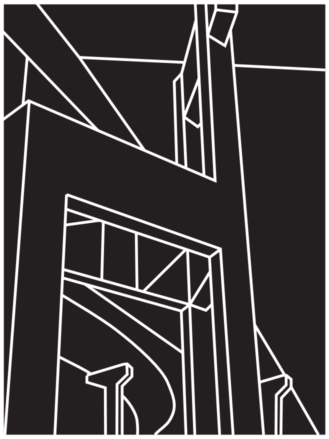
RESEARCH REPORT 987-7

FINAL RESEARCH FINDINGS ON TRAFFIC-LOAD FORECASTING USING WEIGH-IN-MOTION DATA

Clyde E. Lee and Nabil Souny-Slitine



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16. Abstract

The overall objective of Project 7-987 was to develop a long-range pavement rehabilitation plan for a segment of US 59, a four-lane divided principal arterial highway in TxDOT's Lufkin District. To identify feasible pavement structures, test sections that would utilize most efficiently the existing pavements and materials were constructed in the southbound lanes near Corrigan, Texas. To quantify traffic loads on the test pavements, two weigh-in-motion (WIM) systems were installed: one two-lane system adjacent to the five rigid-pavement test sections located 8 km north of Corrigan, and the other adjacent to the five flexible-pavement test sections about 3 km south of Corrigan. These WIM stations were operated virtually continuously from 1993 through 1997 to record data about the date, time, speed, lane of travel, wheel loads, number of axles, and axle spacing of every southbound vehicle (about 7,500 per day) that crossed the sensors in each lane. In addition, special sensors were operated to collect sample data concerning the air and pavement temperature and the lateral position of the vehicle tires (single or dual) within each traffic lane. The result was an exceptionally comprehensive traffic data set. This final project traffic report complements and extends the time frame (to 5 years) of the traffic data analyses presented previously in Research Reports 987-5, -6, and -8. The traffic data analysis included exploration of patterns and trends in vehicle counts, lane use, and axle load frequency distributions by axle type, location on the vehicle, and vehicle class. The results indicated that on average during the 5 years, trucks accounted for about 28 percent of all southbound vehicles, and that five-axle tractor semitrailer trucks comprised about 62 percent of all trucks. Generally, 74 percent of the vehicles, and 82 percent of the trucks, traveled in the right-hand, southbound lane. The overall southbound vehicle count grew at an annual rate of approximately 2.5 percent, while five-axle tractor semitrailer trucks, the dominant truck class, increased in number about 6 percent each year. This suggests that traffic load forecasts should consider separately the respective growth rate for each vehicle class (by axle arrangement and axle-load frequency distribution) as the axles on each vehicle class cause different — often disproportionate — amounts of pavement damage.

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by

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Research Report Number 987-7

Research Project 7-987
A Long-Range Plan for the Rehabilitation of US 59 in the Lufkin District

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

September 1998

This report was prepared in cooperation with the Texas Department of Transportation.

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ABSTRACT

The overall objective of Research Project 987 was to develop a long-range pavement rehabilitation plan for the segment of US 59, a four-lane divided principal arterial highway in east Texas, within TxDOT's Lufkin District. To identify feasible pavement structures, test sections that would utilize most efficiently the existing pavements and materials were constructed in the southbound lanes near Corrigan, Texas. To quantify traffic loads on the test pavements, two weigh-in-motion (WIM) systems were installed: one two-lane system adjacent to the five rigid-pavement test sections located 8 km north of Corrigan, and the other adjacent to the five flexible-pavement test sections about 3 km south of Corrigan. These WIM stations were operated virtually continuously from 1993 through 1997 to record data about the date, time, speed, lane of travel, wheel loads, number of axles, and axle spacing of every southbound vehicle (about 7,500 per day) that crossed the sensors in each lane. In addition, special sensors were operated to collect sample data concerning the air and pavement temperature and the lateral position of the vehicle tires (single or dual) within each traffic lane. The result was an exceptionally comprehensive traffic data set. This final project traffic report, Research Report 987-7, complements and extends the time frame (to 5 years) for the traffic data analyses presented previously in Research Report Numbers 987-5, -

6, and -8. The traffic data analysis included exploration of patterns and trends in vehicle counts, lane use, and axle load frequency distributions by axle type, location on the vehicle, and vehicle class. The results indicated that, on average during the 5 years, trucks accounted for about 28 percent of all southbound vehicles and that five-axle tractor semitrailer trucks comprised about 62 percent of all trucks. Generally, 74 percent of the vehicles and 82 percent of the trucks traveled in the right-hand, southbound lane. The overall southbound vehicle count grew at an annual rate of approximately 2.5 percent, while five-axle tractor semi-trailer trucks, the dominant truck class, increased in number about 6 percent each year. This suggests that traffic load forecasts should consider separately the respective growth rate for each vehicle class (by axle arrangement and axle-load frequency distribution) as the axles on each vehicle class cause different — often disproportionate — amounts of pavement damage. WIM-system sensors are needed in the northbound traffic lanes to quantify the loading patterns of northbound vehicles; these patterns can be quite different from those observed so thoroughly in the southbound direction.

IMPLEMENTATION STATEMENT

The C-language computer programs developed for this project (see Report 987-6) or similar ones should be implemented by the Transportation Planning and Programming (TP&P) Division to:

(1) process the binary-formatted data retrieved from the roadside PAT DAW 100 WIM systems via modem,
(2) classify vehicles according to number of axles per vehicle and spacing between axle pairs,
(3) calculate the axle-load frequency distribution for each axle type (steering, single, tandem, and tridem) and location on every vehicle class,
(4) calculate the equivalent single axle loads (ESALs) produced by each axle on every vehicle,
(5) sum the ESALs for each vehicle by vehicle class, and
(6) compute a representative average ESAL factor for each vehicle class.

Special attention must be given to computing steering-axle ESALs, as these axles usually have single tires; additionally, the damaging effect of steering axles on AASHO Road Test vehicles (all less than 12,000 lb, or 5.44 metric tons) was incorporated into the ESAL factors for other axles on the test vehicles. Traffic load forecasts should consider separately the respective growth rate for each vehicle class (by axle arrangement and axle-load frequency distribution), as the axles on each vehicle class cause different — often disproportionate — amounts of pavement damage. The WIM-system sensors at the site north of Corrigan, in the southbound lanes, should be removed and installed in the northbound traffic lanes at the WIM site south of Corrigan to quantify the loading patterns of northbound vehicles (these patterns can be quite different from the those observed so thoroughly in the southbound direction). To make the WIM site south of Corrigan effective for 20 years or more as a TP&P

traffic monitoring site — the only one in east Texas — the existing flexible pavements in both directions should be replaced with 300-mm thick CRCP slabs 60 to 90 m long, with the surface ground smooth to within 3 mm under a 6-m straightedge before the weigh pads are installed approximately 30 m from the leading end of the slab. A full-depth asphalt pavement transition section about 10 m long should be provided at each end of the CRCP slabs. All required WIM equipment is available from the research project.

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CHAPTER 1. INTRODUCTION

For the past half century, truck traffic in the United States has been constantly on the rise. As a consequence, the damaging effects of traffic loading on the performance and expected life of highway pavements have received continuous attention from both researchers and legislators. Since pavement damage is a direct function of axle loads, highway engineers always need timely and reliable traffic data, such as truck traffic percentage and axle loads, to design and maintain pavement structures. The collection of large representative samples of traffic load data has become both common and efficient with the advent of weigh-in-motion (WIM) technology.

At a low operating cost, WIM systems not only measure and store loads and axle spacing for each vehicle that passes through the WIM site, but also record supplementary data such as the date, time, speed, lane of travel, station identification, and vehicle class. Furthermore, the WIM systems can record the lateral position of each vehicle within the lane of travel and the number of tires (single or dual) at the end of each axle. This report analyzes the data collected from 1993 through 1997, explores traffic trends and patterns as well as axle-load frequency distributions for different axle groups within all truck classes, and compares frequency distributions among sites, years, and different axle groups. This report also shows traffic and equivalent single axle load (ESAL) forecasts using simple regression and a computer program developed for this research project.

BACKGROUND

Project 7-987 was initiated in late 1992 by the Texas Department of Transportation (TxDOT) in cooperation with the Center for Transportation Research (CTR) of The University of Texas at Austin. Its objective was to develop a long-range rehabilitation plan for US 59 in the Lufkin District. US 59 is a four-lane divided primary arterial highway that originates at the Texas-Mexico border in Laredo, traverses northeast through Houston and then north through Lufkin, and exits Texas in Texarkana at the Texas-Arkansas border.

