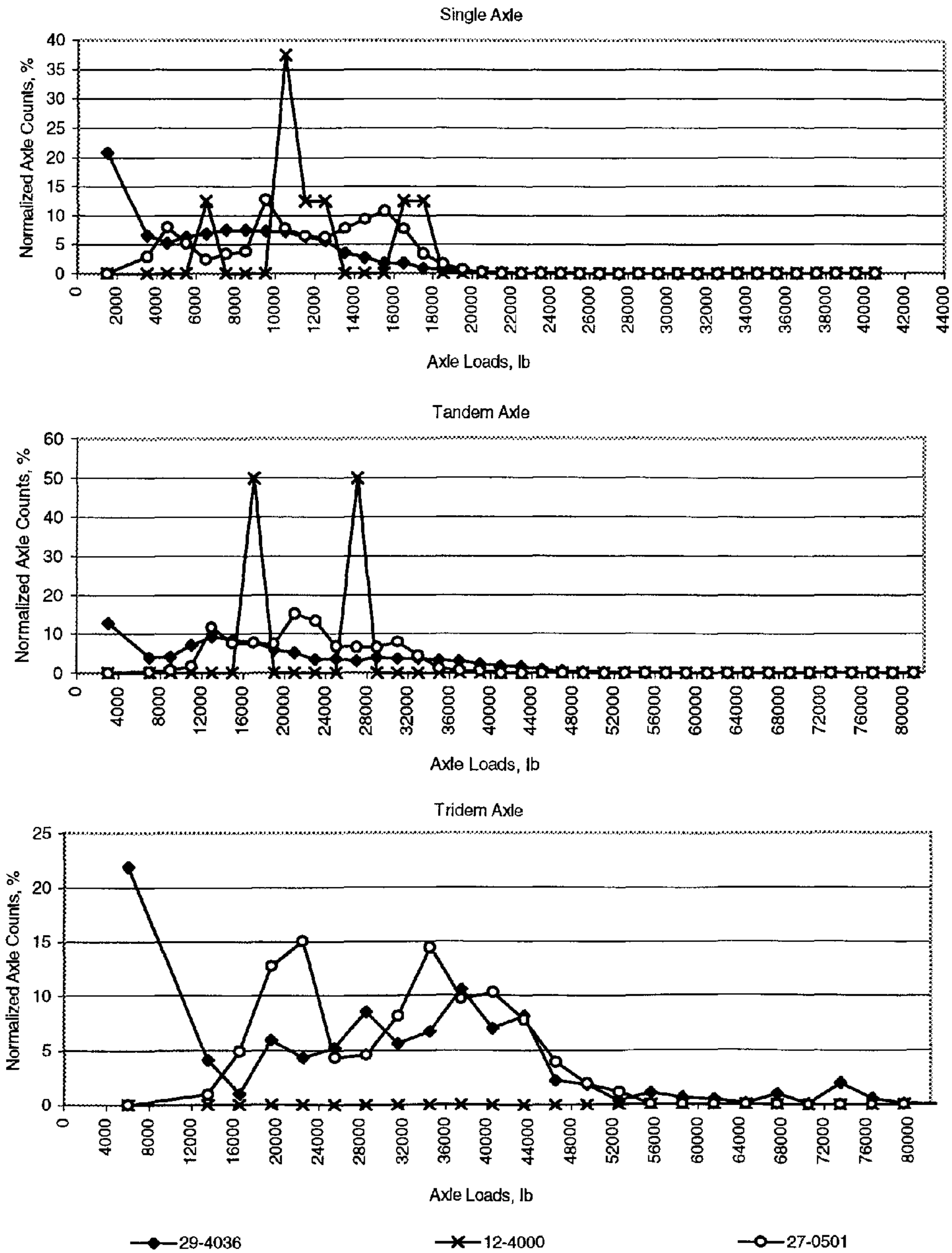

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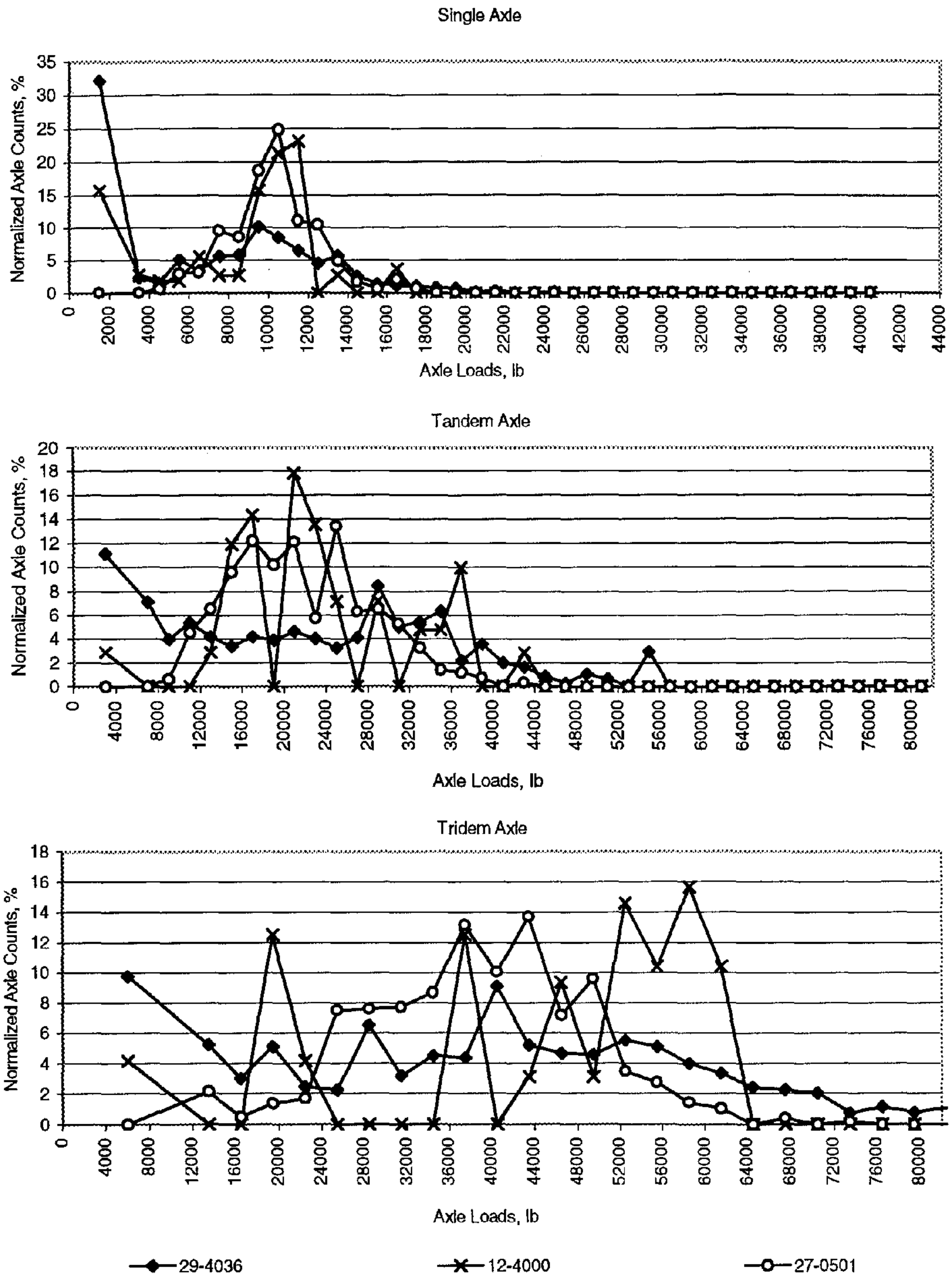
Figure 118. Normalized load spectra for Class 12 vehicles.



1 lb = 0.00445 kN

Figure 119. Normalized load spectra for Class 13 vehicles.