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16. Abstract

The data recorded by two WIM systems installed at Laredo and El Paso provide unique information about trucks crossing the Texas-Mexico border. These trucks make up a large percentage of the total number of heavy vehicles that enter Texas from Mexico. With growing concern for the transportation infrastructure in Texas and other states, the objective of this project was to document United States and Mexican border-crossing truck characteristics for current and future study.

Data obtained from the WIM systems between the summer of 1994 and the summer of 1996 are presented in summary form in this report. Yearly and seasonal trends have been graphed and analyzed for truck traffic volume and composition, axle loads, and equivalent single axle loads (ESALs) for trucks entering the United States at Laredo and both entering and exiting the United States at El Paso. Queuing problems persisted for southbound traffic at El Paso; however, with the addition of on-site sensors and the creation of a computer analysis program which located individual vehicle records within clustered queued vehicle data, a significant sample of southbound truck data was obtained. This report shows characteristic truck traffic patterns throughout the duration of the project and gives representative data to be used for future analysis.

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TRUCK TRAFFIC CHARACTERISTICS AT THE LAREDO AND EL PASO, TEXAS-MEXICO BORDER

by

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and

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Research Report Number 0-1319-5

conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the

U.S. Department of Transportation
Federal Highway Administration

by the

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

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IMPLEMENTATION RECOMMENDATIONS

Two weigh-in-motion (WIM) devices were installed near the north end of the international bridges that cross the Rio Grande at the City of Laredo (1993) and at El Paso (1994) with the purpose of collecting characteristic data about truck traffic crossing the Texas-Mexico border going both northbound and southbound. Patterns of daily truck volumes, truck types, axle loads, and equivalent single axle load (ESAL) factors were all observed and analyzed for the duration of this research project. This data can be used to help assess the current and future impact of border-crossing traffic on the operation and maintenance of highway infrastructure in Texas. All the information gathered on various overloaded axle-types entering and exiting the country can be used to assist in monitoring and regulating these damaging loads, especially as regards NAFTA-induced traffic. The experiences recorded in this report on troubleshooting and the operation and maintenance of the two WIM systems should be applied to future WIM installation projects.

This report was prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

DISCLAIMERS

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SUMMARY

The data recorded by two WIM systems installed at Laredo and El Paso provide unique information about trucks crossing the Texas-Mexico border. These trucks make up a large percentage of the total number of heavy vehicles that enter Texas from Mexico. With growing concern for the transportation infrastructure in Texas and other states, the objective of this project was to document United States and Mexican border-crossing truck characteristics for current and future study.

Data obtained from the WIM systems between the summer of 1994 and the summer of 1996 are presented in summary form in this report. Yearly and seasonal trends have been graphed and analyzed for truck traffic volume and composition, axle loads, and equivalent single axle loads (ESALs) for trucks entering the United States at Laredo and both entering and exiting the United States at El Paso. Queuing problems persisted for southbound traffic at El Paso; however, with the addition of on-site sensors and the creation of a computer analysis program which located individual vehicle records within clustered queued vehicle data, a significant sample of southbound truck data was obtained. This report shows characteristic truck traffic patterns throughout the duration of the project and gives representative data to be used for future analysis.

INTRODUCTION

The United States shares a 3,200-km border with Mexico, with about 1900 km of it running along the southern boundary of Texas. Of all the cargo transported across this Texas-Mexico border, over 70 percent is handled by trucks, with a large percentage of this truck traffic passing through the ports of entry at Laredo and El Paso [Ref 1]. These ports along the Rio Grande have restrictions disallowing trucks (and their drivers) originating in one country to proceed directly to a final destination in the other. Short-haul companies, also known as drayage companies, sometimes use truck-tractors to transport trailers and semi-trailers across the border into a 20-km zone on either side.

The North American Free Trade Agreement (NAFTA), if implemented, will discontinue this zone practice and allow trucks originating in Mexico to travel through and onward into the USA. Likewise, trucks originating in the USA can pass through the Texas-Mexico border and continue towards their destination in Mexico. Many of the time-consuming, port-of-entry restrictions on truck movements, such as those in Laredo and El Paso, will be removed.

One major concern about NAFTA stems from heavily loaded Mexican trucks. The Mexican government allows trucks to be loaded to weights that generally exceed the United States' maximum limit by approximately 10-17 percent [Ref 1]. When such overloaded vehicles travel on existing roads and bridges, premature wear-out of these expensive structures occurs.

Another point of concern is traffic safety. There are certain risks associated with foreign drivers who lack an understanding of local traffic laws and customs. Not being familiar with the language of the country can pose a problem to most drivers. This, along with inexperienced drivers traveling in climatic conditions to which they are not accustomed might prove hazardous. For example, some drivers may never have seen snow or ice conditions on a road, and others may not know how to react on poorly maintained roads. For these reasons, drayage companies may stay in business for those who do not wish to operate their vehicles in the next country. However, there will also be those that wish to travel to their final cargo destination.

For those who decide to travel ahead, there still needs to be an efficient method of enforcing the load limits on northbound trucks coming into the United States and on southbound trucks traveling into Mexico. If effective enforcement can be implemented, then the damaging effects of overloaded trucks on the transportation infrastructure in both countries will be minimized.

To obtain statistical data about the border-crossing trucks in Laredo and El Paso, a weigh-in-motion (WIM) system was installed near the northern end of the truck bridges over the Rio Grande River at both of these ports of entry in August 1993 and February 1994, respectively. This was accomplished as part of a research project entitled "Modal Planning and the U.S.-Mexico Free Trade Agreement" conducted by the Center for Transportation Research (CTR) of The University of Texas at Austin in cooperation with the Texas Department of Transportation (TxDOT) and the City of Laredo. These systems were operated until the termination of the research project in August 1996. The sensors of the WIM system allow the on-site microcomputer hardware and software to measure the dynamic load of each axle and also calculate the distance between successive pairs of axles when a truck passes through the WIM site without stopping. With this information, patterns showing the number of trucks of various types and axle loads that cross the border can be determined, with respect to time. This, in turn, provides a factual basis for estimating the potential damage to highway infrastructure.

The relative pavement damage caused by one pass of a vehicle load of given magnitude is affected by the number and spacing of axles which share the load. Except for a few special vehicles, the total vehicle load (gross vehicle weight) is carried by a combination of axle types: single, tandem (two closely spaced axles), or tridem (three closely spaced axles). Therefore, it is important to know both the magnitude of individual axle loads and the spacing between pairs of successive axles in order to determine the axle type. Typically, a WIM system is programmed to calculate axle spacing as a function of vehicle speed — assuming a constant vehicle speed or a constant rate of acceleration as the vehicle travels over the sensors. When a vehicle stops over the WIM sensors, as southbound trucks often do in El Paso, axle-spacing values calculated by the WIM system are not valid, as the assumed conditions are not satisfied. Without valid axle-spacing data, it is not feasible for the WIM systems at Laredo and El Paso to determine axle type automatically or to associate individual axle load observations with a particular vehicle. Axle loads, however, are measured properly by the WIM system, even under such stop-and-go conditions.

The WIM sites at Laredo and El Paso were located just beyond the U.S. customs stations where departing northbound trucks could pass over the WIM sensors without stopping. However, at El Paso, every southbound truck was required to stop and pay a Mexican bridge toll about 30 m beyond the WIM sensors. This frequently created a queue of stopped trucks over the sensors and prevented the WIM system from calculating and filing axle-load data properly according to axle type and vehicle class. An auxiliary vehicle-presence sensor was added and special software was installed in an attempt to improve this function, though the results were not completely successful. A computer program that was developed to interpret the recorded southbound traffic data and arrange the axle loads into logical groups by vehicle class is described in following chapters.

The work herein is an extension of earlier work by Luis A. Sanchez-Ruiz [Ref 2]. His report was based on Laredo and El Paso data from the installation of the WIM systems through September 1995. Subsequent data for northbound trucks through June 1996 for Laredo and July 1996 for El Paso, along with all southbound trucks observed at El Paso between August 1994 and July 1996, are discussed herein.

Chapter 1 briefly describes how a WIM system works. Explanations of how data are recorded and processed are also given. Vehicle types, characteristics, axle loads and axle spacings are addressed. Chapter 2 presents a discussion of the problems that occur when southbound trucks form a queue over the WIM sensors in El Paso.

Chapter 3 gives examples of this queued southbound data in El Paso and shows patterns from within that can be utilized towards finding useful vehicle records. These patterns were the basis for the reclassifying program that was created for this project. The program is outlined in this chapter.

Chapter 4 takes all northbound data and reclassified southbound data and gives truck counts for vehicles crossing the Texas-Mexico border. Chapters 5 and 6 present additional information gathered from the WIM sensors. Load characteristics and ESAL factors have been calculated and discussed.

Finally, Chapter 7 summarizes all the data collected for this project. It also highlights patterns and major differences and provides suggestions for future improvements.

CHAPTER 1. WEIGH-IN-MOTION (WIM)

A weigh-in-motion system estimates the gross vehicle weight and the axle loads of a static vehicle by measuring and analyzing the dynamic tire forces as the vehicle is moving. Electrical signals from sensors in the road are processed by instruments at the site to make these measurements. Additional information about the vehicles, including speed, number of axles, and axle spacing, is also calculated [Ref 1].

1.1 THE WIM SYSTEM CONCEPT

It is important to the WIM system that the road surface at the site be very smooth. If there are bumps and rough areas on the pavement, components of the vehicle will accelerate vertically. If an axle is accelerating upward from the initial shock of a bump or flaw in the pavement surface, the measured tire force will be less than the corresponding static force. Once the axle accelerates downward after the peak of the jump, the measured tire force will be greater than the corresponding static force. Speed, vehicle suspension, tire pressure, and contact area are some of the characteristics of a vehicle that can affect the measured dynamic tire force. To minimize the effects of these variables, the pavement must be as level and as smooth as possible.

1.2 WIM SENSORS

For a typical WIM system, there are two types of sensors in the pavement. The first type of sensor is called an inductance loop detector. A coil of wire is placed into the pavement using a concrete saw. The sensor detects the presence of metal in a vehicle that passes over the loop of wire. The vehicle-present signal alerts the on-site computer that a vehicle is approaching the tire-force sensors that are located just downstream.

The second type of sensor in the road is a tire-force transducer (weight pad). A pair of such sensors is arranged in the traffic lane so that the tires on each end of an axle pass over a force sensor. Typically these sensors are metal plates supported along their edges and encased in a rubber-like material. The plates are set flush with the pavement surface in order to afford the vehicle smooth travel over the sensor. When a tire passes over the plate, the plate deforms elastically and creates a tensile strain on the bottom surface. This deformation is measured by bonded resistance strain gauges that generate an electrical output signal that is proportional to the vertical force applied by the tire load. These electric signals are what the system uses to estimate the vertical load on each tire. An advantageous arrangement of the plates is in a staggered pattern (see Fig 1.1).

The WIM system can calculate the spacings of successive axles as well as their load. To do this, the speed of a vehicle is determined from the time it takes the axle to travel the known distance, say 1.83 m (6 feet), between the staggered tire-force sensors. The speed, calculated for the first axle, is listed as the truck's speed by the WIM system. This speed is not used, however, to calculate the distance between successive axles. Rather, speed is measured for each individual axle. By assuming a uniform deceleration or acceleration rate, the computer can calculate the distance between each pair of axles as the product of the average speed of both axles and the time between the arrival of the axles at a sensor [Ref 3].

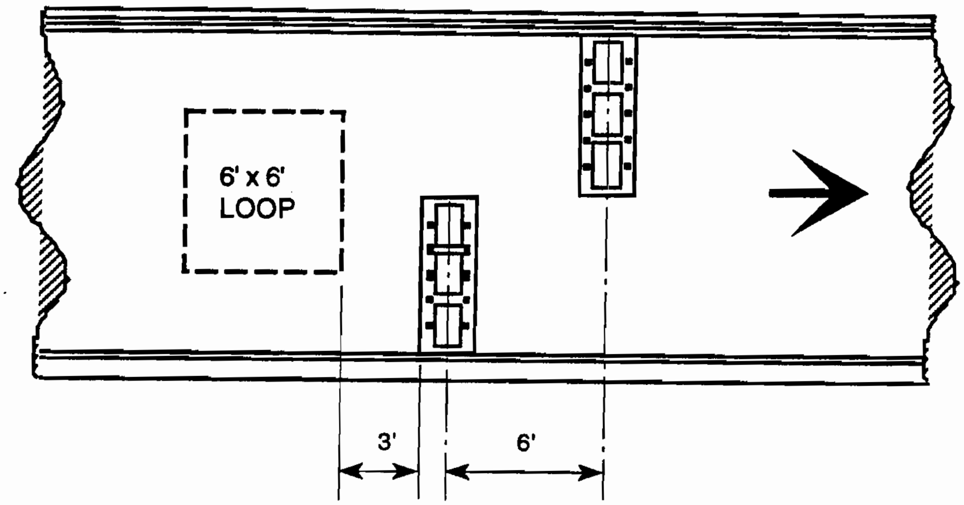

Figure 1.1 Staggered weight-pad arrangement

1.3 WIM INSTRUMENT

The heart of a WIM system is the signal processing unit, in this case an on-site computer. This computer has the basic function of processing and storing all data produced by the sensors. It allows the user to dial in from a telephone and tap into the system as it continues to record data. There are methods for checking the system for problems and for downloading the recorded data. These procedures are all outlined in the PAT manual [Ref 4].

1.4 MODIFICATION OF EL PASO WIM SYSTEM

Because of a queuing problem in southbound traffic, we modified the WIM system at El Paso in February 1994. The problems created from this queuing will be discussed at greater length in the following chapter. The addition was an infrared light-beam sensor. The source of the problem came from the system not being able to determine whether a vehicle was present over the tire-force sensors or not. When a truck was present over the loop detector, there was no question. However, when a line of trucks would form just beyond these sensors, a vehicle that occupied the loop heading into Mexico would have nowhere to go and would stop over the sensors. A truck stationed over the loop detector did not cause an immediate problem; at least the system knew that there was a vehicle present. In such situations, the weight pads would be constantly active and the computer program would continue to look for other axles on the force sensors. However, if the truck passed over the loop and stopped on or over the weight pads, this would cause problems. The truck did not occupy the loop, so the system assumed that the vehicle had come and gone.

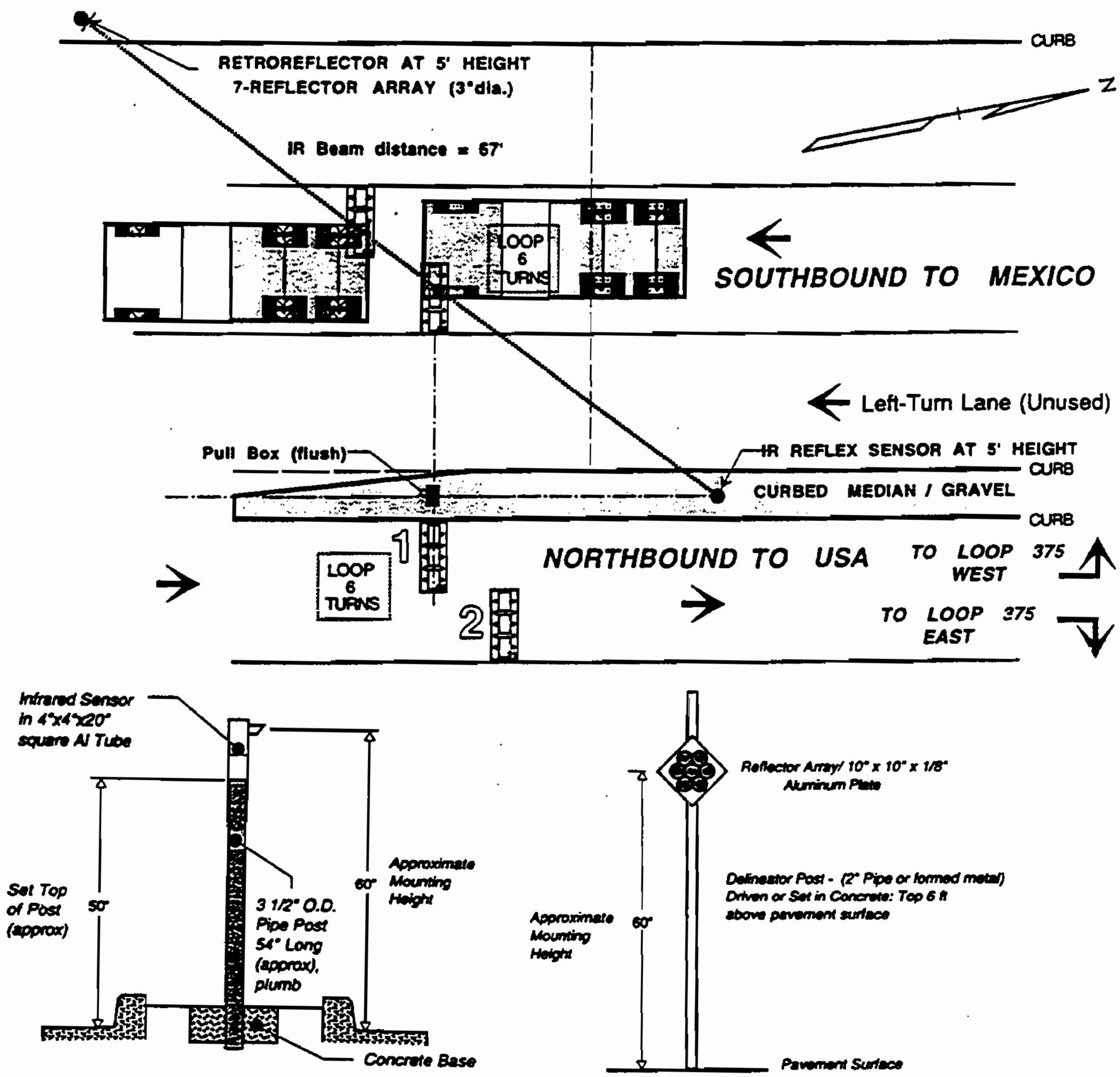

Figure 1.2 Infrared light-beam sensor in the southbound lane in El Paso

The WIM system provides an adjustable time extension of the loop presence signal; however, with the stopped vehicle still over the pads, this feature was inadequate. A solution was to include an infrared light-beam sensor (see Figure 1.2) that could detect whether a vehicle was still present over the tire-force sensors. The beam was positioned at a 37° angle in order for the truck components to block the beam at all times as it passed over the pads, instead of allowing the beam to pass between the tractor and the semi-trailer or through other openings on the truck. This way, the system recognized that there was a vehicle present in the zone covered by the loop and by the infrared light-beam sensor, regardless of the loop detector time-out feature [Ref 5].