As a result of the implementation of the North American Free Trade Agreement (NAFTA), US 59 has been used as a new interstate highway corridor that serves traffic moving between Canada, the U.S., and Mexico. Owing to the increased traffic in this area, two WIM systems augmented with infrared detectors and temperature sensors were installed in late 1992 in two pavement test sections for the purpose of continuously collecting traffic and temperature data. Both WIM systems are in the southbound traffic lanes of US 59 and are located, respectively, to the north (rigid pavement) and to the south (flexible pavement) of Corrigan, Texas. The northern WIM site is located approximately 8 km to the north of Corrigan, while the southern WIM site is located approximately 3 km to the south of Corrigan.

OBJECTIVES

The associated traffic loads on highway US 59 have contributed to the deterioration of the pavements along the route. The initial approach to this problem consisted of periodic pavement maintenance by overlaying an asphalt concrete layer on the existing pavement structure (rigid or flexible). Such resurfacing has left a large assortment of hybrid pavement structures that historically have not performed satisfactorily. The primary goal of Project 7-987 was to recommend long-range pavement rehabilitation plans for the portion of US 59 in the Lufkin District. To achieve this goal, the objectives of this report were (1) to characterize past traffic loading and patterns using the WIM data; (2) to develop axle-load frequency distributions for the individual axles on each vehicle class; and (3) to forecast future volumes and traffic loading using a simple regression method and a computer program, respectively.

CHAPTER 2. TRAFFIC DATA ACQUISITION, PROCESSING, AND ANALYSIS

Since late 1992, when the systems were installed, several CTR investigators have worked on this project. To explore ways of analyzing the unique data, Joseph Garner (1995) initially developed a Microsoft Excel macro program to process the voluminous WIM data sets. This program, which sorts the observed vehicles into classes by number of axles, takes almost 8 hours to process the WIM data from 30 days of records documented by a Pentium PC computer. Jeffrey W. Pangburn (1996) then extended the macro program by adding features (1) to sort the vehicles by vehicle class according to axle spacing presented by Bahman Izadmehr (1982), (2) to calculate the axle weight frequency distribution for axles on each vehicle class, and (3) to forecast a future cumulative traffic volume by using a single growth rate for all vehicle types. Finally, Tongbin Qu (1996) developed two C-language programs that run on PC-compatible machines and take less than 10 minutes to process 30 days of WIM data (about 7,500 vehicles per day). Qu's first program is used for sorting vehicles by TxDOT classification and for calculating the axle-load frequency distribution as well as the weighted average ESALs for each type of TxDOT-classified vehicle. Qu's second program is used for forecasting the ESALs on a user-defined pavement type for a user-defined period. The WIM data analyzed for this report were processed by these two efficient and accurate programs.

WEIGH-IN-MOTION (WIM) SYSTEM

Just as its name implies, the WIM system weighs vehicles in motion. Historically, vehicle weighing has been performed by stopping vehicles at weigh stations and weighing each axle of the static vehicle on scales. This procedure was time consuming, expensive, and hazardous; often only small samples of load data could be collected. On the other hand, the WIM system offers many advantages over conventional static weighting. A WIM system can weigh and dimension virtually every vehicle that passes the site at a relatively low operating cost per vehicle weighed. Although a WIM system might have a higher initial hardware cost compared with the cost of static scales, it is much more cost effective for obtaining representative samples of statistical data related to traffic characteristics.

The two WIM systems used for this project were installed in late 1992 to monitor southbound US 59 traffic north and south of the US 287-US 59 intersection at Corrigan. Figure 2.1 shows the geographic location of the WIM systems. The systems were composed of four basic components: tire force sensors (weight pads), a vehicle presence detector (inductance loop), a tire sensor (infrared light beam), and a signal processor unit. Figure 2.2 shows the layout of the WIM system. For additional details of each component and its function, readers should consult the System Description of Automatic Vehicle Weight and Classification System by PAT Equipment Corporation, Inc., now PAT Traffic Control Corporation (Pietzsch 1992).

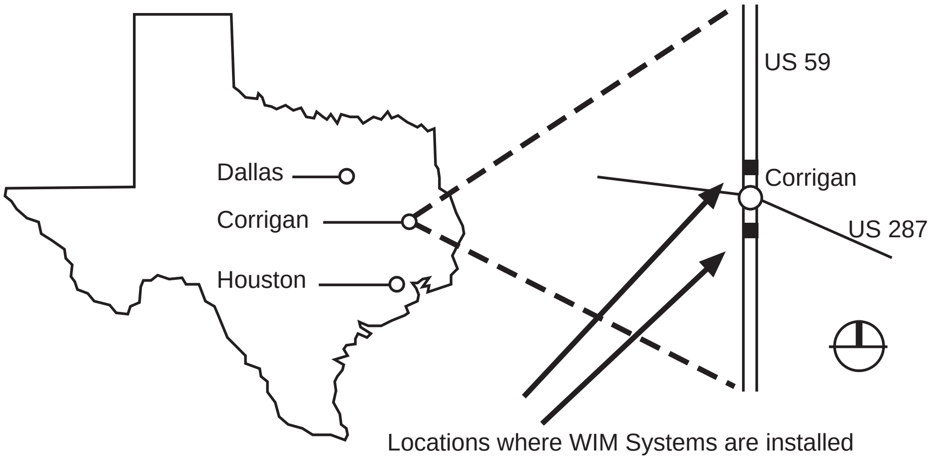


Figure 2.1 Geographic location of WIM systems

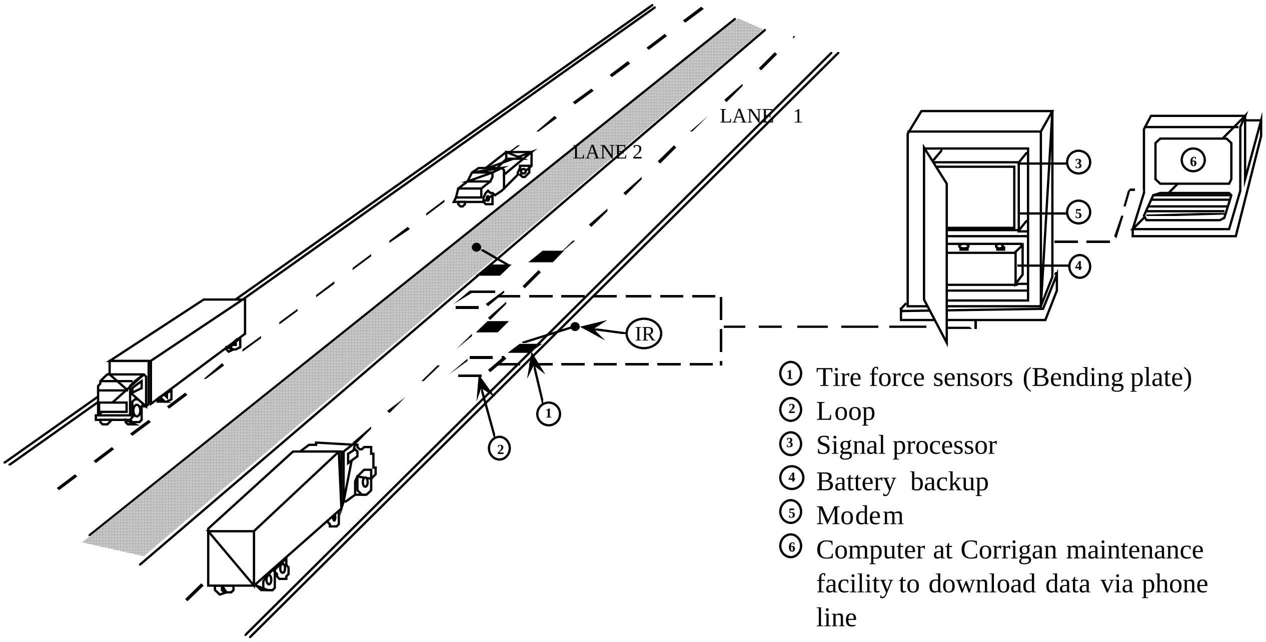


Figure 2.2 Layout of WIM system

DATA HANDLING

The first step in estimating future traffic loads is to process the observed weigh-in-motion (WIM) data. After downloading the WIM system's binary data files to a remote site, these data files can be converted to ASCII code by a program called WIMFTP, developed at CTR by Liren Huang. The new converted files are then run by Qu's computer program (CAR program) to sort the data by TxDOT vehicle classes. For detailed information on the operation of, and logic behind, the CAR program, the reader should consult Tongbin Qu's report (1996). The following section describes a single day's file (about 7,500 vehicles) when it is binary coded and ASCII coded; also shown is an output file of the CAR program.

- **Binary format**

Each daily data file is stored in the WIM system under a unique file name using the "Dsssmmdd.yy" format, where:

D: Raw data file designator

sss: Site number, (i.e., 001 for north site, 002 for south site)

dd: Day

.: Extension separator

yy: Year

For example, a file from the south site on April 26, 1996, would be named: "D0020426.96." After the data file is run by the WIMFTP program, the file is converted to ASCII format and the file name is changed from "Dsssmmdd.yy" to "Vsssmmdd.yy."

- **ASCII format**

An ASCII data file is composed of strings. Each vehicle generates a string of data when it passes through the WIM system. The following is an example of a string drawn from the same file used in the previous example ("V0020426.96"):

```
2,4,26,0,0,26,70,28,12,1.2,1.2,12,0.8,0.3,9.4
```

where:

2: Lane used by vehicle (i.e., 1 for right lane, 2 for left lane)
4: Month
26: Day
0: Hour
0: Minute
26: Second
70: Speed

28: Time used to calculate lateral position (ms)
12: Infrared blocked time for the first axle (ms)
1.2: Weight of the left wheel of the first axle (kip)
1.2: Weight of the second wheel of the first axle (kip)
12: Infrared blocked time for the second axle (kip)
0.8: Weight of the left wheel of the second axle (kip)
0.3: Weight of the right wheel of the second axle (kip)
9.4: Axle spacing between the first and second axle (ft)

The above data string represents a two-axle vehicle. Vehicles having more than two axles have four additional numbers (separated by commas) in the string for each additional axle. The order of the four succeeding numbers is in the sequence: infrared blocked time for the axle, left wheel weight for the axle, right wheel weight for the axle, axle spacing between the previous axle and the current axle.

- **Output file of CAR program**

After converting the binary file to ASCII format, the new file is then run by the CAR program after the user inputs the parameters corresponding to the file to be analyzed. The program prompts the user to input four parameters: year, month, site of the data file, and the output file name. The user is also prompted to select either the “count” function, which counts the vehicles and sorts them by TxDOT classification, or the “weight” function, which extracts weight information (discussed later in this report). The axle-spacing range for TxDOT classifications is shown in Table 2.1, and typical profiles for each type are sketched in Figure 2.3. The following is an output file of the same data file used in the previous two examples “V0020426.96”:

Traffic type	Count on Lane 1	Count on Lane 2
1	2,001	653
2	1,106	402
3	24	6
4	302	192
5	72	9
6	0	1
7	34	12
8	12	25
9	1,310	146
10	25	2
11	54	7
12	10	0
13	2	0
Total	4,952	1,455

Table 2.1 TxDOT vehicle classification table (by axle spacing)

TYPE	CLASS	A-B	B-C	C-D	D-E	E-F	F-G
1	MTR. CYCLE-CAR	0.1 - 10.2					
1	CAR. 1 AXLE TR.	6.1 - 10.2	6.0 - 20.1				
1	CAR. 2 AXLE TR.	6.1 - 10.2	6.0 - 20.1	01 - 3.3			
2	PICKUP	10.3 - 13.0					
2	PICKUP - 1AX TR.	10.3 - 13.0	6.0 - 20.1				
2	PICKUP - 2AX TR.	10.3 - 13.1	6.0 - 20.1	0.1 - 3.3			
3	BUS - 2 AXLE	21.0 - 40.0					
3	BUS - 3 AXLE	21.0 - 40.0	3.4 - 6.0				
4	2D	13.1 - 20.9					
4	2 D - 1 AXLE TR.	13.1 - 20.9	6.1 - 20.1				
4	2 D-2 AXLE TR.	13.1 - 20.9	6.1 - 20.1	0.1 - 3.3			
5	3 AX. SINGLE UN (3A)	6.1 - 20.9	3.4 - 4.7				
6	4 AX. SINGLE UN (4A)	13.1 -20.9	3.4 -4.7	3.4 -4.7			
6	4 AX. SINGLE UN (RIG)	0.1 - 6.0	13.1 -29.0	3.4 -6.0			
7	2S1	6.1 -20.0	20.2 -60.0				
8	2S2	6.1 -20.0	16.5 -40.0	3.4 -6.0			
8	3S1	6.1 -20.0	3.4 -6.0	6.1 -40.0			
9	2S3	6.1 -25.0	6.1 -40.0	3.4 -6.0	3.4 -6.0		
9	3S2	6.1 -25.0	3.4 -6.0	6.1 -40.0	3.4 -12.0		
10	3S3 (SINGLE TR.)	6.1 -22.0	3.4 -6.0	10.4 -40.0	3.4 -6.0	3.4 -6.0	
10	3S4 (SINGLE TR.)	6.1 -22.0	3.4 -6.0	10.4 -40.0	3.4 -6.0	3.4 -6.0	3.4 -6.0
11	2S1 -2 (DBL. TR.)	6.1 -17.0	11.1 -23.0	6.1 -18.0	11.1 -23.0		
12	2S2 -2(DBL. TR.)	6.1 -17.0	11.1 -23.0	3.4 -6.0	6.1 -18.0	11.1 -23.0	
12	3S1 -2 (DBL. TR.)	6.1 -25.0	3.4 -6.0	6.1 -40.0	6.1 -18.0	11.1 -23.0	
13	3S2 -2	6.1 -17.0	3.4 -6.0	11.1 -23.0	3.4 -6.0	6.1 -18.0	11.1 -23.0
14	UNCLASSIFIED						

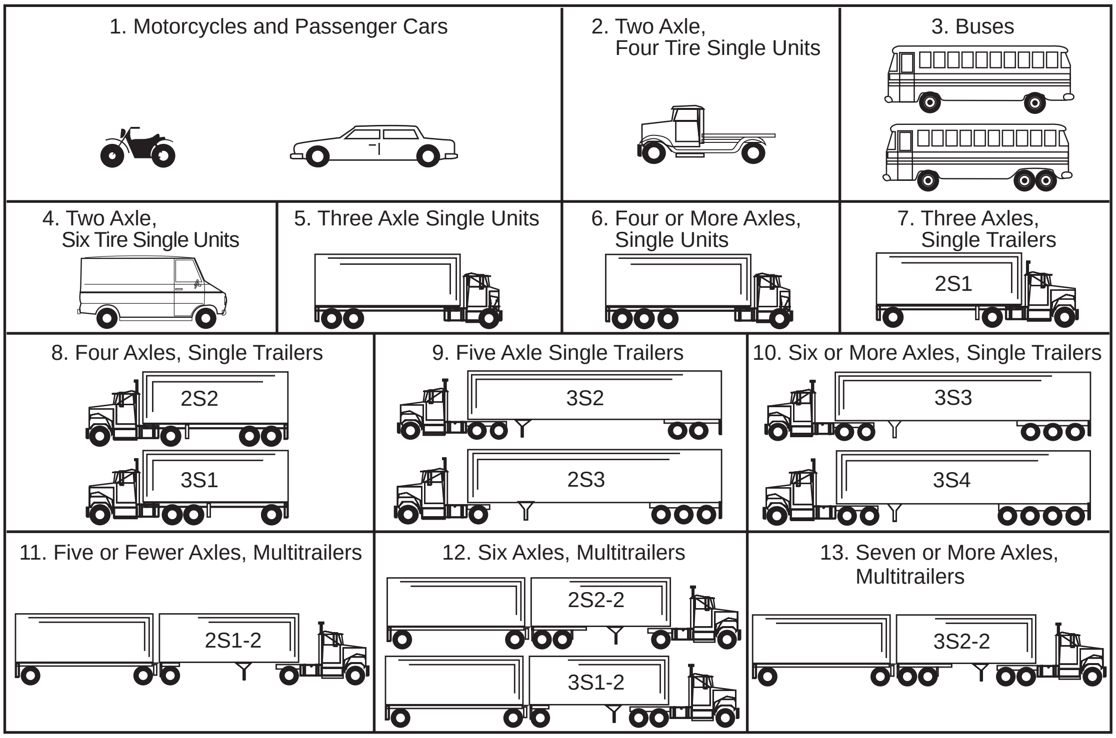


Figure 2.3 Typical vehicle profiles for TxDOT vehicle type

ERRONEOUS DATA

As is the case with any experimental measurements, there is always a tendency for erroneous data to arise. And while their presence does not mean the data set is unacceptable, the erroneous data must nevertheless be edited from the remaining data sets in order to provide worthwhile data. During this project, several types of errors were identified and have been either corrected or accepted. The tracking of the number of error records has been made easier using the CAR program, since it automatically counts the number of records and displays them upon request. Some of the most common causes of errors in this project are described below:

- *Missing data:* Throughout the project, there were occasions when the data were lost. The causes of the missing data have ranged from the preventable, such as not resetting the automated downloading call log-in time, to the unforeseen, such as equipment malfunction. In these cases several techniques were used to fill the gaps in the data sets. The most common technique involved using the traffic and loading data collected from the adjacent WIM system. As shown later in this report, the two WIM sites had very similar data patterns; accordingly, it was determined that data for each site could be extrapolated from data from the other

WIM site. Another technique used in the case where data were not available from either site was using a growth factor that is determined from data available from the previous year to project the missing data from the current year.