1.5 WIM DATA

The data stored by the on-site PAT signal processing unit are in binary format. Once the binary data are downloaded by a process outlined in a previous report (Ref 4), they can be converted to ASCII format by using a software program developed by Liren Huang, a Research Engineer Associate at the Center for Transportation Research, The University of Texas at Austin. A Microsoft Excel software program is then used to format the ASCII data as shown in Figure 1.3. The first seven columns represent site-specific data that the system records every time a vehicle passes over the sensors.

- The first column is the record number. Every record of a vehicle that passes over the sensors is assigned a serial number. In Figure 1.3, the first record number is 382.
- The second column represents the direction that the truck is moving. The number "1" represents a truck moving northward and "2" represents one moving southward. As shown in Figure 1.3, both directions are listed, indicating that this sample of data was taken from the El Paso site since the system in Laredo records truck traffic in only one direction.
- The date is indicated in the third column.
- The fourth through the sixth columns show the time stamp of the record. Every time a vehicle passes over the sensor pads, the time of day is recorded in hours, minutes, and seconds.
- The seventh column indicates the speed at which the truck was moving. This value can also be used to calculate the length of the vehicle as well as the spacing between successive axles if the vehicle is not accelerating.

The columns following are grouped in an order which represents the loads and spacings for each individual axle (AG1 – AG6). These columns are made up of three variables. The first two variables represent the load recorded for the vehicle's left and right wheels, respectively. As a vehicle passes over the sensor pads, a record is produced for each wheel load, axle by axle, until the entire vehicle has rolled over the system. The third column of the grouping represents the spacing, in feet, between two consecutive passing wheels. It is essentially the distance between each axle pair. The first grouping (AG1) has all zeros for axle spacing. This indicates that the values in this group are for the first axle (steering) on the vehicle. Successive groupings, moving from left to right on the page, show values in the third column for the distance between consecutive axles. In order to find all the five-axle trucks in a data set, one would locate all rows filled with values up to and including the AG5 column. The total number of five-axle trucks in the data set sample is eight. There are three six-axle trucks, no four-axle trucks, two three-axle trucks, and three two-axle trucks.

C1	C2	C3	C4	C5	C6	C7	AG1	AG2	AG3	AG4	AG5	AG6
382	1	28	11	36	45	24	3.8 3.5 0	2.4 2.3 16	1.6 1.7 4.4			
383	1	28	11	38	49	24	4.1 3.7 0	2.1 2.2 12	1.8 0 18			
384	2	28	11	42	26	12	4.66 4.3 0	3.8 4.7 9.1	3.7 4.3 3.7	2.6 4.2 42	3.5 4.3 5.6	
385	1	28	11	42	26	12	4.3 3.2 0	6.3 9 13	8.1 8.4 4.7	9.3 8.5 26	5.8 7.2 3.7	
386	1	28	11	42	39	16	1.9 1.6 0	1.7 1.1 12				
389	1	28	11	45	30	15	4.8 4.6 0	4.2 4.7 19	3.5 4 4.5	3.1 3.6 31	3.5 4.1 3.9	
393	1	28	11	50	28	13	3.6 3.5 0	8.1 9.9 15	7.5 9.4 4.4	7.8 8.3 29	7.1 8.1 4	
395	1	28	11	52	33	12	4.6 4.5 0	11 12 17	12 12 4.4	9.1 9.4 23	9.2 10.5 4.3	7.6 9.8 4.2
396	1	28	11	52	56	11	4.4 4.3 0	8.2 11 16	9.1 9.5 4.4	8.2 9.4 23	7.8 6.6 4.4	6.5 8.1 4.1
397	2	28	11	53	2	19	5 4.5 0	5.8 7.1 11	5.2 7.1 4.6	4.2 7.8 31	5.1 9.4 4.3	
398	2	28	11	53	10	10	3.2 3 0	4.6 5.4 21				
399	1	28	11	53	19	17	5.9 0.5 0	7.9 5.8 10	7.5 9.4 11	4.8 8.9 15	6.3 6.9 15	6.4 7.8 4.3
400	1	28	11	53	46	13	4.3 4.3 0	8.2 8.6 13	7.4 9.1 4.5	6.8 9 25	7.9 9.6 4	
401	2	28	11	54	45	9	2.4 2.6 0	3.8 4.9 20				
402	1	28	11	56	15	15	3.8 3.8 0	5.2 5.8 13	4.8 5.8 4.5	5.6 6 32	5.1 6.3 4	
403	1	28	11	57	11	17	4 3.5 0	5.3 6.1 14	4.8 5.2 4.7	5.2 5.6 33	4.6 6.1 4	

Figure 1.3 A sample of El Paso data in hard-copy form

The next chapter will cover the problems encountered with the El Paso southbound traffic. The data did not always come in this clear-cut format.

CHAPTER 2. TRUCK QUEUES IN EL PASO

The WIM system at the El Paso port of entry is located on a 150-m long section of divided (narrow curbed median), four-lane (plus a short left-turn lane for southbound-to-eastbound traffic into a parking lot), two-way roadway which connects the north end of the Zaragosa International Truck Bridge (across the Rio Grande) with Loop 375 at a diamond interchange. The WIM sensors are installed in the two through-traffic lanes — one for northbound and one for southbound traffic — nearest the median; traffic control devices (e.g., pavement markings and plastic barrels) are used to direct trucks into the WIM-instrumented lanes.

2.1 TRUCK MOVEMENTS OVER THE WIM SENSORS

Not all truck drivers chose to drive into the WIM-instrumented lanes as guided by the pavement markings; and when traffic demand is high, long queues of waiting southbound trucks form in advance of the Mexican toll gate near the north end of the bridge. Under both circumstances, inadequate data are provided to the WIM system by the sensors.

The WIM system at the port of entry at El Paso is near the north end of the bridge. Trucks moving from Mexico into the U.S. pay a toll at the south end of the bridge before crossing; they then proceed to a U.S. customs inspection yard at the north end of the bridge. Upon release from the yard, they usually accelerate and pass smoothly over the WIM sensors in the northbound lane; however, occasionally a truck will change lanes or stop over the sensors.

Trucks southbound for Mexico encounter the WIM system about 30 m before reaching the Mexican toll-collection station at the north end of the bridge (in Texas). During rush hours, the traffic demand often exceeds the capacity of the storage space between the WIM sensors and the station; as a consequence, long queues form. When the queue of stop-and-go trucks extends past the sensors, the loop detector and the infrared light-beam sensor inform the on-site computer that the presence of trucks in the sensor zone is constant; in these instances, there is no way for the computer software to determine the separations between trucks. The truck drivers minimize the space between vehicles. As long as the vehicle-present signal is not interrupted, the computer program will assume that all the wheels that pass over the weight pads belong to the same truck and will continue to store wheel-load, time, and calculated axle-spacing data into the same vehicle-record file. The calculated axle spacings for such stop-and-go traffic are not valid in many cases, even though the wheel load and time data are.

2.2 RECORDED DATA FROM LONG QUEUES

Using Figure 2.1 as an example, record numbers (the first column) 2007, 2012, and 2014 stop in the fifth grouping (AG5). This, as described earlier, indicates that the computer is recording a vehicle with five axles. It successfully established the front and rear of the trucks that passed over the sensors. However, for record number 1981, there are values up through the eleventh grouping (AG11). The software only records up to eleven groupings per vehicle and then starts the next line with a new record number.

C1	C2	C3	C4	C5	C6	C7	AG1			AG2			AG3			AG4			AG5		
1981	2	17	19	34	56	3	5.2	4.6	0	4.7	5.7	13.4	4.6	5.5	5	3.9	3.3	45.5	5.2	3.8	4.1
1983	2	17	19	35	44	3	6.5	5.6	0	6.9	5.5	4.5	3.8	6.4	33	5.8	6.2	4.2	7.3	5.8	49
1984	1	17	19	36	16	18	4.4	4.4	0	2.6	3.3	14.6	3.3	3	4.4	3.1	1.7	26.6	2.7	2.5	3.9
1985	1	17	19	36	42	19	5.6	5	0	4.5	6.7	14.1	4.8	5.4	4.5	4.3	4.4	32.8	4.9	6.2	4.1
1986	2	17	19	36	42	19	2.5	2.4	0	3.6	3.4	12.3	7.7	6.8	65.7	10.1	11	15.5	10	9.9	4.6
1987	2	17	19	37	55	19	4.5	0	0	6.9	0	7.4	6.9	0	5.9	5.6	0	99.6	6.7	0	3.4
1988	2	17	19	39	3	19	6	6.2	0	6.9	7.1	15.2	6.6	7	4.7	4.7	5.2	83.1	6.9	0	11
1989	1	17	19	39	32	17	4.6	4.6	0	5.8	5.3	10.9	6.4	5.6	4.3	4.8	5.3	28	4.5	5.4	4.1
1990	2	17	19	40	19	2	5.3	2.6	0	5.2	4.8	10.2	5.6	4.9	4.1	4.3	3	42	5.9	2.4	10
1992	2	17	19	41	19	3	5.3	4.7	0	3.6	3.4	11.6	3.6	3.2	4.4	2.4	3.3	31.5	3.2	3.2	4.8
1993	1	17	19	42	17	21	5.1	4.2	0	5.9	5.6	12.8	5	4.7	4.3	5.3	4.4	31.9	4	4.1	4
1994	2	17	19	42	20	4	6.2	6	0	6.4	7	3.9	4	4	31.5	5.3	5.8	3.9	6.7	5.8	24
1995	2	17	19	42	36	2	3.7	8	0	5.2	3.8	4.2									
1996	1	17	19	42	46	14	5	5.4	0	12.1	11.9	11.7	12	12.5	4.4	8.9	8.8	28.2	7.8	8.9	4.1
1997	1	17	19	42	59	20	5.9	0.7	0	0.7	5.3	21.5	3.8	3.9	29.8	3.5	3.3	4.4	2.5	2.9	31
1998	2	17	19	43	22	4	5.1	4.4	0	6.3	7	9.9	6.9	6.2	4.5	4.1	4.8	43.9	6	5.5	4.1
1999	1	17	19	43	31	13	6.1	6	0	6.9	8.8	13.7	6.4	8.1	4.5	4.9	6.7	37.3	6.1	7.3	4.1
2000	1	17	19	44	6	13	5.9	0.7	0	0.8	5.4	16.8	7.2	0.7	20.6	6.7	9.1	12.5	0.9	9.3	14
2001	2	17	19	44	9	1	6.5	7	0	6.6	6.9	4.3	5.7	7.1	135	9.1	8.7	3.1			
2002	2	17	19	44	43	5	3.7	3.2	0	4.1	4.4	19	4.9	4.8	17.4	5.4	6.4	10.4	7.6	7.7	4.4
2004	2	17	19	45	25	24	5.5	4.6	0	2.4	2.3	10.4	2.7	0	15.7						
2005	1	17	19	46	25	16	5.6	4.8	0	6	5.8	11.8	5.9	5.8	4.3	5.6	5.9	33.5	5.7	5.7	4.1
2006	2	17	19	46	27	19	4.8	4.5	0	4.3	4.8	10.7	4.8	5	4.4	4.8	6.5	12.9	6.3	7	4.2
2007	2	17	19	46	39	15	4.8	4.7	0	8.6	9.7	12.4	6.9	9.8	4.5	6.1	8.8	33.8	8.4	7.5	4.1
2008	2	17	19	46	49	10	5.5	5.3	0	14.6	17	14.9	15	15.7	4.7	9.3	11	26.2	12	14	4.5
2009	2	17	19	47	26	4	5.5	5.1	0	9.6	8.9	11.9	9.5	8.9	4.6	8.1	9	52.4	8.5	9.7	4.2
2011	1	17	19	47	58	15	4.8	4.7	0	6.8	6.6	13.2	5.7	6.2	4.1	5.1	3.3	30.2	6.3	3.8	3.9
2012	2	17	19	48	14	13	6.7	6	0	9	8.8	11	8.7	8.1	4.5	6.6	7.3	36.6	8.6	7.3	4.2
2013	1	17	19	48	27	14	5.7	5.2	0	5.7	6.9	10.9	6	7.4	4.3	6.7	3.5	34.2	7.7	3.8	3.9
2014	2	17	19	48	42	13	7.3	6.3	0	9.1	10.6	11.1	7.9	10.5	4.4	10.9	11	28.4	11	9.5	4.6
2015	1	17	19	49	3	21	5.8	4.2	0	5	6.3	9.7	6.1	5.3	4.5	4.4	5.2	31.1	4.4	4.8	4.2
2016	2	17	19	49	39	10	5.1	4.7	0	4.9	5	13.9	5.6	4.6	4.4	2.8	3.1	30.7	2.8	3.7	4.1
2018	1	17	19	50	35	18	5.4	5	0	3.4	3.7	15.9	2.8	3.7	4.4	3	2.8	29.5	3	2.4	4.1
2019	1	17	19	50	59	22	2.7	2.5	0	4.1	5	17.1									
2020	2	17	19	51	4	13	6.3	6	0	9.2	9.9	16.5	10	10.6	4.4	8.4	11	31.1	9.4	10	4.3
2021	2	17	19	51	17	11	6.1	5.5	0	14.6	14.7	14.8	17	15.4	4.5	12	13	23.3	12	13	4.3
2022	1	17	19	51	22	17	4.9	4.4	0	5.3	5.9	10.3	5.6	5.6	4.4	4.1	4.5	37.7	5.2	5.1	4
2023	1	17	19	52	48	23	4.1	3.6	0	4.9	6	21.3									
2024	2	17	19	53	21	12	6.9	6.2	0	10.7	10.6	17	11	11.3	4.4	9.1	8.7	29.7	10	12	4.2
2025	2	17	19	53	42	9	6.7	6	0	9.9	10.8	15.8	10	10.9	4.5	9.6	9.6	28.1	9.8	11	4.2
2026	1	17	19	53	47	15	5.3	5.3	0	8.9	9.5	13.5	7.9	8.4	4.3	8.3	8.4	31.8	7.9	9.3	4
2027	1	17	19	54	46	14	5.5	4.9	0	6.1	7.4	12	5.3	7.1	4.4	5.3	6.7	37.1	7.5	7.8	4.2
2028	1	17	19	54	53	19	5.1	5.1	0	6.5	7.6	12.2	6.6	6.6	4.5	7.1	6.3	31.6	7.6	6.9	4
2029	2	17	19	55	0	18	7	7.3	0	10.8	9.9	15.6	10	10.6	4.4	10.9	10	29.5	9.2	11	4.2
2030	2	17	19	55	5	15	5.9	4.9	0	6	5.8	10.2	6	5.7	4.3	4.8	4.5	34.5	6.1	6.3	4.1

C1	AG6			AG7			AG8			AG9			AG10			AG11		
1981	5.5	4.6	125.8	7	5.9	14.6	6.8	6.1	4	3.5	5.7	36	5.8	5.3	5.2	5.4	4.6	56.7
1983	7.4	7.2	5.5	7.6	6.9	4.5	6.2	7.5	26.6	7.4	6.5	4.7						
1986	10	0	90.8	9.7	0	2.9												
1987	5	0	15.6	6.2	0	9.2	6.3	0	4.3	4.6	0	69	5.8	0	3.9			
1990	5.6	2.8	7.4	5.6	4.4	11.9	6	4.3	4.3	4.6	4.2	76	7.5	5.7	0.5			
1992	5.8	4.9	52.9	7.6	6.8	14.5	7.3	6.9	4.6	4.5	5.6	33	7.8	7.2	4.2	4.9	4.6	24.6
1994	9.2	11.2	10.8	9.3	9.8	4.5	10	9.1	30	11	9.9	4.5	5	4.6	134	7.1	8	8.1
1997	2.9	2.7	4.1															
1998	6.8	6.2	25.7	7.8	10.1	11.7	8.2	9.6	4.7	9.8	11	34	11	9.6	4	5.6	4.8	24.7
2000	0.8	7.8	48.9	6	9.6	2.8	6.4	0	23.5	0.8	0	0.5	0.8	0	0.6			
2002	7.9	7.4	29.2	6.8	7.6	4.3												
2008	13	13.4	4.5															
2009	5.7	4.7	22.4	4	4.2	12	4.5	4.6	4.3	3.2	3.3	38	4.7	4.1	4.3			
2021	14	14.4	4.2															

Figure 2.1 A sample of queued El Paso data in hard-copy form

There are a number of things that could have happened when the computer recorded this eleven-axle vehicle. One possibility is that an eleven-axle vehicle passed; another is that there were two vehicles.Perhaps the sensors did not find the separation between the two vehicles and the computer program assumed that the axles were all on one vehicle. There could have been one six-axle truck followed by a five-axle truck, totaling eleven axles. Another possibility is that more than two vehicles were involved: a three-axle truck followed by another three-axle truck, and then finally followed by a five-axle truck, totaling eleven axles.

An additional consideration is that only part of the axles on a vehicle were stored in the eleven-axle vehicle record and the others were carried over into the next line. Looking at record number 1995, data are recorded up through the second axle grouping (AG2). This could be a normal two-axle vehicle. It also could be the rear axles of a vehicle that had some of its axles recorded in the previous line (1994). Thus, an apparently good record (1995) is rendered questionable. A few other record numbers might also raise questions: Record 1987 has a ten-axle vehicle listed. This could have been two five-axle trucks or a four-axle followed by a six-axle truck. The same is true for record number 2009, another ten-axle vehicle record.