- *Ghost record:* Ghost records refer to the occurrence of records that were generated without the presence of any vehicles. This kind of error record appeared frequently in the data files from 1993. However, the WIM system manufacturer adjusted the system software and such records have not appeared in the more recent data.
- *Off scale:* On occasion vehicles miss a weighpad at the WIM sites when drivers change lanes or drive with one wheel on the shoulder. In these cases the DAW 100 does not take any corrective measure; it records a zero wheel weight and a large (and improbable) axle spacing.
- *Several vehicles in one record:* Occasionally, some records are unusually long, which indicates that the record is actually a combination of several vehicles. This type of error could be caused by the use of an inappropriate value for the extension time of the inductance loop on the DAW 100, since a long extension time can cause the system to combine successive vehicles into a single vehicle record.
- *Unreasonable axle spacing:* Some records have unreasonable axle spacing, but they are not associated with off-scale conditions. The cause for such records has not been identified.
- *Combined error:* In some cases the above-mentioned errors occur together in one error record. For example, one common combined error is the occurrence of two vehicles in one record, with one or both of them off scale.

ANALYSIS OF OBSERVED DATA

Data from the last 5 years (1993 through 1997) were used to represent the traffic situation at the WIM sites.

Traffic composition

Table 2.1 summarizes all thirteen types of vehicles and error files recorded during the months of January and February for the last 5 years. Of all vehicles, motorcycles, two-axle passenger cars, pickup trucks, and buses (Type 1, Type 2, Type 3) accounted for an average of 72 percent throughout all the years, and trucks accounted for the remaining 28 percent. Of the trucks, an average of 62 percent were five-axle single trailers (Type 9) and an average of 25 percent were two-axle, six-tire single units (with or without a one- or two-axle trailer). An average of 4 percent were four-axle semitrailers (Type 8) and the rest of the trucks accounted for an average of 9 percent. Figure 2.3 and Figure 2.4 show the average traffic composition and truck composition of the last 5 years during the months of January and February, respectively.

Table 2.1 Summary of vehicle count by class during January and February, 1993–1997

Type	**1993 Total**	**%**	**1994 Total**	**%**	**1995 Total**	**%**	**1996 Total**	**%**	**1997 Total**	**%**	**Average**		
											Total	**% Veh.**	**% Tru.**
1	157331	46%	172961	45%	166697	43%	205864	50%	197141	48%	179999	**46.4%**	
2	96701	28%	104592	27%	108987	28%	81609	20%	88097	21%	95997	**24.8%**	
3	1214	0%	1465	0%	1657	0%	1366	0%	1411	0%	1423	**0.4%**	
4	21457	6%	25766	7%	29564	8%	28328	7%	27814	7%	26586	**6.9%**	**24.6%**
5	2539	1%	3248	1%	3312	1%	4637	1%	4662	1%	3680	**0.9%**	**3.4%**
6	28	0%	35	0%	32	0%	46	0%	43	0%	37	**0.0%**	**0%**
7	1719	0%	1733	0%	1833	0%	1651	0%	1716	0%	1730	**0.4%**	**1.6%**
8	3982	1%	4978	1%	5252	1%	4408	1%	4501	1%	4624	**1.2%**	**4.3%**
9	55232	16%	63200	16%	66706	17%	72608	18%	77322	19%	67014	**17.3%**	**62%**
10	621	0%	773	0%	838	0%	900	0%	969	0%	820	**0.2%**	**0.8%**
11	2790	1%	2936	1%	3190	1%	3097	1%	3392	1%	3081	**0.8%**	**2.9%**
12	219	0%	305	0%	527	0%	475	0%	531	0%	411	**0.1%**	**0.4%**
13	2	0%	25	0%	31	0%	23	0%	27	0%	22	**0%**	**0%**
14	1247	0%	1191	0%	1488	0%	4063	1%	3866	1%	2371	**0.6%**	
Total	345082	100%	383208	100%	390114	100%	409075	100%	411491	100%	387794	**100%**	

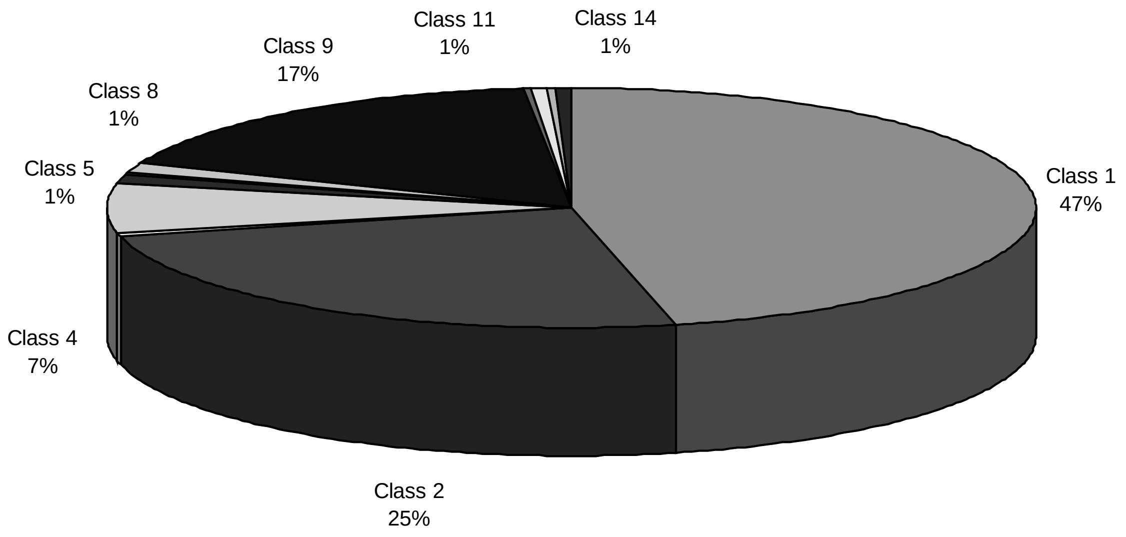


Figure 2.2 Traffic composition (average 1993–1997)

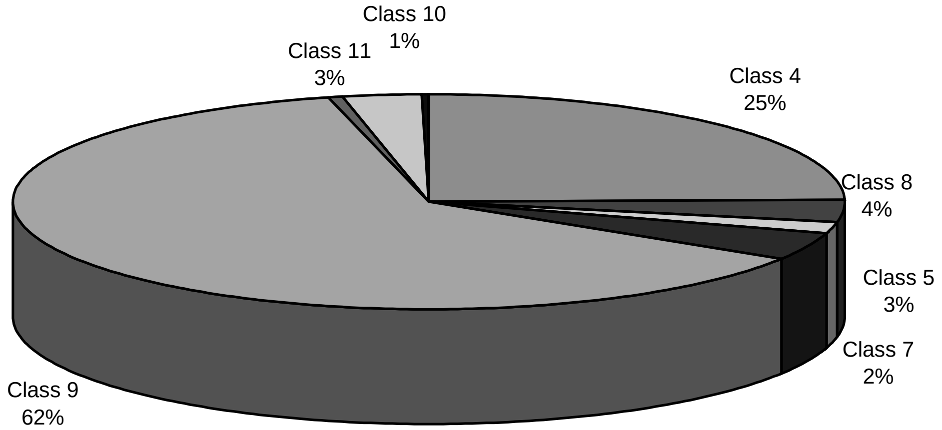


Figure 2.3 Truck composition (average 1993–1997)

North and South Site Traffic Composition

As mentioned previously, two WIM systems are installed north and south of Corrigan at the intersection of US 59 and US 287. Since both WIM systems are installed on the southbound lanes of US 59, vehicles coming from the north and traveling through Corrigan, along with southbound vehicles turning to and from US 287, can be observed. Figure 2.5 compares traffic at the two sites recorded from the months of January and February of each year from 1993 to 1997. The traffic count is almost identical at the two sites. Thus, most of the traffic travels through Corrigan, with a very small percentage of traffic using US 287.

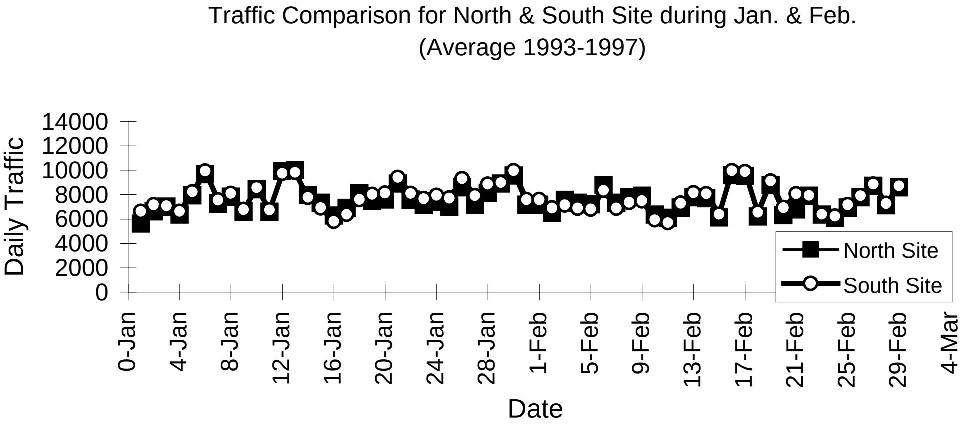


Figure 2.5 Traffic composition for north and south WIM site

Traffic Lanewise Distribution

Traffic lanewise distribution is also an important factor in pavement design. Unequal distribution of traffic between lanes significantly affects pavement design and performance. Table 2.2 summarizes the lanewise distribution of vehicle classes during the months of January and February of each year from 1993 to 1997. As shown in Figure 2.6, Lane 1 and Lane 2 are the right-hand lane and the left-hand lane, respectively. From Table 2.2 and Figure 2.6, it can be observed that passenger cars (Type 1), pickups (Type 2), small trucks (Type 4) and 3S2-2s (Type 13) use the left-hand lane more often than the rest of trucks and buses (Type 3). In general, an average of 74 percent of the vehicles travels in the right-hand lane and 26 percent in the left-hand lane. Moreover, an average of 82 percent of the trucks travels in the right-hand lane.