Because of the many possibilities, when the on-site WIM software was unable to distinguish a definite separation between vehicles, vehicle records which contain up to eleven axles were created. An Excel macro was then used to identify all vehicle records with seven to eleven axles; these were stored into a separate error data file for further analysis. Such records cannot be used directly because there is no way of telling what type of truck had passed. It was not possible for the computer software to distinguish axle type either. This error file will be discussed further in the next section.

Such ambiguity indicates the need for additional analysis of the data recorded by the system when queues of stop-and-go traffic had formed over the WIM sensors. The program that was developed to interpret the various time, axle-load, and axle-spacing data items recorded by the WIM system in an attempt to identify the steering, single, tandem, and triple axles associated with each truck that crossed the sensors is described in the following chapter.

2.3 THE SEPARATE ERROR DATA FILE

After the ASCII data has been processed through the Microsoft macros, when seven-to-ten and eleven-axle vehicle records are encountered, they are moved into a separate error file. However, complications with separating the front and rear of trucks are not the only type of data error that could occur. The error file is a gathering of all the vehicle records that can have one of the following four problems.

- "Zero" load recorded for a wheel. This occurs when a vehicle travels outside the marked lanes of the road, causing some of the tires to miss the tire-force sensors.
- Unreasonable axle spacings. These values are recorded when vehicles remain on or over the weight pads for extended periods of time.

- Seven-axle to ten-axle record. This occurs when the vehicle-presence sensors cannot find the front and rear of a vehicle, and the computer adds two or more vehicles to the same vehicle record.
- Eleven-axle record. This is an error similar to the type listed just above. It can result from two or more vehicles being added together, or it can include only part of a vehicle record with the remainder continuing on the next record line.

Figure 2.2 shows a count of the erroneous vehicle records that occurred for northbound traffic at the El Paso site, March 1996, with all four problem types included. The percentages of errors are as follows: 95.0 percent "zero" loads, 4.0 percent unreasonable spacings, 0.5 percent seven to ten-axle vehicle records, and 0.5 percent eleven-axle vehicle records. The median number of such erroneous vehicle records per weekday was 277.

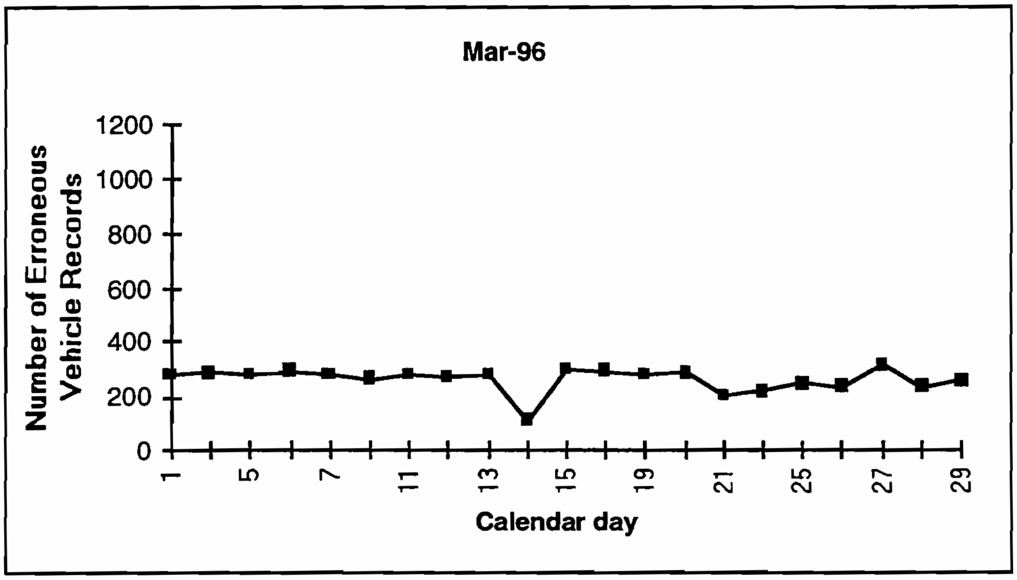

Figure 2.2 Number of erroneous vehicle records per weekday, NB El Paso, March 1996

Figure 2.3 shows the erroneous vehicle record count per weekday for southbound El Paso traffic during March 1996. The percentages of errors are as follows: 42.0 percent "zero" loads, 19.0 percent unreasonable axle spacings, 15.5 percent seven-to-ten-axle vehicle records, and 23.5 percent eleven-axle vehicle records. The median number of erroneous records per weekday was 303.

The number of erroneous vehicle records per weekday that were identified at the El Paso site during March 1996 was similar for both northbound and southbound traffic; however, the cause for these records being generated by the WIM system was quite different. The number of seven-to-ten and eleven-axle vehicle record errors was much higher in the El Paso sample than in

Laredo, where northbound traffic was weighed in a single, designated lane. The procedure used to further evaluate these error files is outlined in Chapter 3.

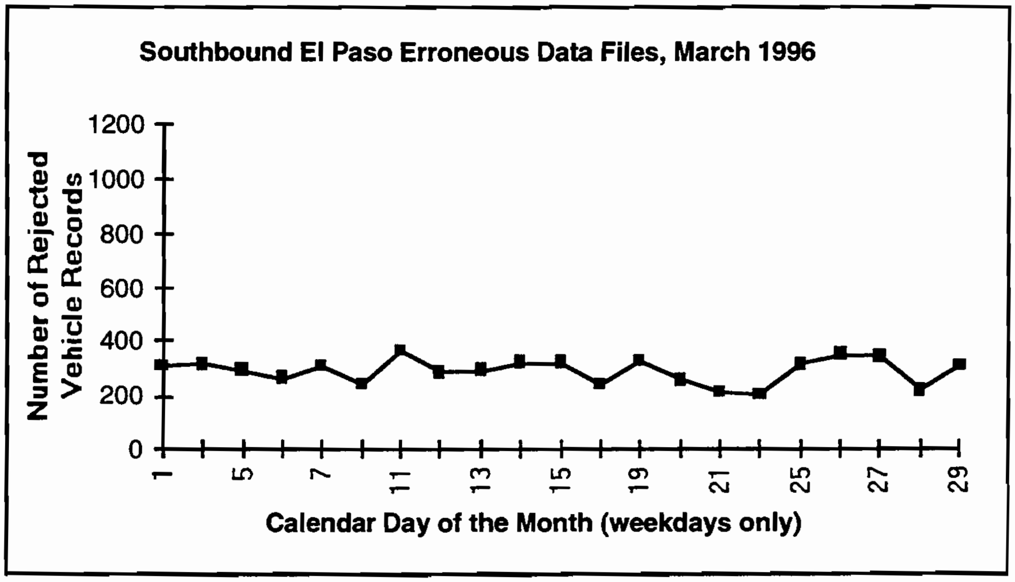

Figure 2.3 Number of erroneous vehicle records per weekday, SB El Paso, March 1996

CHAPTER 3. ANALYSIS OF ERROR FILES

Analyzing data for southbound El Paso traffic became very difficult due to the relatively large amount of data from queued trucks. Various ranges of axle spacings and wheel loads were determined so that a computer program could be created to help sort through and find individual vehicles within a cluster of queued vehicle data. The reasoning and technique used to structure the program is outlined in this chapter.

3.1 FINDING PATTERNS WITHIN CLUSTERS OF QUEUED VEHICLE DATA

As the truck queue lines at El Paso for southbound traffic formed, the WIM sensors and on-site computer continued to record data. The fact that errors occurred within vehicle records did not stop the ongoing data collection. The computer continued to record seven-to-ten-axle records, eleven-axle records, zero wheel loads, and unreasonable spacings along with the good, reliable vehicle records.

This ongoing collection of information was downloaded in binary format (a process outlined in Chapter 1) and then converted to an ASCII hard-copy form. Once the data had been transferred into a readable format, an analyst could visually inspect the data for sections of query. Queuing did not occur twenty-four hours a day, so when one looked at the data and located clumps of seven-to-ten-axle and eleven-axle records, it became easy to tell the time of day when queuing occurred. In the El Paso situation, queuing occurred mostly between the hours of 12:30 and 20:00.

After studying the data, certain patterns were readily noticed. For example, there tended to be extremely high values for calculated axle spacings. Looking at the sample of queued data from El Paso shown in Fig 3.1, in various spots, there are unusually large spacings. Sometimes these spacings were as large as 500.0 ft. This was obviously too large for the axle spacing of a truck. Another point noticed about these spacings was that there were not two such values together. For example, if a spacing of 500.0 ft was found, the next adjacent axle spacing would not be an equally unreasonable value. A likely reason for this was that when the rearmost axle of a vehicle passed beyond the weight pads while the vehicle-presence sensors were still activated, the computer program would continue the calculation of the space between this rearmost axle of the departed truck and the front steering-axle of the next oncoming truck. The computed axle-spacing value would then be listed in the same vehicle record with axle values for the previous vehicle as if there had been only one vehicle passing over the weight pads. As the next vehicle continued to travel over the pads, the axle count in the vehicle record would grow. This also explains why there would not be two unusually large axle spacings together. Once the spacing between the rearmost axle of the departed truck and the front steering-axle of the oncoming truck had been calculated, the next axle-spacing would come from the vehicle's second axle as it passed over the sensors. Therefore, the second spacing stayed at a reasonable value and the computer program continued to count axles.

C1	C2	C3	C4	C5	C6	C7	AG1			AG2			AG3			AG4		
838	1	17	12	50	42	13	6.2	5.2	0	4.8	5	11.6	4.1	4.9	4.4	3.3	2.5	30.7
839	2	17	12	50	58	3	4.9	4.5	0	5.5	4.9	17.3	5.7	4.6	5	3.2	4	85.4
840	1	17	12	51	13	13	5.7	5.1	0	6	7.1	11.2	5.9	6.7	4.3	4.1	4.5	29.7
841	1	17	12	51	41	11	6.2	5.8	0	10	12	13.8	10.7	11.1	4.2	6.5	10.4	23.6
844	2	17	12	51	55	4	2.8	2.5	0	5.7	5.2	15.1						
845	1	17	12	52	24	10	5.5	5.1	0	7.8	8.7	9.7	9	9.6	4.2	8.1	8.9	31.4
846	1	17	12	52	40	10	6.1	5.5	0	9	11	10.3	11	13.3	4.2	8.3	10.2	36.6
848	2	17	12	53	3	2	4.8	4.2	0	7.7	8.4	57.6	7.9	8.4	1.3	7.1	8.8	4.8

C1	AG5			AG6			AG7			AG8			AG9			AG10		
838	3.8	3.2	4															
839	4.5	5.6	4.4	4.8	3.5	110.3	5.8	5.5	4.2	4.5	4.6	4.5	6.8	7	34	7.8	8.2	4.2
840	4	4.6	3.9															
841	7.9	6.6	4.1	9.1	7.3	3.9												
844																		
845	8.4	8.1	4.1															
846	8.4	9.8	4.1	5.7	4.6	32.3	6.3	5.6	11	6.5	5.8	4.3	4	4.2	27.5	6.6	5.6	4.2
848	9.2	9.8	4.1	5.6	4.7	99	8.9	7.6	12.3	9.5	8.9	4.3	8.3	7.7	28.2	8.7	7 8	4.1

Figure 3.1 A sample of queued El Paso data in hard-copy form

Under these circumstances, it was rationalized that when an unusually large axle-spacing value was encountered in a vehicle record, it could indicate the beginning of a new vehicle. This was also convenient because the on-site WIM software identifies the beginning of a truck record, by assigning its first axle a zero spacing. To edit such a data file, the large axle-spacing value could simply be replaced with zero.

There were also other patterns noticeable. Axle spacings fell into definite ranges that were easy to identify. Table 3.1 lists the axle-spacing ranges for two- through six-axle trucks. This enabled an analyst to look at the ASCII data and discover truck records based on the individual axle spacings, matching them one-by-one against the ranges of Table 3.1.

Table 3.1 Range of values for spacing between successive axles

Truck Type	Axle Spacing, ft				
No. Axle	A - B *	B - C *2	C - D *3	D - E *4	E - F *5
2	7.0 - 21.0				
3	7.0 - 21.0	3.0 - 7.0			
4	7.0 - 21.0	3.0 - 7.0	> 20		
4	7.0 - 21.0	> 20	3.0 - 7.0		
5	7.0 - 21.0	3.0 - 7.0	> 20	3.0 - 7.0	
6	7.0 - 21.0	3.0 - 7.0	> 20	3.0 - 7.0	3.0 - 7.0

* Distance from the steering axle to the second axle
*2 Distance from the second axle to the third
*3 Distance from the third axle to the fourth
*4 Distance from the fourth axle to the fifth
*5 Distance from the fifth axle to the sixth

Referring to Fig 3.1, record number 846 (a ten-axle record), there are two sets of axle spacings that have values approximately in the range for a five-axle truck listed in Table 3.1. In the first grouping (AG1), there is a 0 m (0.0 ft) spacing, followed by 3.14 m (10.3 ft) in AG2, 1.28 m (4.2 ft) in AG3, 11.16 m (36.6 ft) in AG4, and 1.25 m (4.1 ft) in AG5. The ASCII axle-spacing data fit within the ranges of Table 3.1; therefore, a five-axle truck can be reasonably assumed. In the next grouping (AG6), there is an unusually large spacing. This is a possible indicator of the separation between two trucks; so this spacing value can be replaced with a value of 0.0 ft. to indicate that the following data values are probably for the axles of a new truck. The next spacing in AG7 is 3.35 m (11.0 ft), followed by 1.3 m (4.3 ft) in AG8, 8.38 m (27.5 ft) in AG9, and 1.28 m (4.2 ft) in AG10. These values are also within reasonable ranges of axle-spacing — following the steering axle — for a five-axle truck.

After extensive manual evaluation of the vehicle records from El Paso southbound traffic, it seemed best to check the ASCII axle-spacing data for a six-axle truck first, then for a five-axle truck, and on down to a two-axle truck. The reasoning behind this is that if there is a pattern that fits a three-axle truck, (e.g., see Fig 3.1; AG1, AG2, and AG3 for record number 846) and it is labeled as such without further examination, the following axle data for the rear tandem of a five-axle truck would be missed.

In addition to noticing axle-spacing patterns within the data, there were also load patterns. The steering axle on five-axle trucks is typically loaded to about 4.6 kips per wheel, or 9.2 kips. It seemed that this value might be helpful in finding data associated with the beginning of a truck record; so another table was created, Table 3.2, listing a reasonable range of wheel loads on the various axles of two- through six-axle empty and loaded trucks. An analyst can manually examine the recorded pattern of wheel loads and axle locations on various types of trucks and compare them to this table in order to group the axle-load data according to truck type.

Table 3.2 Range of wheel load by truck type, loading condition, and axle location

Truck Type	Range of Wheel Load, kips					
No. Axles	A *	B *2	C *3	D *4	E *5	F *6
2 empty	1.5 - 4.0	1.5 - 4.0				
2 loaded	1.5 - 4.0	1.5 - 4.0				
3 empty	4.0 - 7.0	2.0 - 3.5	2.0 - 3.5			
3 loaded	4.0 - 7.0	3.6 - 5.0	3.6 - 6.0			
4 empty	4.0 - 7.0	3.0 - 5.0	3.0 - 5.0	3.0 - 5.0		
4 loaded	4.0 - 7.0	5.1 - 16.0	5.1 -16.0	5.1 -16.0		
5 empty	4.0 - 7.0	3.0 - 5.0	3.0 - 5.0	3.0 - 5.0	3.0 - 5.0	
5 loaded	4.0 - 7.0	5.1 - 16.0	5.1 - 16.0	5.1 - 16.0	5.1 - 16.0	
6 empty	4.0 - 7.0	3.0 - 5.0	3.0 - 5.0	3.0 - 5.0	3.0 - 5.0	3.0 - 5.0
6 loaded	4.0 - 7.0	5.1 - 16.0	5.1 - 16.0	5.1 - 16.0	5.1 - 16.0	5.1 - 16.0

* Steering axle
*2 Second axle
*3 Third axle
*4 Fourth axle
*5 Fifth axle
*6 Sixth axle

For example, referring to Fig 3.1, record number 839, AG1 through AG5 appear to be associated with a five-axle truck when looking at the spacings alone. The next five lines in the record appear to relate to a five-axle truck as well; however, one of the spacing values in AG7 does not fit within the ranges of Table 3.1. In these instances, one can then check to see whether the wheel loads in the record fall within the load ranges of Table 3.2 for a certain truck type. AG6 (4.8, 3.5 kips), AG7 (5.8, 5.5 kips), AG8 (4.5, 4.6 kips), AG9 (6.8, 7.0 kips), and AG10 (7.8, 8.2 kips) all have load values that lie within the ranges given in Table 3.2 for five-axle loaded trucks; therefore, it can be labeled as such. This two-part method, gives an analyst a good chance of determining what type of vehicle lies within these long vehicle records. This same principal was used to create a computer program for finding groups of axles associated with a particular truck class among the axle data contained in a long vehicle record.

3.2 COMPUTER PROGRAM TO IDENTIFY VEHICLES AND AXLE ARRANGEMENTS

These patterns were the basis for creating a reclassifying program to break up the seven-to-ten and eleven-axle records into new vehicle records. Bobby Inman, a Research Engineering Associate for the Center of Transportation Research, The University of Texas at Austin, wrote a "C"-language computer program for the purpose of grouping the axle-load and axle-spacing data into appropriate vehicle records so that the reclassified vehicle records could be retracted and added to the reliably recorded vehicle records.

The reclassifying program takes the data in ASCII format and searches for any record that has seven or more axles. Once a record of this sort is found, it uses the axle-spacing ranges in Table 3.1 and searches sequentially all axle spacing values in these records to find a series of spacings that match the range for one of the five truck types. If the program successfully locates a truck, the data set associated with that truck is removed from the records being searched and given its own vehicle record number. It is then placed together with all the two through six-axle recorded vehicles that remain unaltered. The program continues this process until no more trucks can be identified by axle-spacing.

The next step in the program operates on the same principal, but it uses the wheel-load ranges in Table 3.2 and searches sequentially all wheel load values in these records to find a series of wheel loads that match the range for one of the five truck types. If the program successfully locates a truck, the vehicle's axles (as a whole) would be removed from the queued data and given its own vehicle record number. These too, are placed together with all the two- through six-axle recorded vehicles that remained unaltered. The program continues this until no more trucks can be identified.

Just as an analyst evaluates the ASCII data manually, the computer program checks the ASCII axle-spacing and the axle-load data for a six-axle truck first, then for a five-axle truck, and on down to a two-axle truck. This prevents overlooking rear tandem or tridem axles. If a six- or five-axle truck has not been identified, then the program will search for a four-, three- or two-axle truck.

A benefit to having the program search through the data, axle-by-axle, until a group of axles fits within a certain truck type becomes evident with the eleven-axle records. These records have a tendency to spill over into the next record line. This spillover was discussed in the previous chapter. The computer software only allows eleven axles to be recorded per vehicle record line, but the system does not stop recording wheel loads passing over the sensors. An example of this is shown in Fig 2.1, record number 1981, where the eleventh axle grouping (AG11) has a very large spacing value. This is a possible indication of the beginning of a new vehicle. Looking at record number 1983, the first axle grouping AG1 has a zero spacing, followed by a spacing of 4.5 ft in AG2. This seems to resemble a tandem-axle spacing. AG3 has a spacing of 33.0 ft and AG4 has a spacing of 4.2 ft Checking these spacings with Table 3.1 indicates to the analyst that this is probably a five-axle truck that had its axle-load data recorded into two separate vehicle record numbers. The reclassifying program would recognize this and place the five-axle truck among the reliable truck records. Again, if one of the spacings did not fall within Table 3.1 guidelines, the program would next check for loading patterns to fit within Table 3.2 guidelines.

Once the program has reclassified all the trucks that it can, the remaining axle records are placed into a residual error file. These axle-by-axle records, each with a time stamp, can be counted. Once the total number of unused axle records is known, historical percentages of two- through six-axle trucks can be used to estimate the number of vehicles that are probably represented in the residual error file.

The following figures are presented to show how effective the reclassifying program was at deciphering southbound vehicles. Fig 3.2 shows an illustration of the vehicle records that were processed without the assistance of the reclassifying program in El Paso, March 1996. Fig 3.3 graphs the rejected vehicle records for the same month.

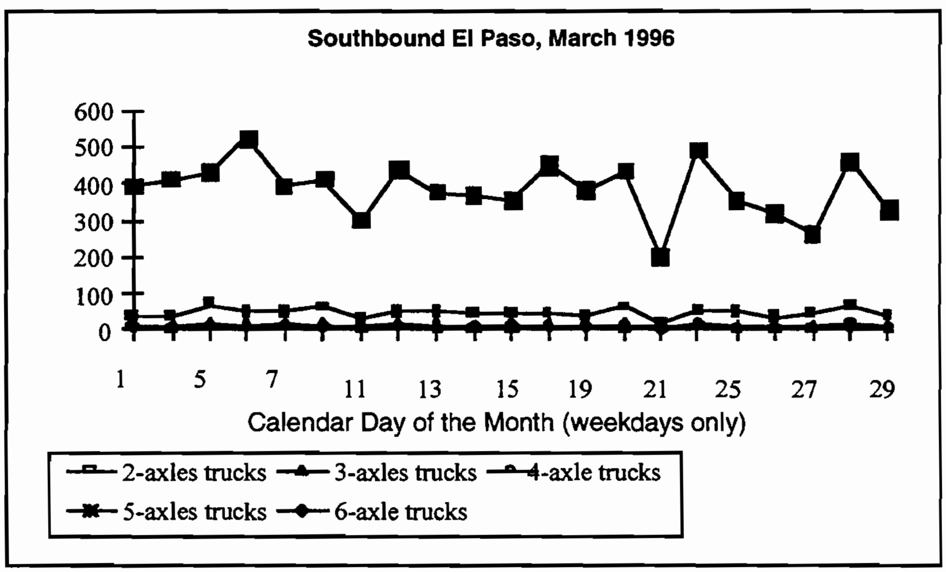

Figure 3.2 Southbound weekday traffic counts, March 1996

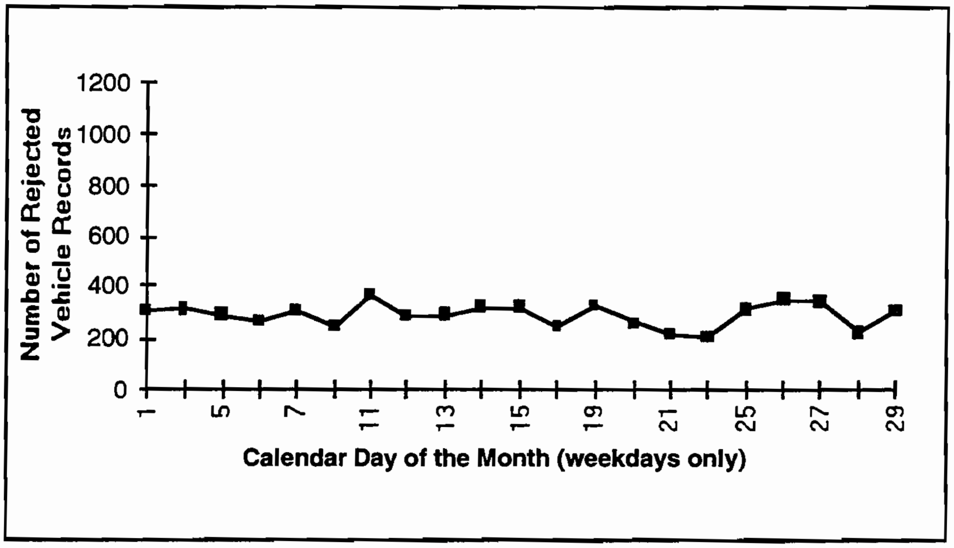

Figure 3.3 Southbound El Paso erroneous data files, March 1996

The median weekday counts for the two- through six-axle vehicles are as follows: two-axle (42), three-axle (12), four-axle (8), five-axle (395), and six-axle (10). The median number of rejected vehicle records was 303. The next figures will show the data attained after the reclassifying program was used for March 1996 southbound El Paso traffic.

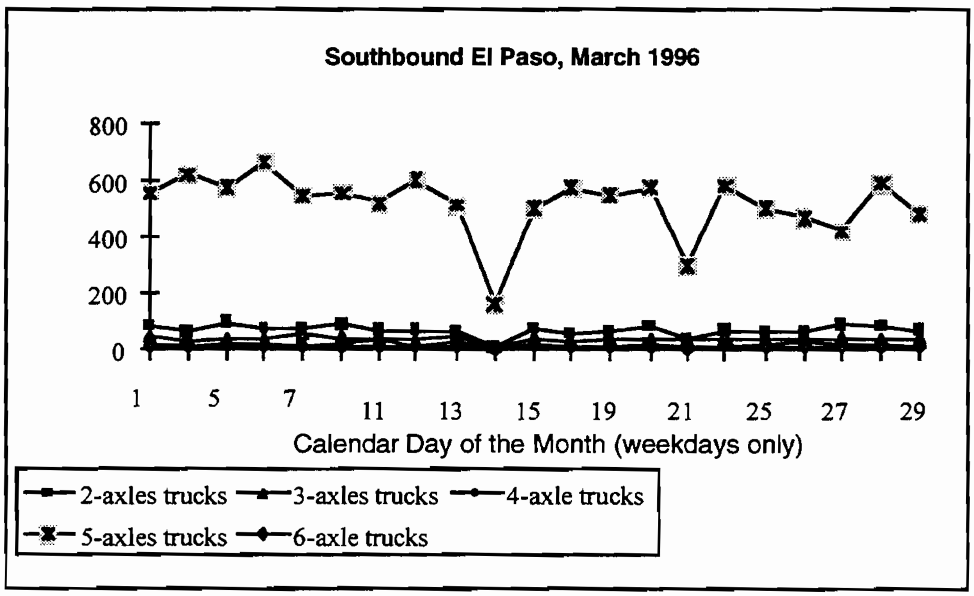

Figure 3.4 Southbound weekday traffic counts, March 1996, including salvaged records

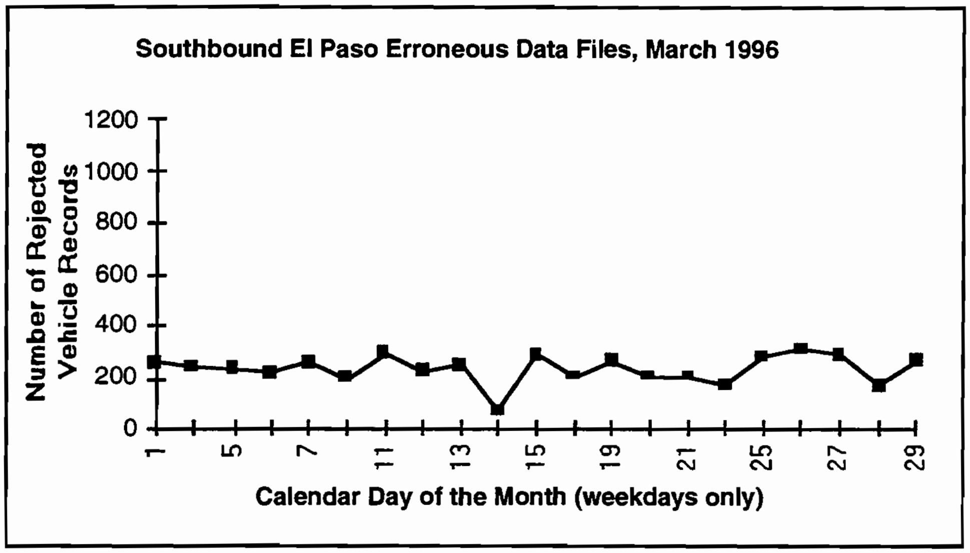

Figure 3.5 Southbound weekday traffic counts, March 1996, including salvaged records

After processing the same data through the reclassifying program, the median weekday values changed. In Fig 3.4, the median weekday counts for the two- through six-axle vehicles are as follows: two-axle (71), three-axle (41), four-axle (24), five-axle (557), six-axle (13). The median number of rejected vehicle records per day was 240. Fig 3.6 shows graphically how the two methods of data processing compared.

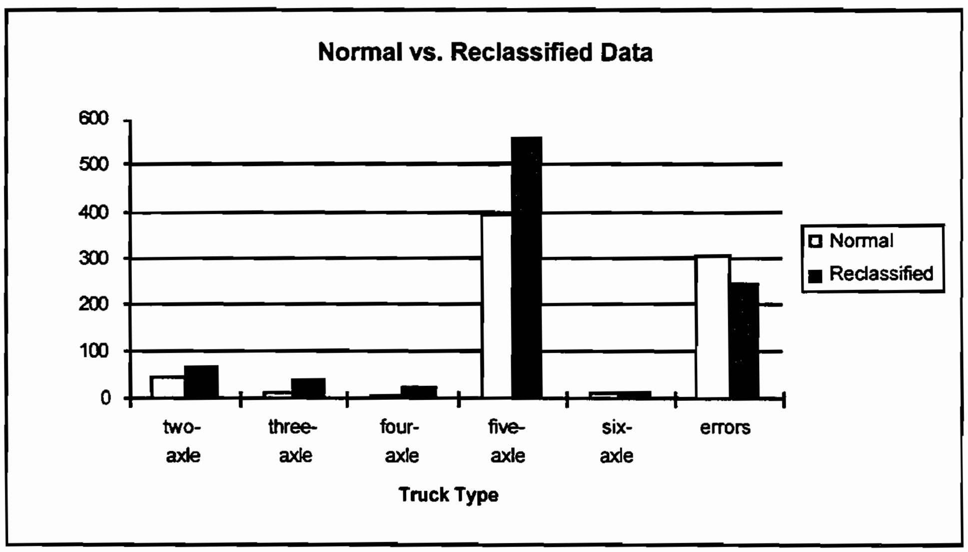

Figure 3.6 Normal vs. reclassified data, SB El Paso, March 1996

The reclassified values show a definite improvement over the previous set calculated without the use of the program. The two-axle truck records almost doubled in number. The three-axle truck records tripled in number. The reclassifying program showed its largest effect with the five-axle truck records. There were 162 more five-axle truck records counted per day. In fact, every truck type increased. The last category that also improved was the amount of errors. The program reduced the amount of errors per day from 303 to 240. One point to remember here is that the program discards unusable axles into a separate file. Normally, these unusable axles would be counted with the erroneous data file; therefore, the errors would naturally be lower but the main focus of this exercise was to increase the amount of usable vehicle records. This improvement on finding new vehicle records continued for every month the reclassifying program was used. The program proved to be beneficial for all the southbound data from El Paso.

CHAPTER 4. TRUCK COUNT CHARACTERISTICS

Truck count data were collected at both the Laredo and El Paso WIM sites. Daily and monthly truck count patterns were examined in order to find any distinct patterns that existed.

4.1 DATA COLLECTION

The El Paso WIM system recorded northbound and southbound traffic data from August 1994 through July 1996. Truck counts throughout this period are considered in this chapter. For the Laredo site, only the northbound traffic data collected from March to June 1996 are presented, as data from August 1994 through January 1995 were analyzed and presented elsewhere [Ref 3]. During the winter of 1995–1996, problems were experienced with the WIM system at Laredo. The Center for Transportation Research (CTR) at The University of Texas at Austin sent technicians to Laredo several times with new modems, new circuit boards, and new components for the motherboard, but equipment malfunctions continued. City of Laredo technicians replaced faulty loop detector wires, but the system still did not work properly. On December 23, 1995, the on-site WIM instrument was removed and sent to PAT in Pennsylvania for repair. Upon reinstallation of the machine on February 10, 1996, problems persisted. A technician from PAT made a service call to Laredo and diagnosed an intermittent problem with the leading weight pad. The pad, with a broken wire in the lead-in cable, was replaced by CTR personnel; by February 22, 1996, the site was back in operating order. The site was tested for one week, and data collection resumed on March 1, 1996.

For this study, only weekday traffic is considered. Weekend traffic dropped by about 75 percent on Saturdays and about 87 percent on Sundays. Data analyses presented in this chapter emphasize monthly traffic counts for two- through six-axle trucks; these truck-types are also featured in subsequent chapters. When a large variation in the truck count pattern was noticed, data for the month in which it occurred was evaluated further on a day-by-day basis.

4.2 ANALYSIS OF TRUCK COUNT DATA

All the daily traffic data files from the WIM system were further grouped by month and placed together to form one long stream of vehicle records. Figures 4.1, 4.3–4.5 show median values for weekday truck counts of various truck types for every month in which data was available during the analysis periods. The curves have been labeled to show the northbound traffic in both Laredo and El Paso and the southbound El Paso traffic. Figure 4.2 shows the weekday count of the various types of northbound trucks recorded at Laredo during May 1996.

Figure 4.1 shows the median weekday two-axle truck counts for each month during the analysis period. There was a steady increase and then a decrease in the count for both northbound and southbound El Paso traffic. The northbound El Paso count peaked in August 1995 at 137. Southbound El Paso peaked in October 1995 at 100. During the summer months, two-axle truck traffic was generally high. The lowest median weekday counts of two-axle trucks for both directions in El Paso occurred in December 1994 (42 for SB and 53 for NB), and April 1996 (64 for NB and 71 for SB). These were during the winter and spring seasons. The Laredo northbound counts surged from 127 to 174 between May and June 1996. This jump was no doubt related to the closing of one of the bridges at Laredo. Normally, empty trucks used a separate bridge across the Rio Grande, but this bridge was closed to trucks on May 20, 1996, and all northbound trucks were routed over the bridge near the WIM site. Truck counts for each weekday during the month of May 1996 in Laredo are shown in Figure 4.2. After May 20, 1996, there was a large increase in two- and three-axle vehicles. This change was probably associated with the truck tractors operating without a semi-trailer that had previously used the other bridge (for empty trucks) and began crossing the same bridge with loaded trucks and passing through the WIM system.

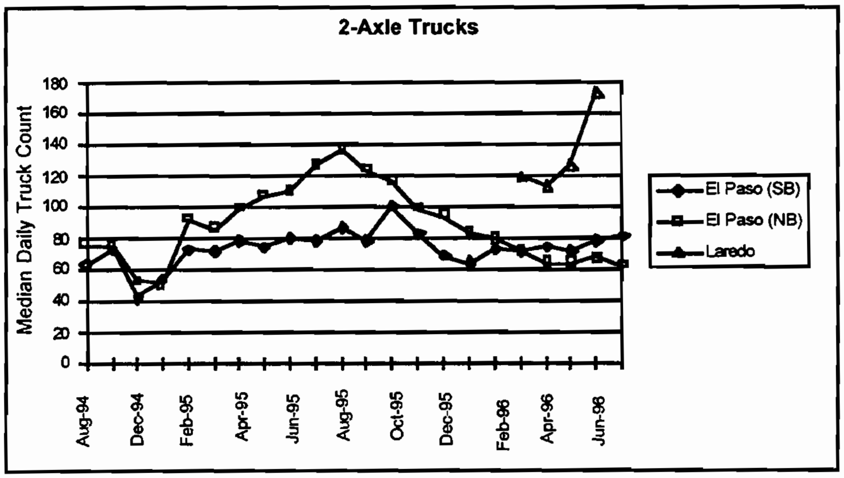

Figure 4.1 Two-axle truck counts

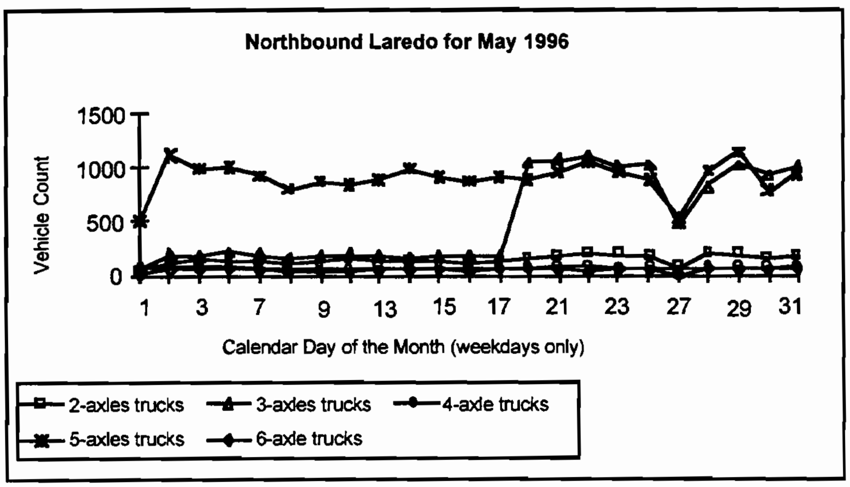

Figure 4.2 Weekday northbound traffic for Laredo, May 1996

Figure 4.3 shows the median weekday three-axle truck counts. El Paso traffic was quite constant in both directions with a median weekday count of about 41 going southbound and 32 going northbound. The Laredo traffic, however, jumped from 171 to 870 in late May 1996. This jump was, again, probably attributable to the closing of the bridge to truck traffic and the rerouting of empty trucks, including the three-axle truck tractors commonly used for short hauls of semi-trailers across the border. The change is shown clearly in Figure 4.2.