Table 2.2 Traffic lanewise distribution of January and February of 1993-1997

Year	**Lane**	**Type 1**	**Type 2**	**Type 3**	**Type 4**	**Type 5**	**Type 6**	**Type 7**	**Type 8**	**Type 9**	**Type 10**	**Type 11**	**Type 12**	**Type 13**	**Type 14**	**Total**
1993	1	122104	71804	928	11340	2022	20	1339	3222	49246	545	2602	191	2	932	266297
	2	35227	24897	286	10117	517	8	380	760	5986	76	188	28	0	315	78785
1994	1	122314	77073	1289	14973	2483	32	1421	4147	54280	657	2671	261	18	907	282526
	2	50647	27519	176	10793	765	3	312	831	8920	116	265	44	7	284	100682
1995	1	114839	78100	1408	16870	2636	25	1450	4362	57848	690	2742	438	21	1063	282492
	2	51858	30887	249	12694	676	7	383	890	8858	148	448	89	10	425	107622
1996	1	141417	55483	1134	14575	3895	35	1299	3523	66948	802	2877	432	16	3365	295801
	2	64447	26126	232	13753	742	11	352	885	5660	98	220	43	7	698	113274
1997	1	144245	56593	1157	14867	3973	36	1325	3593	68287	818	2935	441	16	3432	301717
	2	52895	31505	254	12948	690	7	391	908	9035	151	457	91	10	434	109774
Ave.	1	128984	67811	1183	14525	3002	30	1367	3769	59322	702	2765	353	15	1940	285767
	2	51015	28187	239	12061	678	7	364	855	7692	118	316	59	7	431	102027
	Sum	179999	95997	1423	26586	3680	37	1730	4624	67014	820	3081	411	22	2371	387794
%	**1**	**72%**	**71%**	**83%**	**55%**	**82%**	**80%**	**79%**	**82%**	**89%**	**86%**	**90%**	**86%**	**68%**	**82%**	**74%**
	2	**28%**	**29%**	**17%**	**45%**	**18%**	**20%**	**21%**	**18%**	**11%**	**14%**	**10%**	**14%**	**32%**	**18%**	**26%**

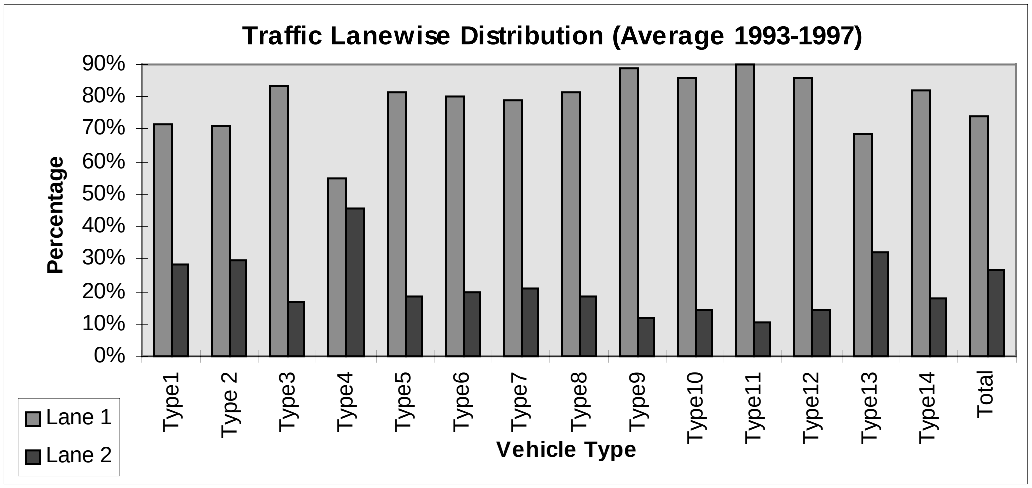


Figure 2.6 Lanewise traffic distribution

Annual Average Daily Traffic (AADT)

Since the main goal of this project was to produce a long-term forecast of traffic loading on US 59, the annual average daily traffic (AADT) calculated from the WIM data (1993 through 1997) were used to estimate a traffic growth rate. However, these AADTs include only the southbound traffic; therefore, a study of traffic on the northbound lanes of US 59 would help determine the traffic growth rate for both directions. Assuming that US 59 has a 50/50 directional distribution factor, AADTs for both the north and south sites were plotted by multiplying the southbound traffic by 2, as shown in Figure 2.7.

Using simple linear regression over the 5-year period, a best fit was performed to determine a linear growth rate. Both sites provided a goodness of fit greater than 0.8 and had an annual growth rate of approximately 2.5 percent.

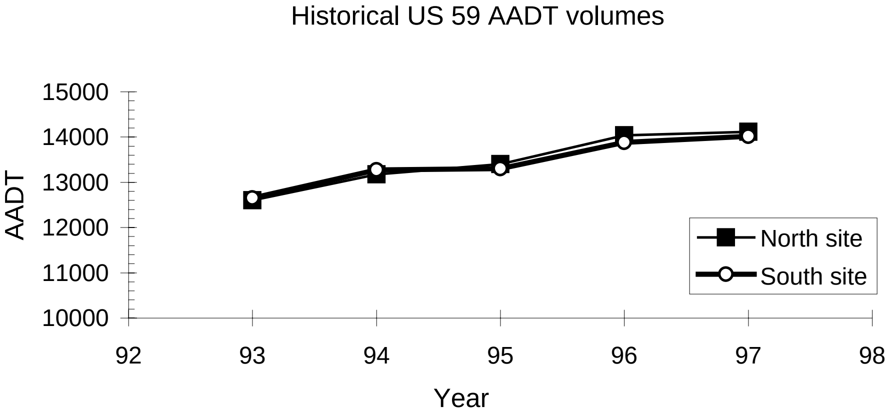


Figure 2.7 AADTs for north and south sites using WIM data (93–97)

CHAPTER 3. LOAD DATA PROCESSING AND ANALYSIS

This section is an extension of the analysis of load distributions performed by Tongbin Qu. Qu's report includes an analysis of load frequency distributions for each axle group of each truck type using the 1993, 1994, and 1995 WIM data. This section uses the same results obtained from the 1993, 1994, and 1995 data, in addition to the 1996 and 1997 data, to compare load distributions among sites, years, and different axle groups. The 1996 and 1997 WIM data were processed using the same computer program (CAR program) developed by Qu for the 1993, 1994, and 1995 data. The following sections discuss the data processing method and compare load distributions among sites, years, and axle groups.

DATA HANDLING

After downloading the binary data files from the WIM systems to a remote site, these data files are converted to ASCII files by the WIMFTP program developed at CTR by Liren Huang. The newly converted files are then run by Qu's computer program (CAR program) to compute the weight distributions of all axle groups of the different vehicle types.

The output file breaks each vehicle type into different axle groups. The different axle groups are shown in Table 3.1. The letter "S" stands for the single axle group, "T" stands for the tandem axle group, "R" stands for the tridem axle group, and "E" stands for the steering axle. "DT" and "DS" stand, respectively, for the tandem and single axle group of 3S2 spread. The first number in the footnote of the axle group stands for the vehicle type, while the second number indicates the number of repetitions of the same axle group. If there is only one repetition of the same axle group in any truck class, the second number is ignored. For more information about the operation or the logic behind Qu's program, the reader should consult Qu's report (1996).

The load interval for tandem axles and tridem (triple) axles is in 1.8-Mg (4-kip) increments from 0 to 21.7 Mg (0 to 48 kip). The load interval for a single axle is in 0.9-Mg (2-kip) increments from 0 to 10.8 Mg (0 to 24 kip) and for the steering axle in 0.9-Mg (2-kip) increments from 0 to 9 Mg (0 to 20 kip). However, Qu's computer program counts only the steering-axle loads greater than 5.4 Mg (12 kip) and gives the frequency distribution with the loads ranging from 5.4 to 9 Mg (12 to 20 kip). Pangburn's report (1996) discussed the fact that, in the AASHO Road Test, the steering-axle loads ranged from 0.9 to 5.4 Mg (2 to 12 kip) and were not analyzed separately, but rather were incorporated into the single-axle and tandem-axle load factors. Therefore, Qu's program counts only axle loads over 5.4 Mg (12 kip), since they were never analyzed and can cause significant damage to pavement structures.