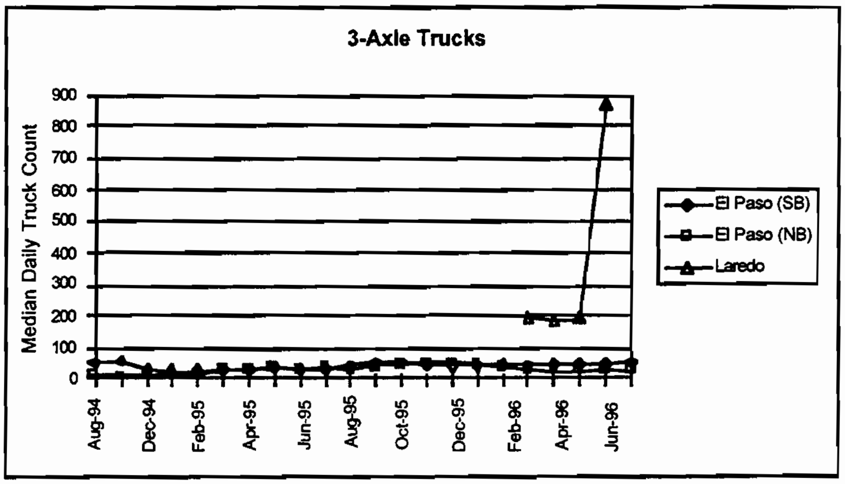

Figure 4.3 Three-axle truck counts

Figure 4.4 shows the median weekday four-axle truck counts. Both El Paso northbound and southbound show a similar median weekday count of about 20 until March 1996. At that time, the northbound and southbound counts moved in opposite directions. The southbound traffic increased to a high of 50 in June 1996. The northbound traffic decreased to a low of 8 in May 1996. The Laredo traffic decreased over a four-month period between March 1996, with 88, and June 1996, with 75.

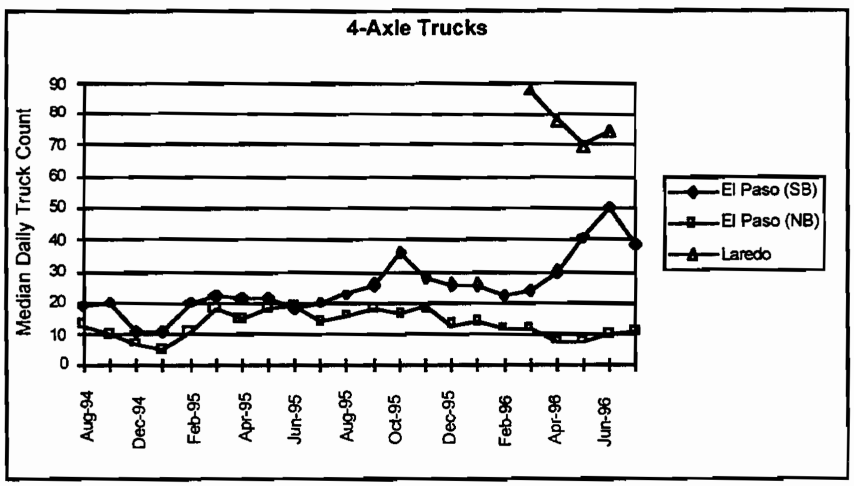

Figure 4.4 Four-axle truck counts

Figure 4.5 shows the median weekday five-axle truck counts. For this dominant truck type, both northbound Laredo and El Paso had decreasing median weekday counts during the analysis period. The Laredo site had about a 50-vehicle drop from March to May but by June averaged 947. Northbound El Paso had a steady decrease of almost 400, starting from 701 in August 1994 and ending at 312 in July 1996. Southbound El Paso had a steady count of 438 vehicles throughout the analysis period.

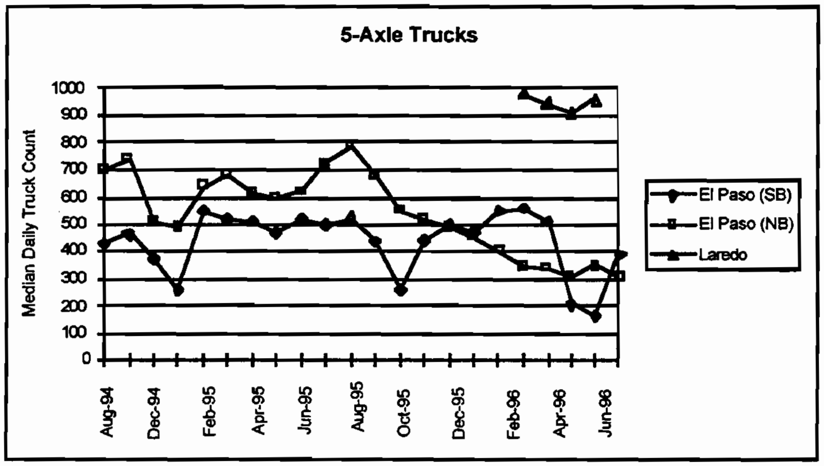

Figure 4.5 Five-axle truck counts

Figure 4.6 shows median weekday values of the six-axle truck counts for each month. Here, all three of the curves show decreasing numbers of trucks counted during the analysis period. The Laredo count dropped from 47 in March 1996 to 40 in June 1996. Northbound El Paso traffic dropped steadily from 16 in August 1995 to 3 in July 1996. The southbound El Paso counts fluctuated between 16 and 4 six-axle trucks per weekday.

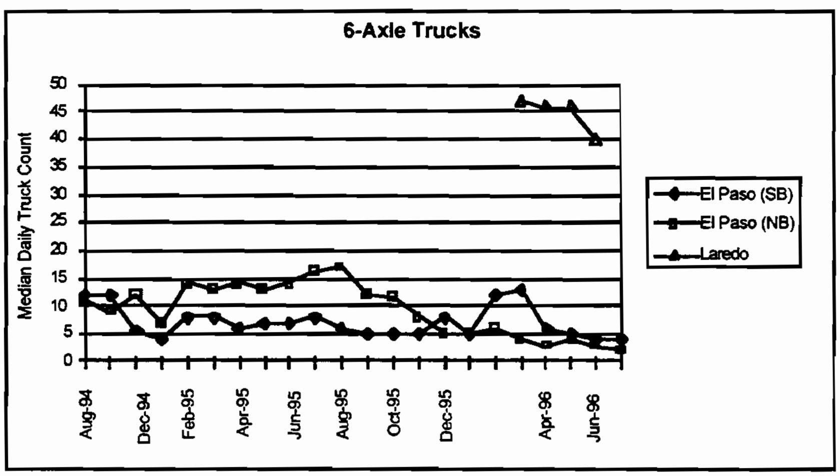

Figure 4.6 Six-axle truck counts

4.3 CONCLUSION

After examining all available truck count data from the two WIM systems during the analysis period, certain patterns in the average value of the median weekday count for each truck type were recognized. At both Laredo and El Paso, the dominant truck type was the five-axle. The average weekday count value was about 947 northbound five-axle trucks per day at Laredo, 539 northbound at El Paso, and 438 southbound at El Paso. Corresponding values for three-axle trucks were 361 at Laredo, 31 northbound at El Paso and 41 southbound at El Paso. Two-axle truck counts had average weekday values of 134 at Laredo, 88 northbound at El Paso, and 74 southbound at El Paso. Sudden changes in the northbound counts of two- and three-axle trucks occurred at Laredo in May 1996, concurrently with a rerouting of empty trucks across two adjacent bridges. Four-axle trucks had a mean weekday count of 78 in Laredo, 13 northbound at El Paso, and 25 southbound at El Paso. The smallest average weekday count value for both WIM sites was the six-axle truck: 45 at Laredo, 9 northbound at El Paso, and 7 southbound at El Paso.

CHAPTER 5. TRUCK LOAD CHARACTERISTICS

Throughout the year, the axle loads on trucks tend to change with the seasons. During some seasons, truck loads might be heavier owing to market demand for certain products, and in other seasons the loads might be lighter, as the need to transport various types and quantities of goods changes.

5.1 AXLE LOADING CHARACTERISTICS

The data in this chapter refer to the loads measured for the various axle types crossing the Texas-Mexico border. Three main types of axle configurations were analyzed: 1) single axle, 2) tandem axle, and 3) tridem axle. The steering (front) axle of trucks will not be discussed, since its load rarely exceeds the allowable single-axle limit. Figure 5.1 graphically shows the different types of trucks and axle configurations that will be discussed in this chapter.

The single-axle load of 2S1 trucks will not be discussed as the total number of this truck type observed comprises less than about 10 percent of the three-axle truck population. The axle configurations that will be analyzed are: 1) the single-drive for two-axle trucks, 2) the tandem for three-axle (SU) trucks, 3) the single-drive and trailer-tandem for 2S2 trucks, 4) the single-trailer and tractor-drive tandem for 3S1 trucks, 5) both tandems for 3S2 trucks, and lastly 6) the tractor-tandem and trailer-tridem for 3S3 trucks.

The axle loads for each axle group have been divided according to the different seasons. Referring to the equinoxes and solstices, the seasons are: autumn (August-September-October), winter (November-December-January), spring (February-March-April), and summer (May-June-July). The purpose of this was to determine whether there was any noticeable trend in axle loads that could be detected as the seasons changed. First, data from the Laredo location during the spring and summer months of 1996 are discussed. Then, El Paso northbound data during three seasons (from October 1995 through July 1996) are examined, and finally, the El Paso southbound data during eight seasons (from August 1994 through July 1996) are evaluated.

5.2 LAREDO LOAD CHARACTERISTICS (MAR 1996–JUN 1996)

The graphs in Figures 5.2–5.4 show the frequency distribution for axle loads observed during the spring and summer seasons of 1996 for northbound Laredo traffic. The legal axle loads in Texas are 20 kips for single axles, 34 kips for tandem axles, and 42 kips for tridem axles. These limitations are graphically shown in each respective figure. Numerical values in the legend give the number of axles that were included in the data set during the time frame given.

Figures 5.2–5.4 display the axle load, frequency distributions for four spring and summer months of 1996 (March–June), northbound Laredo. In Figure 5.2, the single-axle loads during this time period as graphed indicate that about 22 percent of the single-drive axles on 2S2 trucks were overloaded. Less than 8 percent of the single-drive axles on two-axle trucks and only a few of the single-trailer axles on 3S1 trucks exceeded the legal limits. A small number of the observed loads were as much as 60 percent heavier than the legal limit.

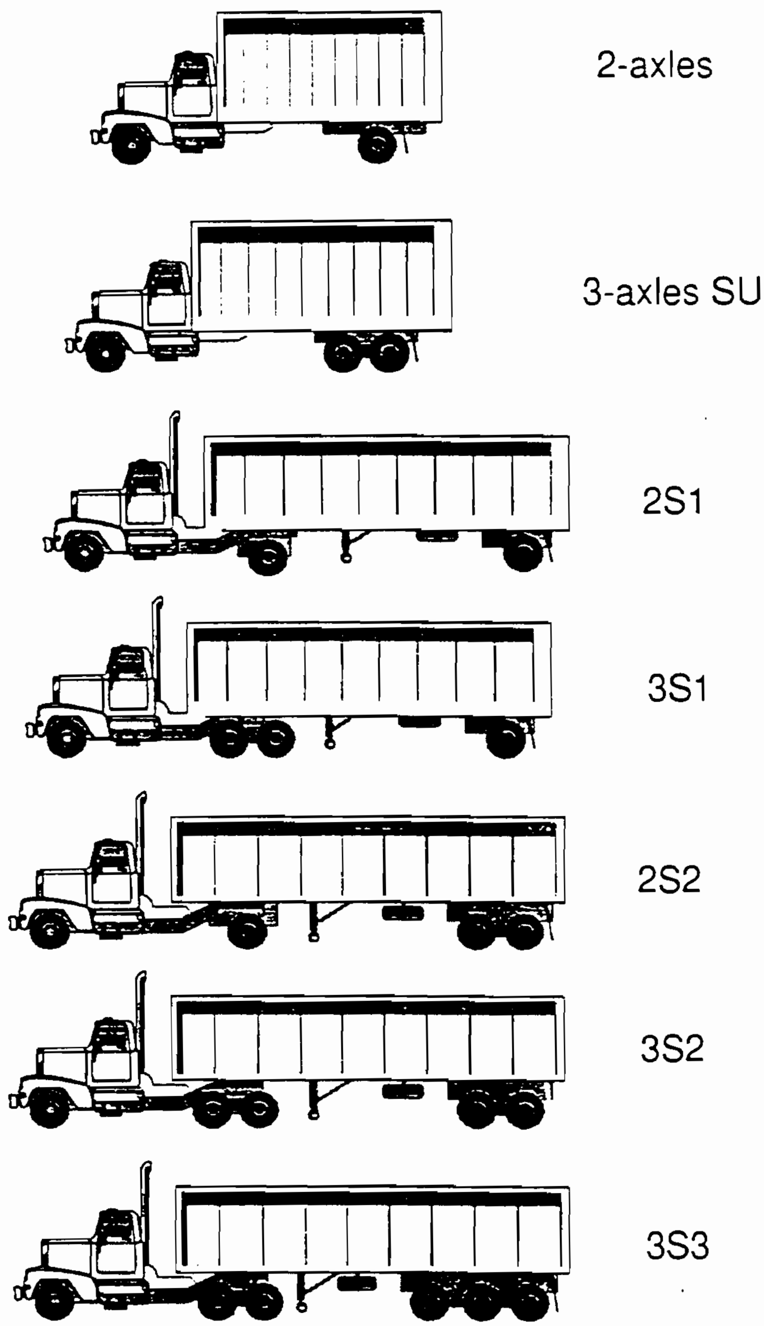

Figure 5.1 Trucks observed at Texas south border crossing

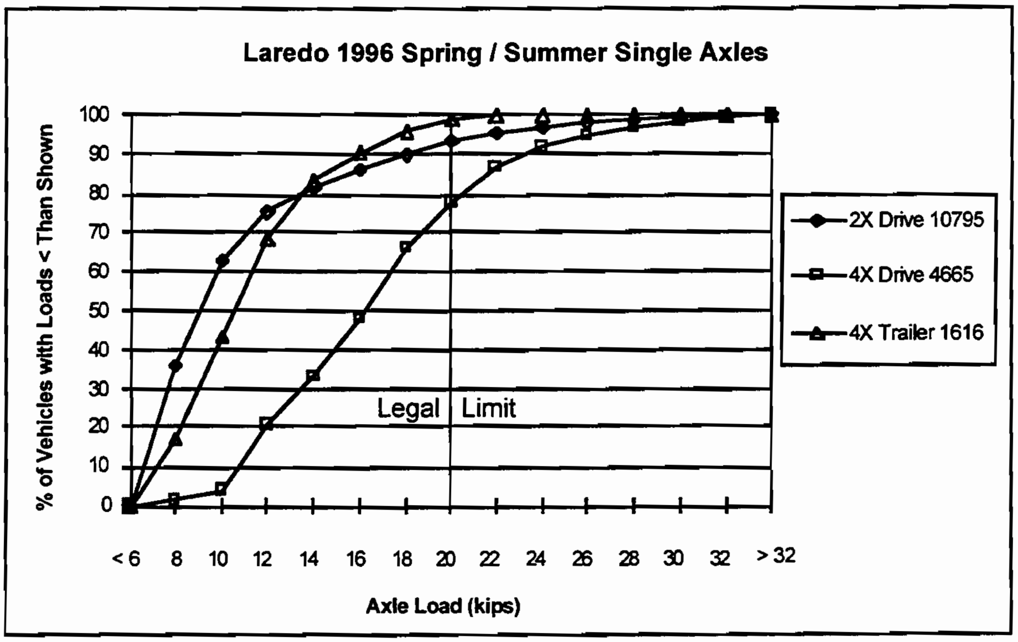

Figure 5.2 Laredo spring / summer 1996 single-axle loads

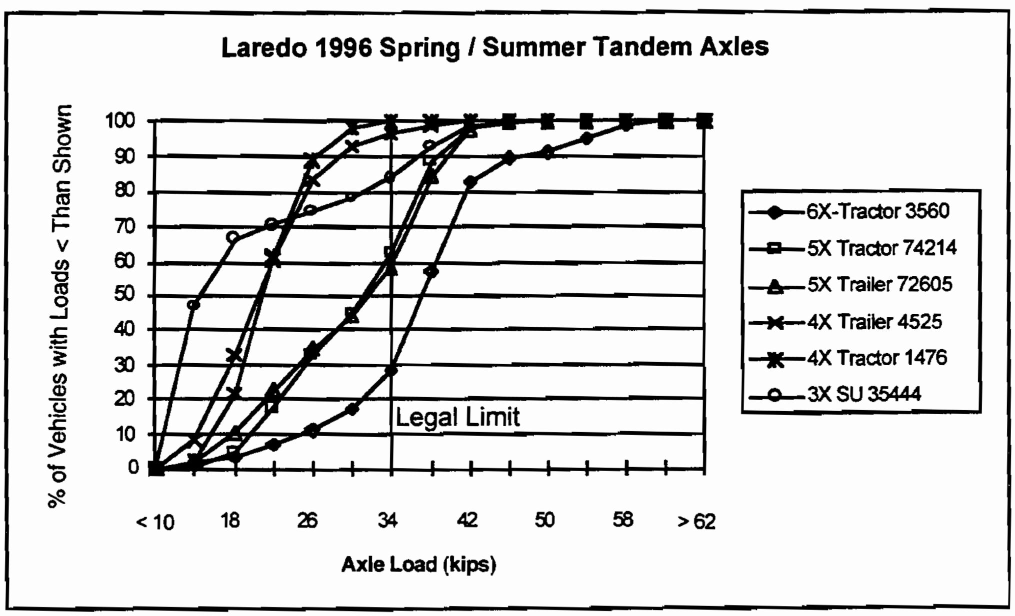

Figure 5.3 Laredo spring / summer 1996 tandem-axle loads

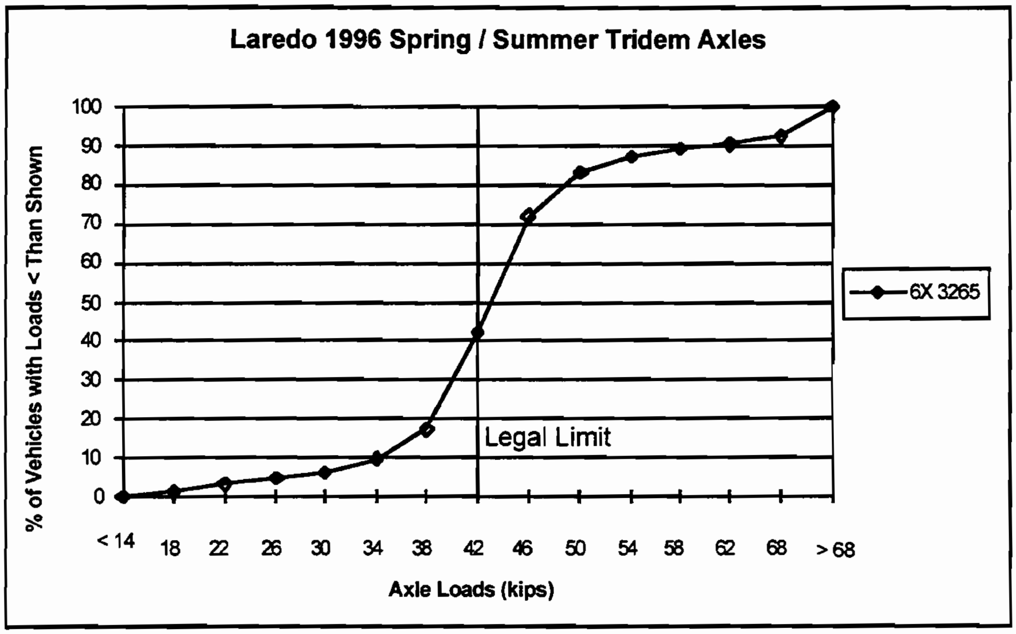

Figure 5.4 Laredo spring / summer 1996 tridem-axle loads

Figure 5.3 shows the tandem-axle loads where 71 percent of the 3560 tandem-drive axles on the tractor of 3S3 trucks exceeded the 34-kip limit. However, on average during these four months, only about 30 northbound 3S3 trucks per weekday (3600/120) were weighed at Laredo. About 40 percent of all tandem axles (tractor and trailer) on 3S2 trucks were overloaded. About 73,000 3S2 trucks were weighed during the spring and summer months of 1996, and on average, some 29,000 of these trucks had both tandem axles loaded in excess of 34 kips. The three-axle (SU) truck had the next largest percentage of overloaded tandems with about 16 percent. Four-axle (both 2S2 and 3S1) trucks had very few overloaded tandem axles.

Figure 5.4 shows the 3S3 tridem-axle loads. About 57 percent of these axle loads were greater than the 42-kip legal limit for tridems in Texas, as determined by application of the bridge formula. As stated previously, there were only about 30 such trucks per weekday that crossed the WIM system at Laredo.

5.3 NORTHBOUND EL PASO LOAD CHARACTERISTICS (OCT 1995–JUL 1996)

The El Paso northbound data set includes one extra month, October, with the winter months. The axles counted for analysis were rather high for the winter season and this note to the reader was necessary in order to avoid confusion. These were the three seasons grouped together: winter (October-November-December-January), spring (February-March-April) and summer (May-June-July).

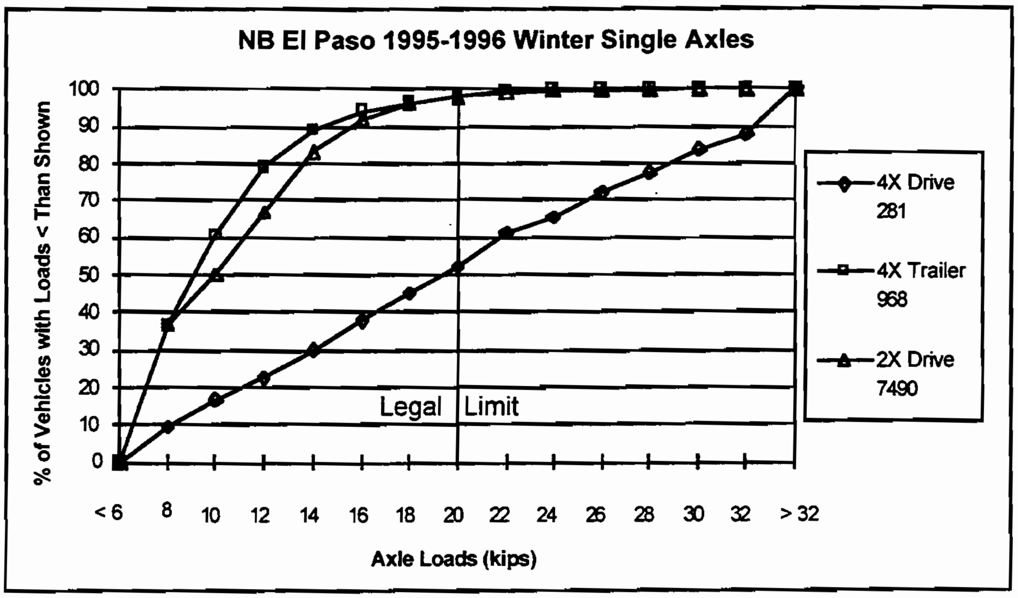

Figure 5.5 NB El Paso winter 1995-1996 single-axle loads

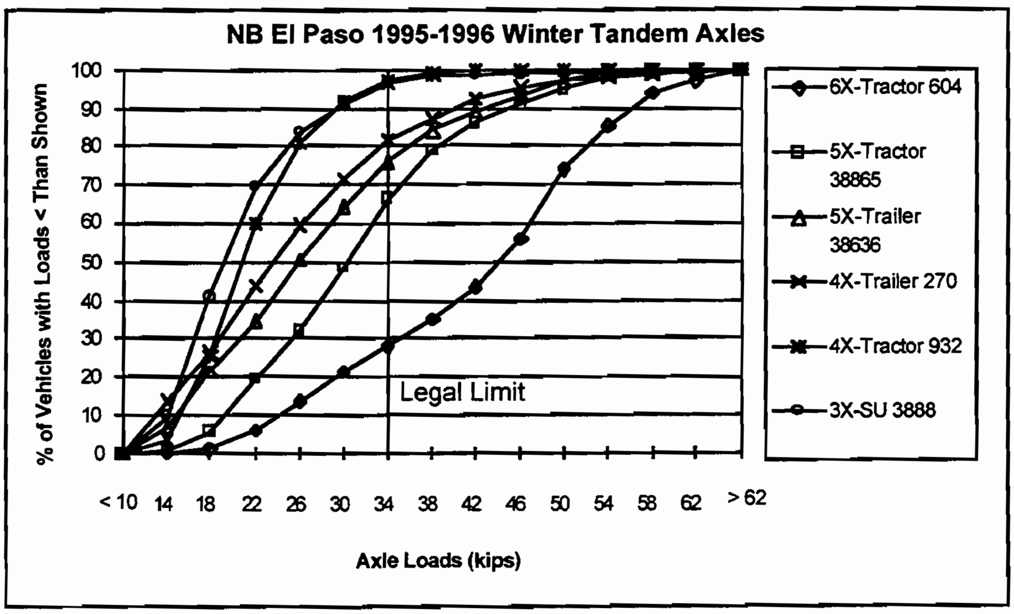

Figure 5.6 NB El Paso winter 1995-1996 tandem-axle loads

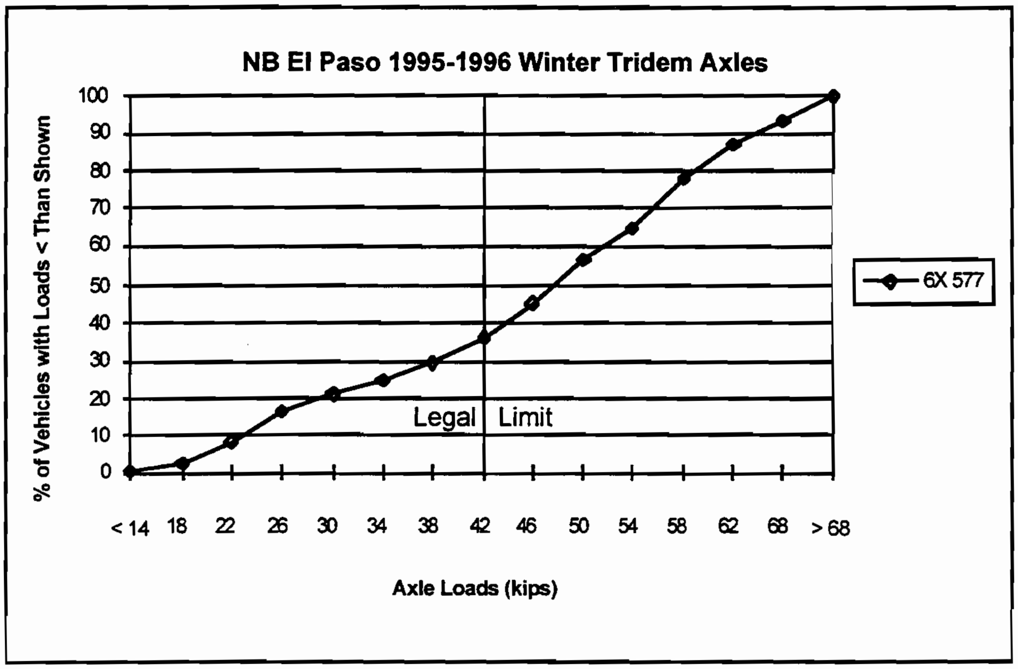

Figure 5.7 NB El Paso winter 1995-1996 tridem-axle loads

Figures 5.5–5.7 display the axle load, frequency distributions for the winter of 1994–1995, northbound El Paso. In Figure 5.5, the single-axle loads observed during the winter are shown, where over 45 percent of the 2S2 trucks exceeded the 20-kip limit. The 3S1 and two-axle trucks had almost none of their axles exceeding the legal limit.

Figure 5.6 shows the tandem-axle loads, where the 3S3 tractor-tandem was the most dominant offender of the 34-kip limitation. It had over 70 percent of its axles exceeding the legal limit. The 3S2 tractor and trailer-tandems had 30 percent and 25 percent of their axles exceeding the limit, respectively. The 2S2 trailer-tandem had 19 percent of its axles past the limit, and the rest of the tandem-axles recorded for 3S1 and SU trucks were reasonably within the guidelines.

Figure 5.7 graphs the tridem-axle loads observed during the winter, where the 3S3 trucks had over 60 percent of their tridem-axles exceeding the 42-kip limit.

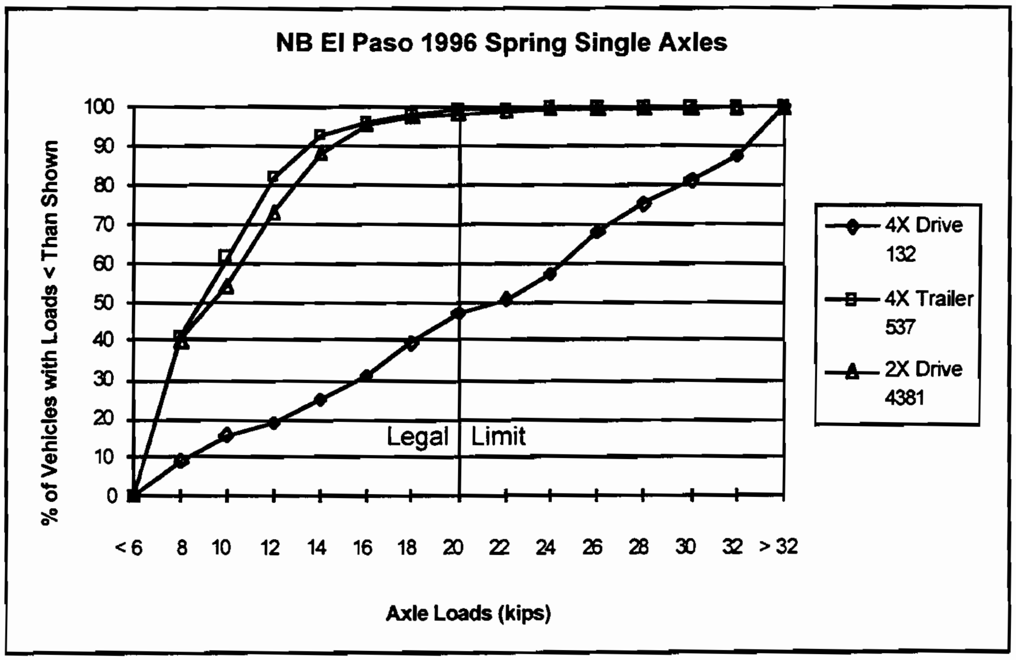

Figure 5.8 NB El Paso spring 1995 single-axle loads

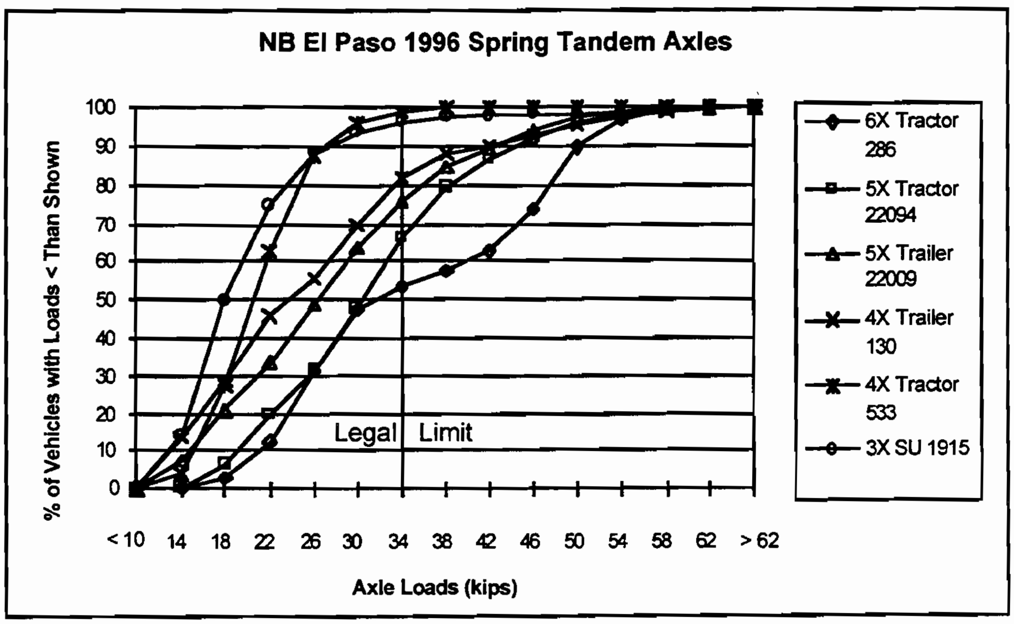

Figure 5.9 NB El Paso spring 1995 tandem-axle loads

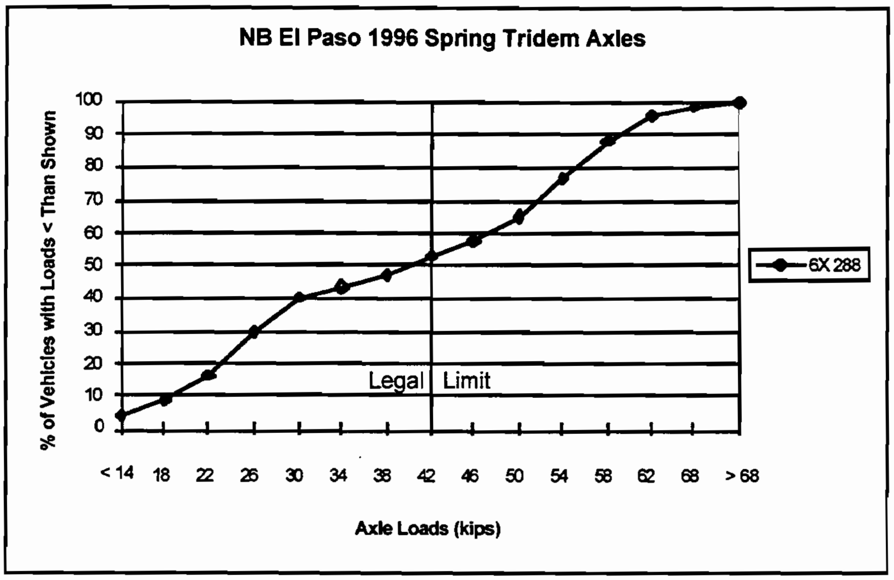

Figure 5.10 NB El Paso spring 1995 tridem-axle loads

Figures 5.8–5.10, displaying the spring 1996 season for northbound El Paso, did not show much difference from Figures 5.4–5.6. The axle loads appeared to stay constant with the previous season, but there were a few variations. Forty-five percent of the 3S3 tandem-axles (Figure 5.9) were overloaded. This was an improvement from the winter (1995–1996) where the 3S3 tandem-axle loads had over 70 percent of their axles overloaded. Also, the 3S3 tridem-axle loads (Figure 5.10) improved to having 46 percent overloaded instead of the 60 percent for the winter (1995–1996).