LOAD DISTRIBUTION AMONG YEARS

To explore the difference among years, load distributions of the two tandem axles of 3S2s from the years 1993 through 1996 were used as examples. Sample sizes (observations) are listed in Table 3.2.

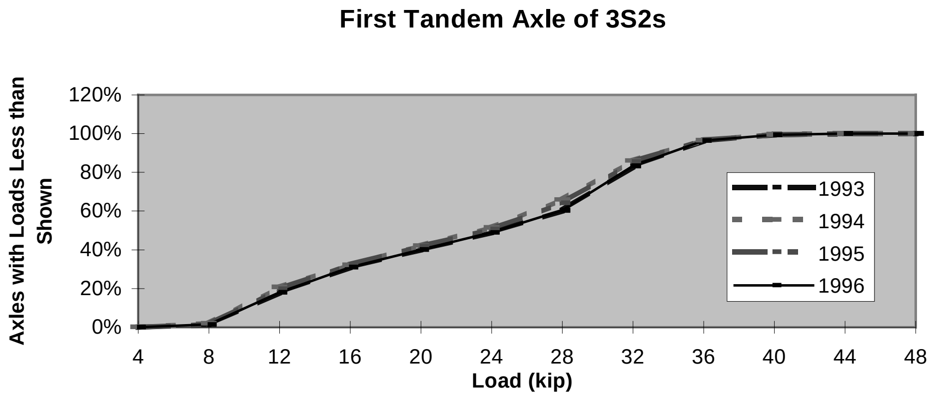
Table 3.1 Axle groups for all truck classes

Vehicle Type	Truck Type	Axle Groups
Type 4	2D 2D-1 axle trailer 2D-2 axle trailer	S41, E41 S42, S43, E42 S44, T4, E43
Type 5	3-axle single unit (3A)	T5, E5
Type 6	4-axle single unit (4A) 4-axle single unit (Rig)	R6, E62 S6, T6, E61
Type 7	2S1	S71, S72, E7
Type 8	2S2 3S1	S81, T81, E81 T82, S82, E82
Type 9	2S3 3S2 3S2 spread	S9, R9, E91 T91, T92, E92 DT9, DS91, DS92, E93
Type 10	3S3	T10, R10, E10
Type 11	2S1-2	S111, S112, S113, S114, E11
Type 12	2S2-2 3S1-2	S1211, T121, S1212, S1213, E121 T122, S1221, S1222, S1223, E122
Type 13	3S2-2	T131, T132, S131, S132, E13

The load distributions for all 4 years are shown in Figures 3.1 and 3.2. It can be observed that the distributions of the 4 years are almost identical. This observation shows that the axle weight distribution for the same axle group remained the same.

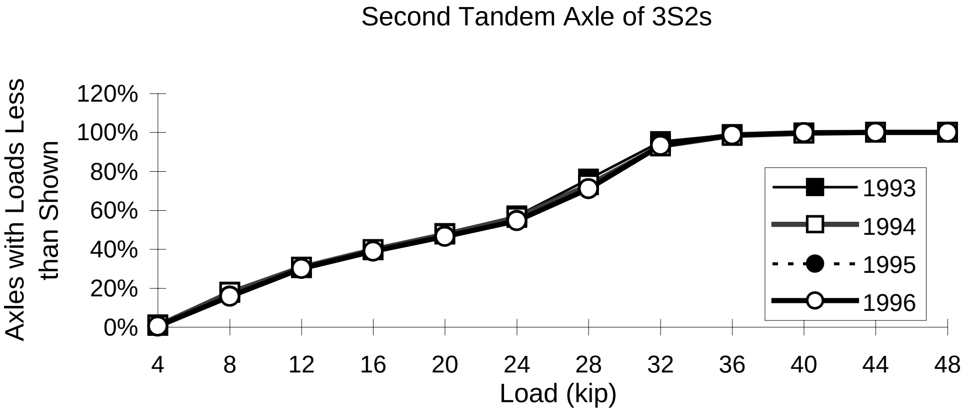
Table 3.2 Sample size of 3S2 trucks

Year	North Site	South Site
1993	222,196	212,681
1994	228,105	299,304
1995	247,643	278,395
1996	250,251	275,279



First Tandem Axle of 3S2s

Figure 3.1 Load frequency distribution of the first tandem of 3S2s by year (Note: kip=0.453 Mg)



Second Tandem Axle of 3S2s

Figure 3.2 Load frequency distribution of the second tandem of 3S2s by year (Note: kip=0.453 Mg)

LOAD DISTRIBUTION BETWEEN SITES

As discussed in Chapter 2, most of the traffic went through both sites. However, some vehicles passed through only the north site and then turned at US 287. To show the difference between sites, load distributions of the two tandem axles of 3S2 as well as the single axle of 2D were chosen as examples from the 1993 through 1996 data, as shown in Figures 3.3, 3.4, and 3.5. It can be observed that the load distributions of both sites are almost identical. This observation confirms the results discussed in Chapter 2 and shows that the pavement in both sites withstands the same loads.

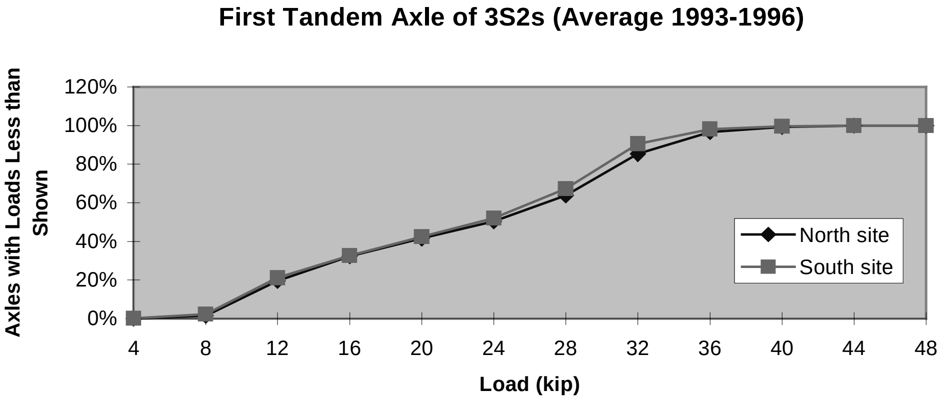


Figure 3.3 Load frequency distribution of the first tandem of 3S2s at north and south sites (Note: kip=0.453 Mg)

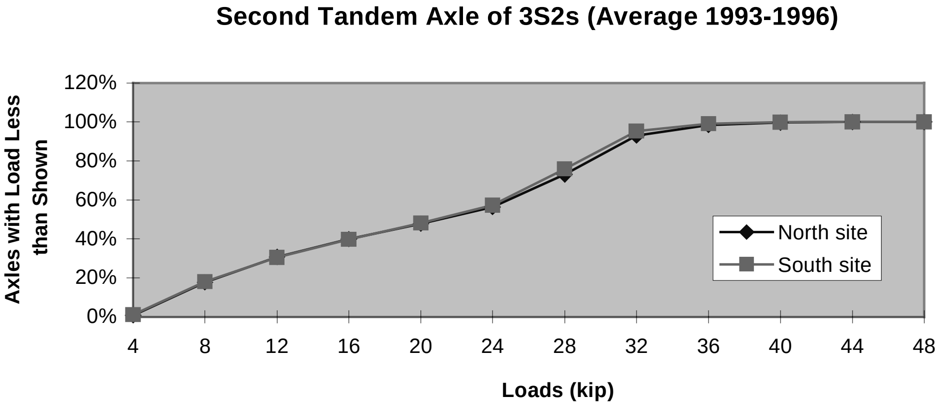


Figure 3.4 Load frequency distribution of the second tandem of 3S2s at north and south sites (Note: kip=0.453 Mg)

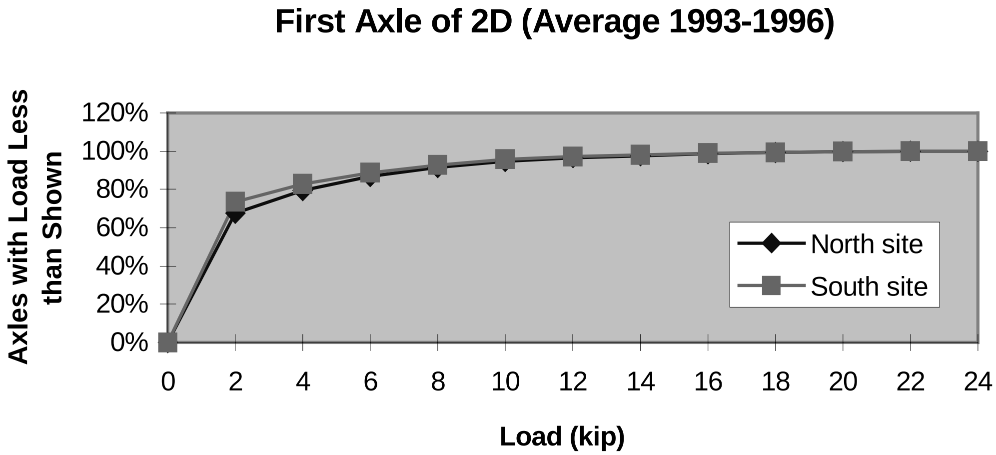


Figure 3.5 Load frequency distribution of the first axle of 2D at north and south sites (Note: kip=0.453 Mg)

LOAD DISTRIBUTION AMONG DIFFERENT TRUCK CLASSES

In addition to load distribution differences among years and sites, load distributions among different classes are also important. In fact, it was observed that the same axle groups had different load distributions when they were in different truck classes or at a different position in the same truck class. The following sections depict load frequency distributions of similar axle groups in the same truck class as well as in different truck classes. Data from 1993 through 1996 were used for this analysis.