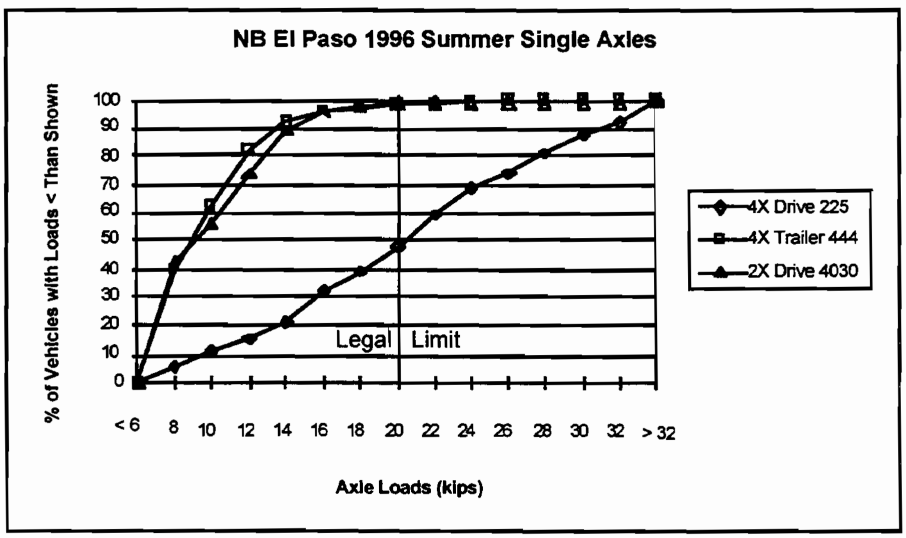

Figure 5.11 NB El Paso summer 1996 single-axle loads

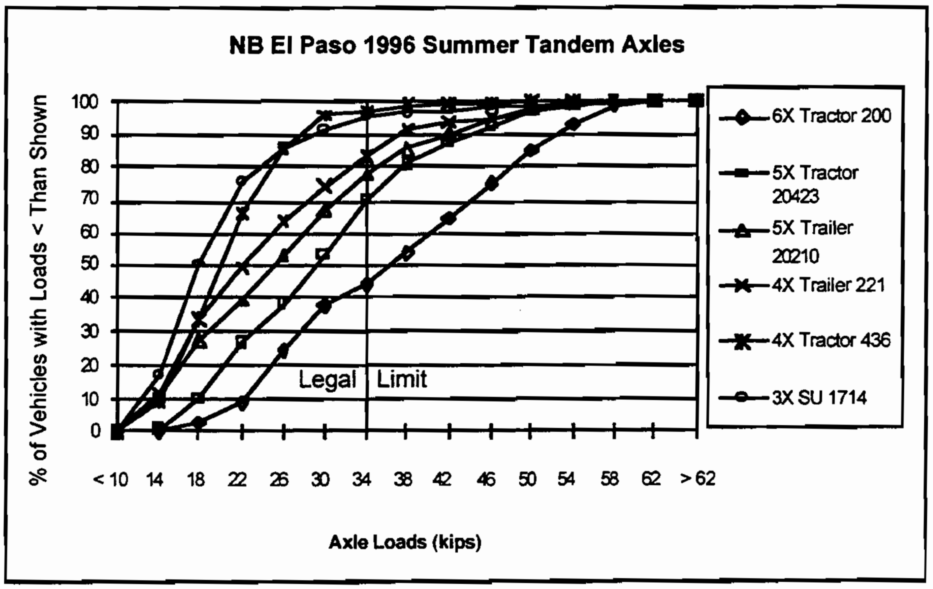

Figure 5.12 NB El Paso summer 1996 tandem-axle loads

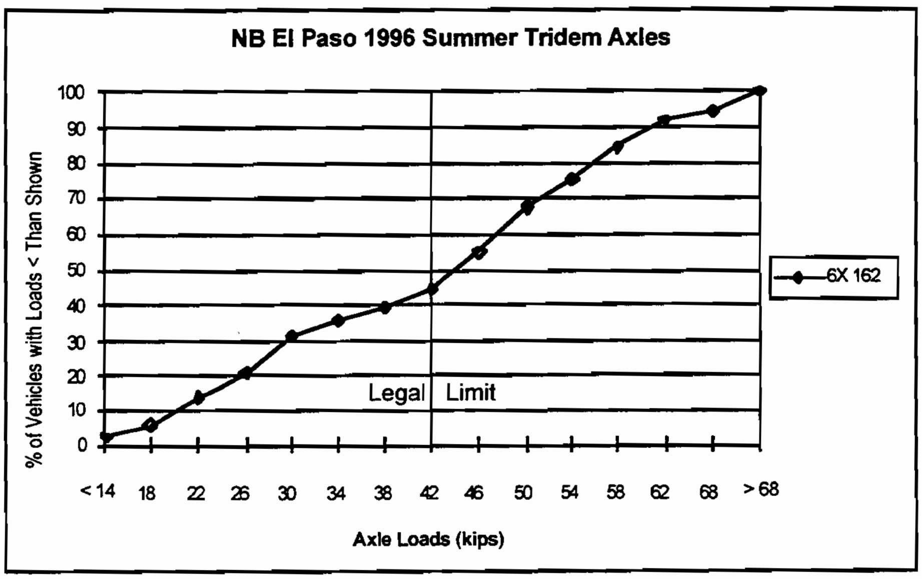

Figure 5.13 NB El Paso summer 1996 tridem-axle loads

Figures 5.11–5.13 show the summer 1996 months for northbound El Paso. Again, the loads on the different axle configurations behaved very similarly to the winter (1995–1996) and spring (1996) months in El Paso. The only major difference was an improvement with the 3S3 tandem and tridem axle loads (Figures 5.12 and 5.13). The 3S3 trucks reduced their overloaded tandem-axle loads by 10 percent and the 3S3 tridem-axle loads by 5 percent.

After comparing the three seasons as a whole, it appeared that the axle loads stayed rather constant for El Paso northbound traffic. The only noticeable change came with the 3S3 trucks with their tandem- and tridem-axle loads decreasing over time.

5.4 SOUTHBOUND EL PASO LOAD CHARACTERISTICS (AUG 1994 - JUL 1996)

The graphs in Figures 5.14–5.37 show the frequency distribution of axle loads measured during a two-year span for southbound El Paso traffic.

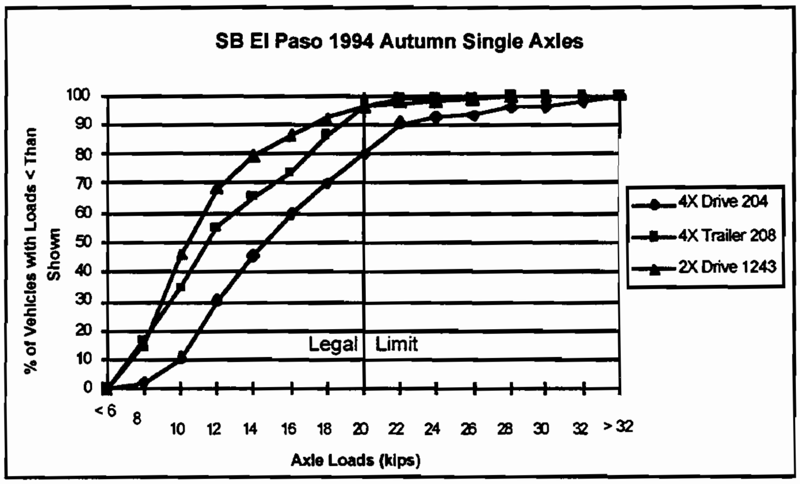

Figure 5.14 SB El Paso autumn 1994 single-axle loads

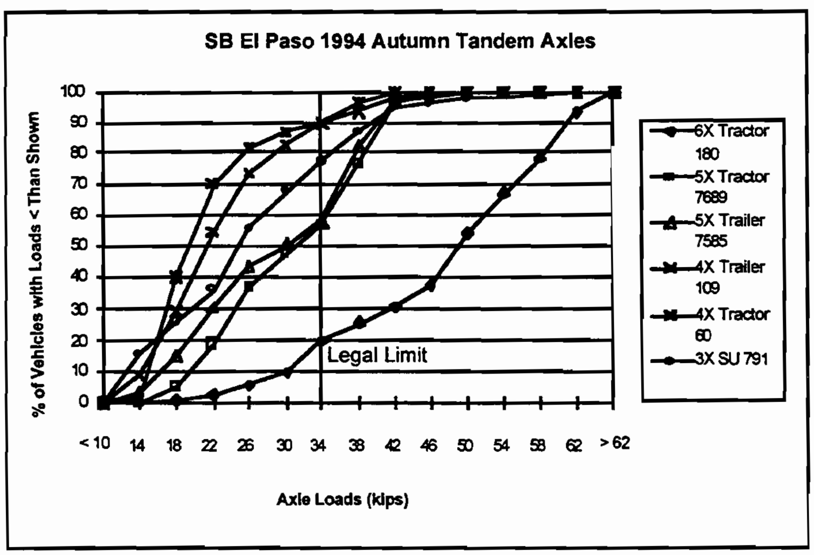

Figure 5.15 SB El Paso autumn 1994 tandem-axle loads

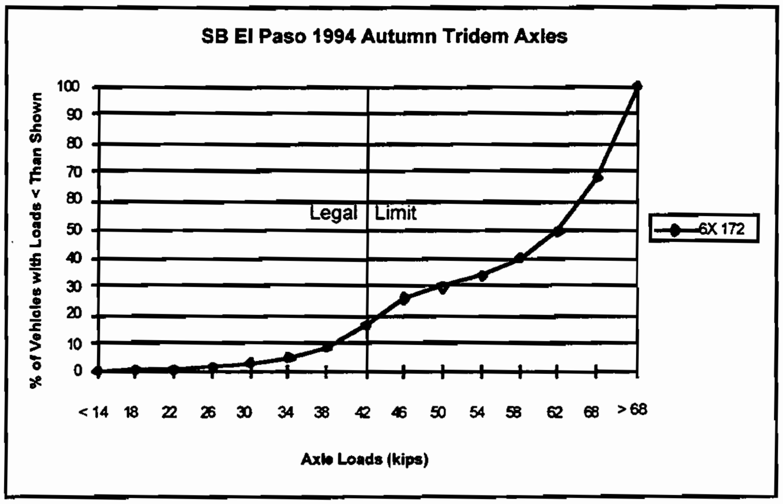

Figure 5.16 SB El Paso autumn 1994 tridem-axle loads

Figures 5.14–5.16 display the axle load, frequency distributions for the autumn of 1994, southbound El Paso. In Figure 5.14, the autumn single-axle loads are shown where about 20 percent of the 2S2 trucks were overloaded past the 20-kip U.S. limitation. Less than 5 percent of the 3S1 trailer-axles and two-axle truck, single-drive axles exceeded the legal limits.

Figure 5.15 graphs the tandem-axle loads where the major offender was the 3S3 tractor-axle loads having 80 percent exceeding the 34-kip limit. Forty-two percent of the 3S2 tractor- and trailer-axle loads exceeded the legal limits. Next in line were the three-axle (SU) trucks with 21 percent of their tandem-axle loads being overloaded. The 3S1 and 2S2 trucks had about 10 percent of their tandems overloaded. Figure 5.16 graphs the tridem-axle loads for 3S3 trucks where about 83 percent of the trucks that passed over the sensors were overloaded past the 42-kip limitation.

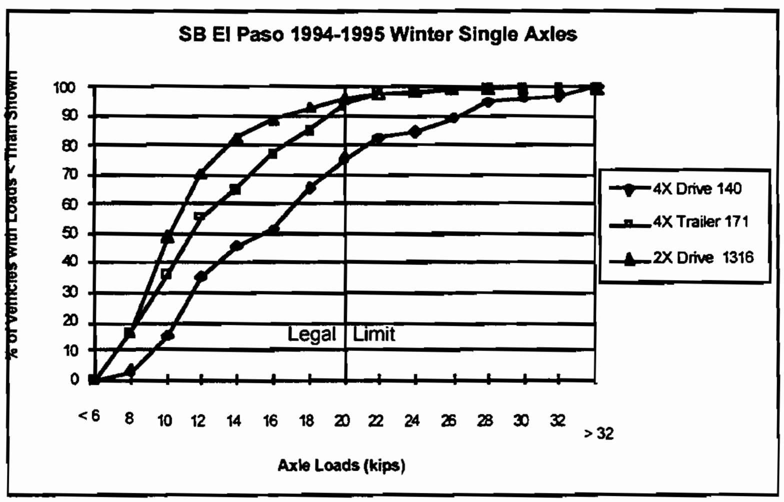

Figure 5.17 SB El Paso winter 1994-1995 single-axle loads

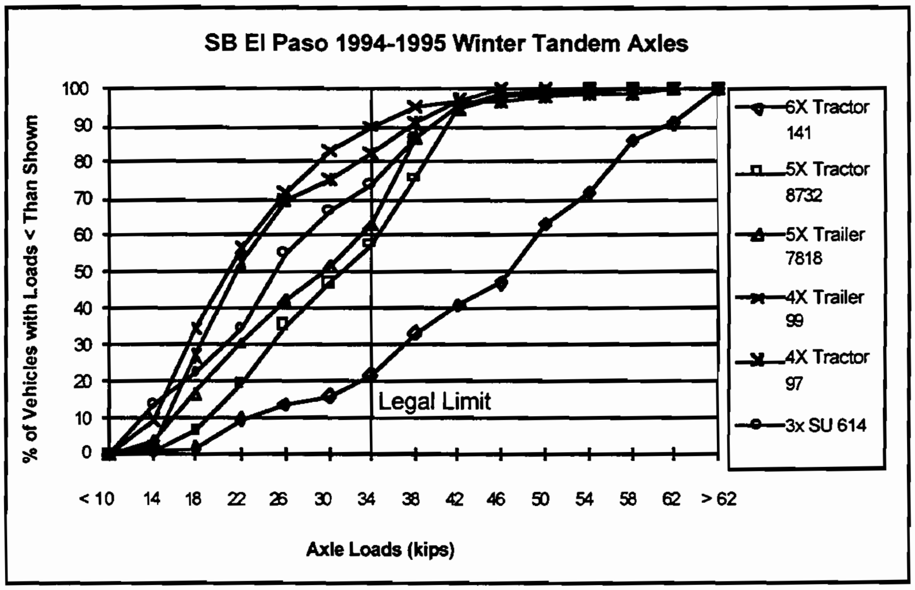

Figure 5.18 SB El Paso winter 1994-1995 tandem-axle loads

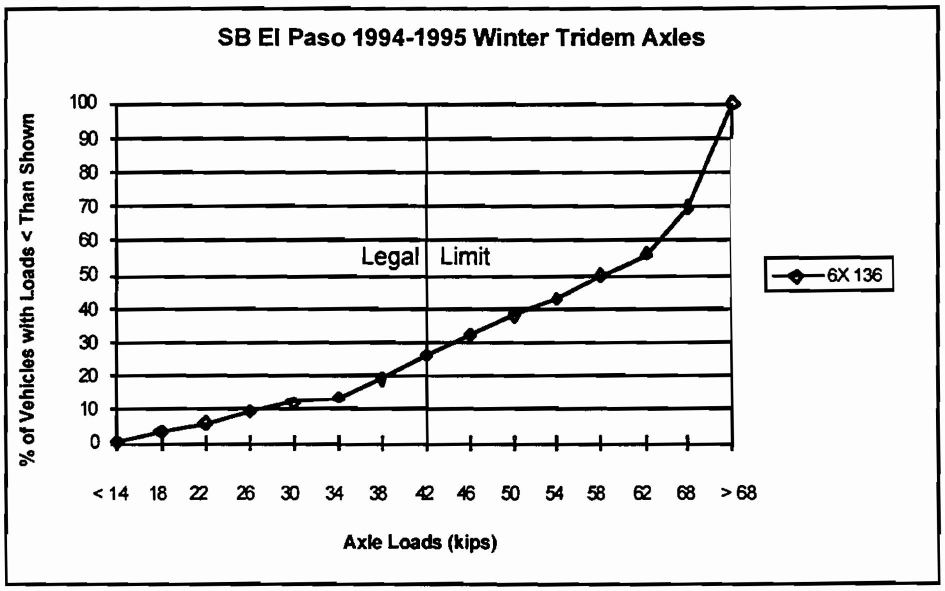

Figure 5.19 SB El Paso winter 1994-1995 tridem-axle loads

Figures 5.17–5.19 display the axle load, frequency distributions for the winter of 1994–1995, southbound El Paso. In Figure 5.17, the single-axle loads observed during the winter showed 24 percent of the 2S2 single-drive axle loads being overloaded. The 3S1 trailer-axle and two-axle truck single-drive axle loads were 5 percent overloaded.

Figure 5.18 presents the tandem-axle loads where the 3S3 tractor tandems were 79 percent overloaded. The 3S2 tractor and trailer tandems averaged 40 percent overloaded. The three-axle (SU) trucks had over 25 percent of their tandems overloaded; the 3S1 tractor tandems and the 2S2 trailer tandems were 18 percent and 9 percent overloaded, respectively. Figure 5.19 shows the winter tridem-axle loads, where about 72 percent of the 3S3 tridems were overloaded.