Difference of Load Distribution of the First and Second Tandem Axle on 3S2

A similar load distribution shape was observed for the two tandem axles on 3S2s. However, the load distribution of the first tandem axle was shifted to the right of the second tandem axle (see Figure 3.6). This difference shows that the first tandem axle carried a heavier load than the second tandem axle.

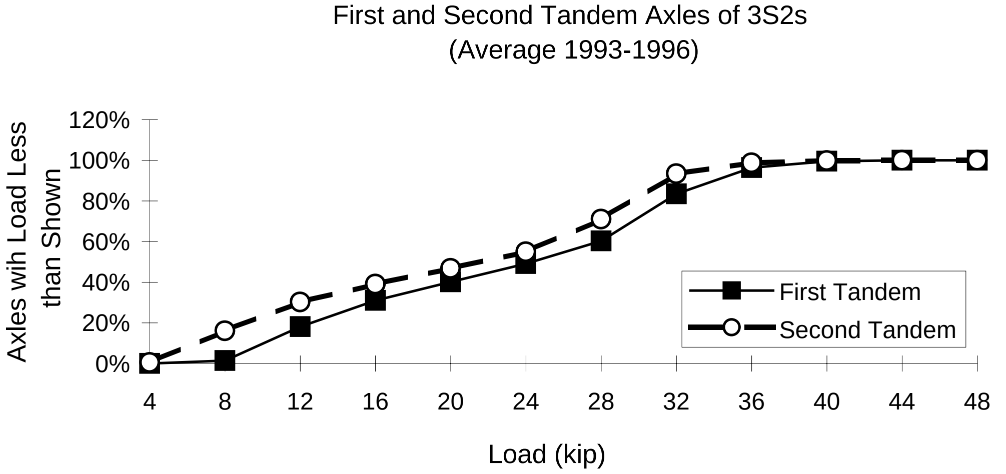


Figure 3.6 Load frequency distribution between the first and second tandem axle of 3S2s (Note: kip=0.453 Mg)

Difference of Load Distribution of First Tandem Axle between 3S2 and 3S2 Spread

Different distribution shapes were observed for the first tandem axle of 3S2 and 3S2 spread (see Figure 3.7). The two distributions intersected at 12.6 Mg (28 kip). For loads less than 12.6 Mg (28 kip), the first tandem of a 3S2 spread carried a heavier load than that of a 3S2. For the loads more than 12.6 Mg (28 kip), the first tandem of a 3S2 spread carried lighter loads, as compared with a 3S2.

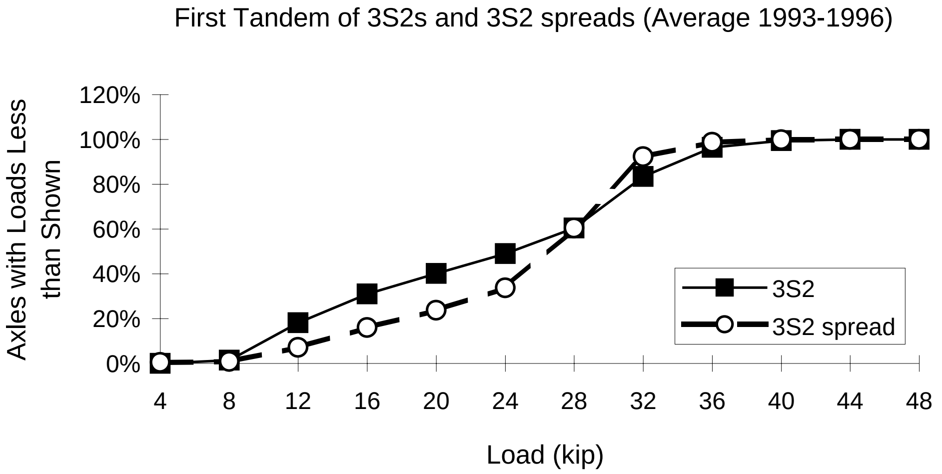


Figure 3.7 Load frequency distribution of the first tandem between 3S2s and 3S2 spreads (Note: kip=0.453 Mg)

Difference of Load Distribution of the Four Single Axles on the 2S1-2

Load frequency distributions of the four single axles on the 2S1-2 are shown in Figure 3.8. The first single axle carried a heavier load than the second single axle. The third axle and the fourth axle have similar load distributions, and both carried less load than the second axle.

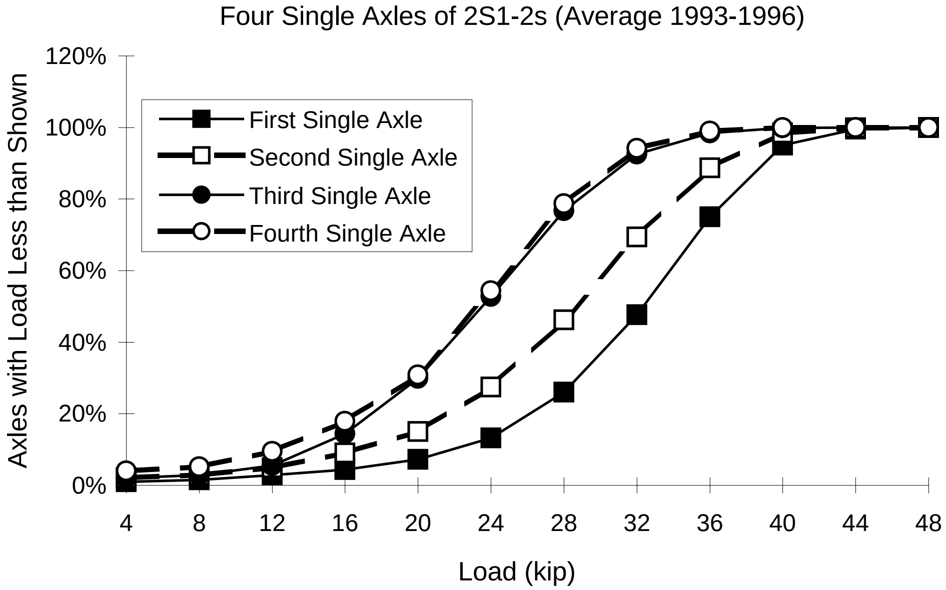


Figure 3.8 Load frequency distribution by four single axles of 2S1-2s

Steering Axle

To get an idea of how many steering axles are over 5.4 Mg (12 kip), a percentage was calculated for each truck class using the average of the 1993 through 1996 data, as shown in Figure 3.9. Except in the case of the “Rig,” small percentages of the steering axles over 5.4 Mg (12 kip) were observed for most of the samples. However, taken together the steering axle loads greater than 5.4 Mg (12 kip) may cause additional pavement damage not accounted for in current practice.

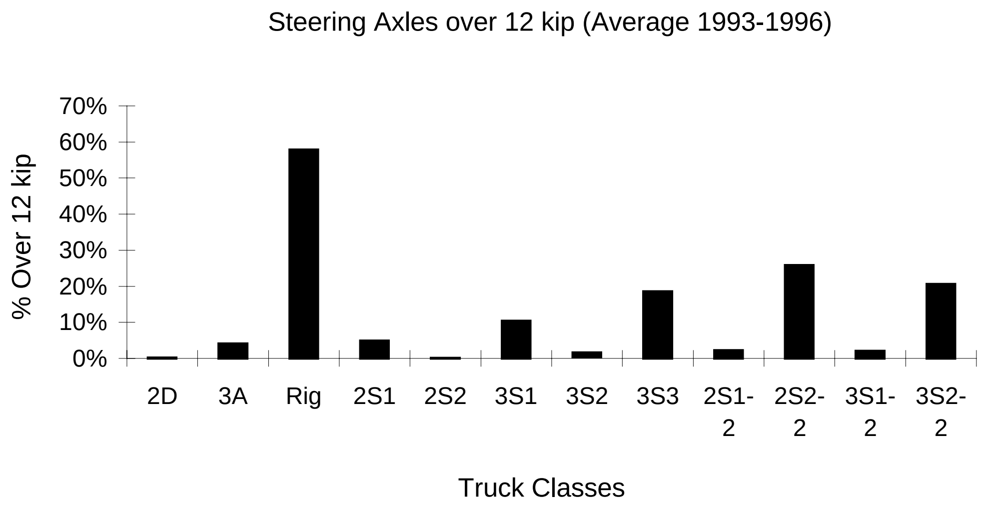


Figure 3.9 Percent of steering axles over 12 kip (5.4 Mg)

CHAPTER 4. FORECASTING TRAFFIC AND ESALS

TRAFFIC FORECASTING

In order to forecast highway pavement performance and to design adequate pavement structures, detailed traffic information is essential. Traffic forecasting can be performed by calculating annual growth rates for different vehicle types. In previous work reported by Qu (1996), the annual growth rates for different truck classes were analyzed and an emphasis was placed on five-axle, single-trailer trucks. Figure 4.1 shows an increasing linear trend of the five-axle single trailers over 4 years (1993–1996).

Figure 4.1 Average counts of five-axle single trailers over 4 years (93–96)

Using simple linear regression over the 4-year period, a best fit was performed to determine a linear growth rate. R^2, the coefficient of determination, is a summary measure that tells how well the sample regression line fits the data. The value of R^2 lies between 0 and 1, with $R^2 = 1$ representing a perfect fit. In this case, the R^2 value was above 0.8 for both sites, which means that more than 80 percent of the annual counts of five-axle single trailers can be explained by the regression model. According to the regression analysis, the average annual traffic growth rate for five-axle single trailers was approximately 6 percent for both the north and south sites.

FORECASTING ESALs

This section depicts the work described in Qu's report (1996) on forecasting ESALs. In order to apportion the relative contribution to cumulative pavement damage of the mixed axle-group load distributions, equivalency equations are applied to convert the mixed loads into 8.2-Mg (18-kip) ESALs. These equivalency factors are then multiplied by each vehicle type's axle-load frequency distribution to calculate the weighed average equivalency factor for each truck type. These factors are automatically calculated by CAR program once all the appropriate parameters are inputted. To forecast ESALs, Qu's second program (ESAL program) automatically calculates the total cumulative ESALs during an analysis period once data are input, such as the weighed average equivalency factors, the forecasting period, simple or compound growth rate, the growth rate, and AADT for each truck type. For more information about the ESAL program, the reader should consult Qu's report (1996).

Table 4.1 shows an example of the output of the ESAL program. In this example, a 20-year analysis period is used for a typical flexible pavement structure located within the project limits with a structural number of 6 and a terminal serviceability of 2.5. The data for AADT and weighted ESALs per vehicle were obtained from south site data during 1995.

Once all the data are input and a compound growth rate option is selected, the program calculates the total cumulative ESALs (9,746,969 ESALs) predicted during the analysis period for both lanes. This number of ESALs can then be distributed between lanes using a lanewise distribution factor.

Table 4.1 Example of forecasting ESALs (compound growth rate)

					$p_t = 2.5$
Analysis Period: 20 years					SN = 6
Truck Types	Current Traffic (AADT)	Growth rate	Design Traffic (20 years' accumulation)	Weighted ESALs (/vehicle)	Design ESALs
Type 4	600	5%	7,240,140	0.031	224,444
Type 5	70	0%	511,000	0.178	90,958
Type 6	2	0%	14,600	0.297	4,336
Type 7	30	0%	219,000	0.277	60,663
Type 8	100	0%	730,000	0.261	190,530
Type 9	1,100	6%	14,771,185	0.567	8,375,261
Type 10	20	0%	146,000	0.851	124,246
Type 11	60	0%	438,000	1.521	666,198
Type 12	10	0%	73,000	0.615	44,895
Type 13	1	0%	7,300	0.745	5,438
All Truck	1,993		24,150,225	Total ESALs	9,746,969

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

As part of Project 7-987, the traffic data set collected is one of the most complete and detailed ever compiled. The initial collection effort was undertaken in late 1992 and has continued through mid-1997. When functioning properly, the WIM systems measure and record data on every vehicle traveling through the southbound stretch of US 59; these data include wheel loads, axle spacings, lateral lane position, speed, time and date, whether an axle has single or dual tires, and the lane of travel. The principal objectives of this report were (1) to use the WIM data to characterize past traffic loading and patterns, (2) to develop axle-load frequency distributions for the individual axles on each vehicle class, and (3) to forecast future traffic loading and volumes using a computer program and a simple regression method, respectively. The following two sections include conclusions and recommendations.

CONCLUSIONS

1. Of all vehicles, motorcycles, two-axle passenger cars, pickup trucks and buses accounted for an average of 72 percent, while trucks accounted for an average of 28 percent.
2. Of all trucks, an average of 62 percent were five-axle single trailers, 25 percent were two-axle, six-tire single units, 4 percent were four-axle semitrailers, and the rest of the trucks accounted for an average of 9 percent.
3. Traffic counts between the north and south WIM sites are almost identical. Thus, most of the traffic goes through Corrigan and only a small percentage turns onto US 287.
4. In general, 74 percent of the vehicles traveled in the right-hand lane and 26 percent traveled in the left-hand lane. Moreover, 82 percent of the trucks traveled in the right-hand lane.
5. There was no significant change of loading pattern from 1993 through 1996. The axle weight distribution for the same axle group remained the same. It was observed that the axle weight distributions for the same axle were similar or almost identical between the two WIM sites. The same axle groups were observed to have different load distributions when they were in different truck classes or at a different position on the same truck class. Thus, it is necessary to calculate the load frequency distribution by truck class and by the axle position on the truck.
6. A small percentage of steering axles over 5.4 Mg (12 kip) was observed in the large samples. These steering axle loads greater than 5.4 Mg (12 kip) may cause additional pavement damage that is not accounted for in current practice. However, their effects were included in the analyses by Qu’s computer program.

7. Traffic forecasting can be performed by calculating annual growth rates for different vehicle types using a linear regression analysis. ESAL forecasting can be performed by the ESAL program developed by Tongbin Qu (1996).
8. Overall traffic is growing at an annual rate of approximately 2.5 percent, while five-axle single trailer trucks (Type 9) are growing at approximately 6 percent.

RECOMMENDATIONS

1. A study of economic factors, the population, and lane-use of the area will help to improve the forecast of future traffic.
2. Based on evaluation of the TxDOT classification scheme, it might be desirable to separate some of the axle groups. Trucks, such as 3S2 and 2S3, whose axle weight distributions are very different, should be classified separately.
3. Five-axle single trailer trucks (Type 9) should be carefully analyzed because they cause serious damage to the pavement and have a high annual growth rate.
4. Load frequency distributions are usually more significant when calculated by truck class and by the axle position on the truck.
5. Steering axle loads, which are over 5.4 Mg (12 kip), should be included in the traffic load analysis because they may cause additional pavement damage.
6. It is necessary to add at least one WIM system capability on the northbound lanes of US 59 to quantify the traffic count and loading data, since traffic before and after Corrigan is almost identical.

REFERENCES

Tongbin Qu, “Traffic-Load Forecasting Using Weigh-In-Motion Data,” Research Report 987-6, Center for Transportation Research, The University of Texas at Austin, 1996.

Garner, J. E., and C. E Lee, “Augmented Weigh-in-Motion System for Traffic Data Collection and Analysis,” Transportation Research Record No. 1501, Pavement-Vehicle Interaction and Traffic Monitoring, Transportation Research Board, National Research Council, National Academy Press, Washington, D.C., 1995, pp. 81-86.

Highway Research Board, “The AASHO Road Test,” Report 5, Pavement Research, Highway Research Board Special Report 61E, 1962.

Izadmehr, B., “Truck Traffic Loading on Multilane Highways,” MS thesis, The University of Texas at Austin, 1982.

Lee, C. E., P. R. Shankar, and B. Izadmehr, “Lateral Placement of Trucks in Highway Lanes,” Report No. 310-1F, Center for Transportation Research, The University of Texas at Austin, 1983.

Pangburn, J. W., “Preliminary Research Findings on Traffic-Load Forecasting Using Weigh-In-Motion Data,” Research Report 987-5, Center for Transportation Research, The University of Texas at Austin, April 1996.

PAT Equipment Corporation, Inc., “DAW 100 — Bending Plate, System Description of Automatic Vehicle Weight and Classification System,” 1992.

U.S. Department of Transportation Federal Highway Administration, “Traffic Monitoring Guide,” Office of Highway Information Management, Washington, D.C., 1995.