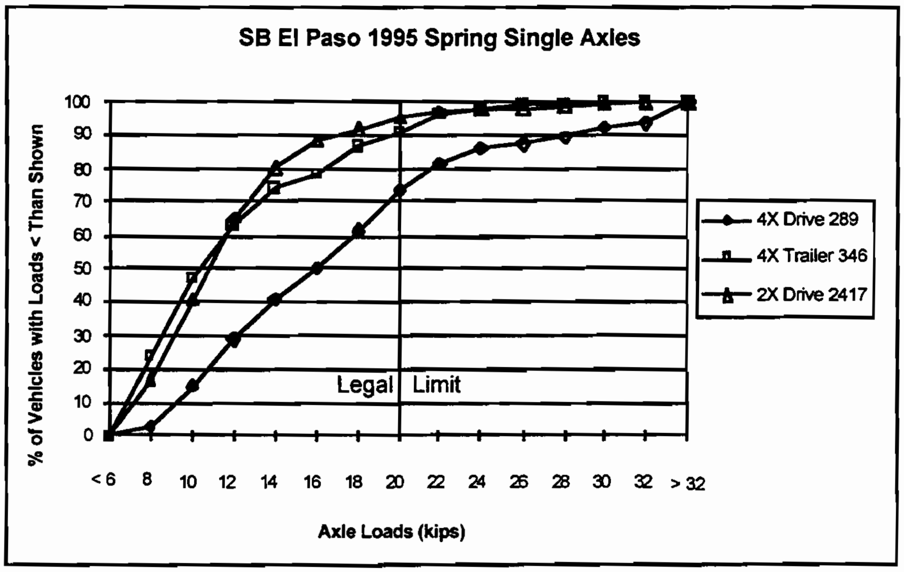

Figure 5.20 SB El Paso spring 1995 single-axle loads

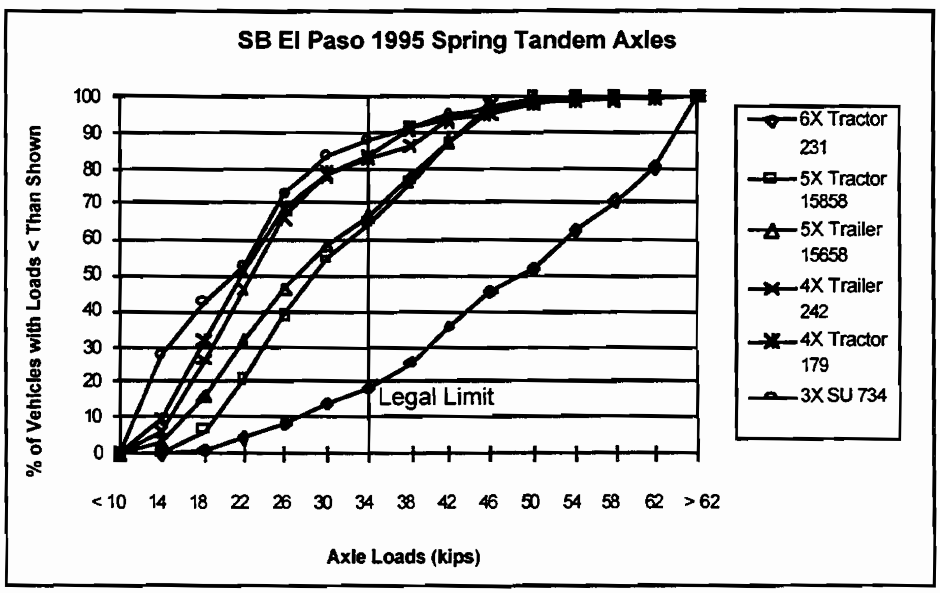

Figure 5.21 SB El Paso spring 1995 tandem-axle loads

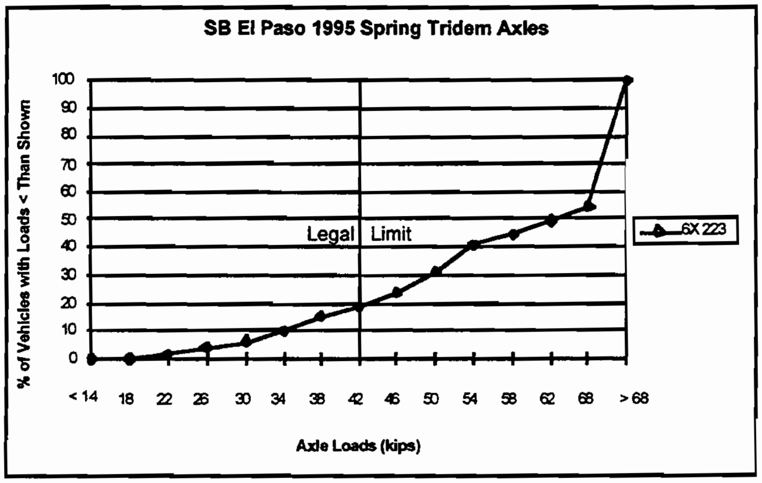

Figure 5.22 SB El Paso spring 1995 tridem-axle loads

Figures 5.20–5.22 display the axle load, frequency distributions for the spring of 1995, southbound El Paso. Figure 5.20 graphs the single-axle loads during the spring where the 2S2 drive single-axle loads were 26 percent overloaded. Ten percent of the 3S1 single trailer-axle loads were overloaded, and about 5 percent of the two-axle trucks were overloaded.

Figure 5.21 shows the tandem-axle loads observed during the spring where the 3S3 tractor tandems led the group with 80 percent of their weighed axle loads being over the legal limitations. The 3S2 tractor and trailer tandems followed with about 35 percent overloaded. There was a sign of change in the spring months. The three-axle (SU) trucks moved to having the least amount of tandems exceeding the limits. The 3S1 and 2S2 tandems were 18 percent overloaded and the three-axle truck, tandems were 11 percent overloaded. Figure 5.22 shows the spring tridem-axle loads where the 3S3 trucks had 80 percent of their tridems exceeding the U.S. limitations.

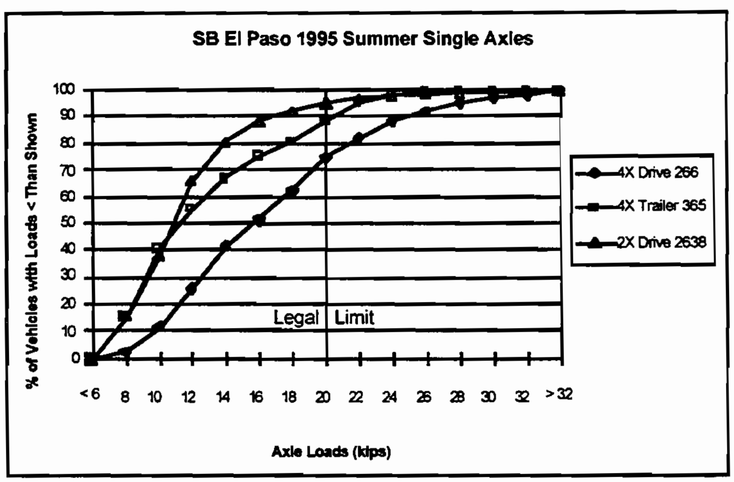

Figure 5.23 SB El Paso summer 1995 single-axle loads

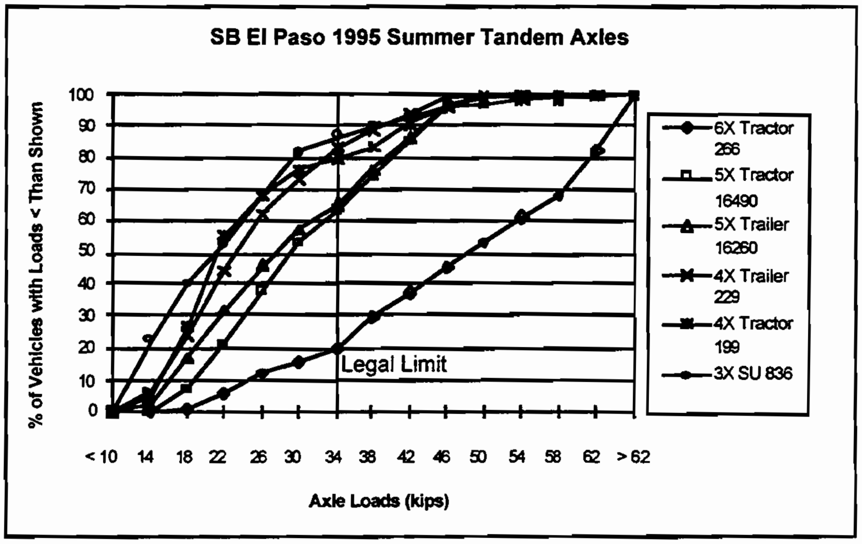

Figure 5.24 SB El Paso summer 1995 tandem-axle loads

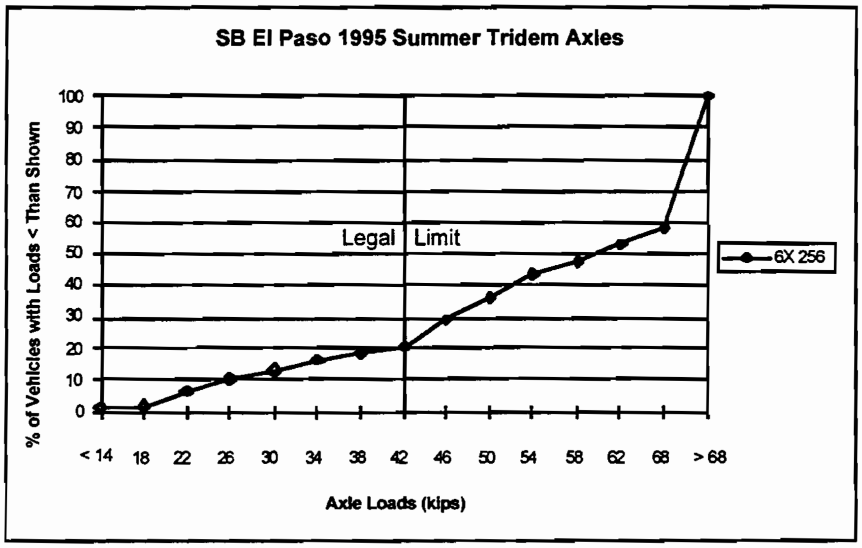

Figure 5.25 SB El Paso summer 1995 tridem-axle loads

Figures 5.23–5.25 display the axle load, frequency distributions for the summer of 1995, southbound El Paso. Figure 5.23 graphs the single-axle loads observed during the summer where over 25 percent of the 2S2 trucks exceeded the 20-kip limit. The 3S1 trucks had 11 percent overloaded, and the two-axle trucks had about 5 percent over the legal limit.

Figure 5.24 shows the tandem-axle loads in the summer where the 3S3 tractor-tandems were the most dominant offender of the 34-kip limitation. It had over 80 percent of its axle loads exceeding the legal limit. The 3S2 tractor and trailer-tandems had about 36 percent of their axle loads exceeding the limit. In the summer months, the three-axle (SU) trucks, again, had the least amount of tandems that were overweight. The 3S1 and 2S2 had about 20 percent of their tandems overloaded, and the three-axle trucks had about 11 percent. Figure 5.25 graphs the tridem-axle loads observed during the summer, where the 3S3 trucks had over 80 percent of their tridems exceeding the 42-kip limit.

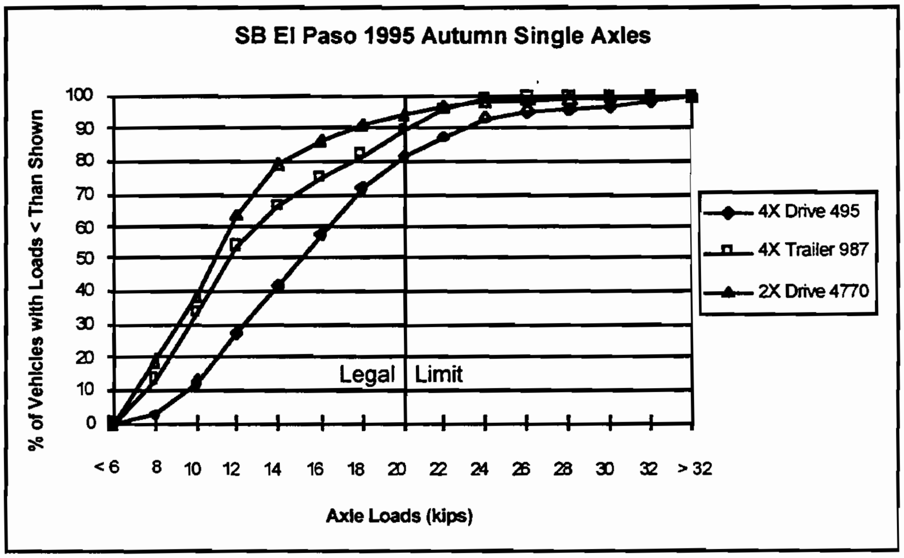

Figure 5.26 SB El Paso autumn 1995 single-axle loads

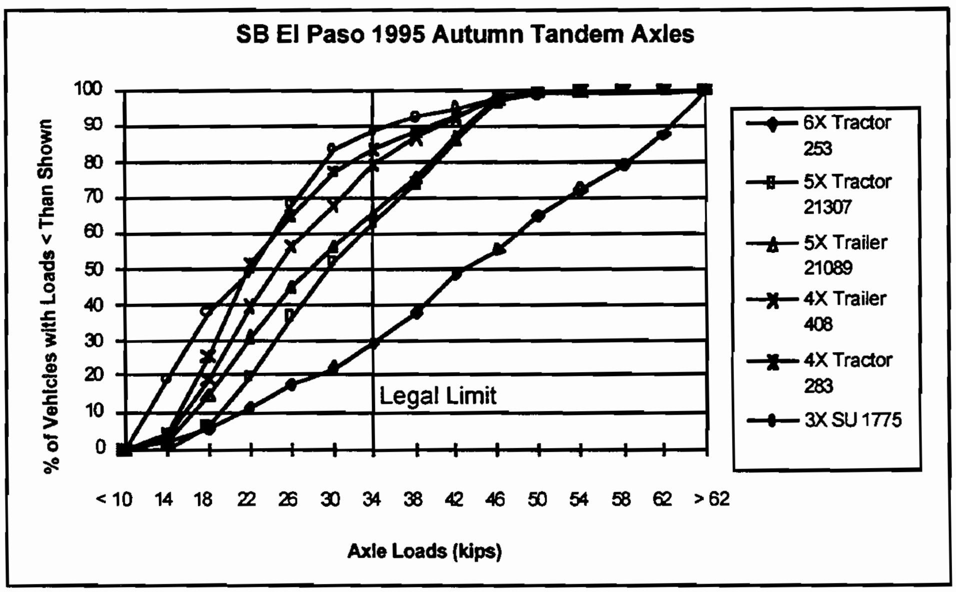

Figure 5.27 SB El Paso autumn 1995 tandem-axle loads

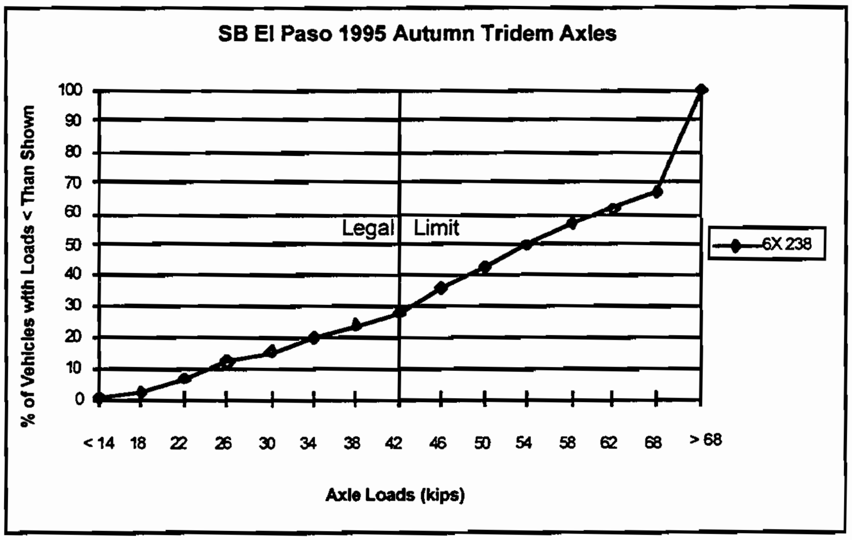

Figure 5.28 SB El Paso autumn 1995 tridem-axle loads

Figures 5.26–5.28 display the axle load, frequency distributions for the autumn of 1995, southbound El Paso. Figure 5.26 graphs the single-axle loads observed during the summer where only about 18 percent of the 2S2 trucks exceeded the 20-kip limitation. This was a noticeable improvement over the previous sets of graphs. The 3S1 single trailer-axle and the two-axle truck, drive-axle loads had about 10 percent and 7 percent exceeding the legal limit, respectively.

Figure 5.27 shows the 3S3 tractor-tandems had 70 percent of their axle loads exceeding the 34-kip limit. Both the 3S2 trailer and tractor tandems had about 36 percent of their loads exceeding the limits. The 2S2 tandems had 20 percent overloaded, the 3S1 tandems had 16 percent overloaded and the three-axle (SU) truck tandems had 11 percent overloaded. Figure 5.28 shows 71 percent of the 3S3 tridems exceeded the 42-kip limitations.

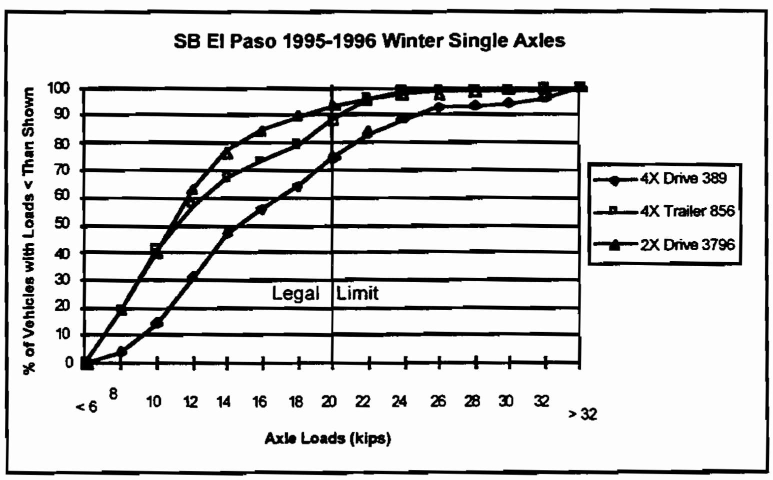

Figure 5.29 SB El Paso winter 1995-1996 single-axle loads

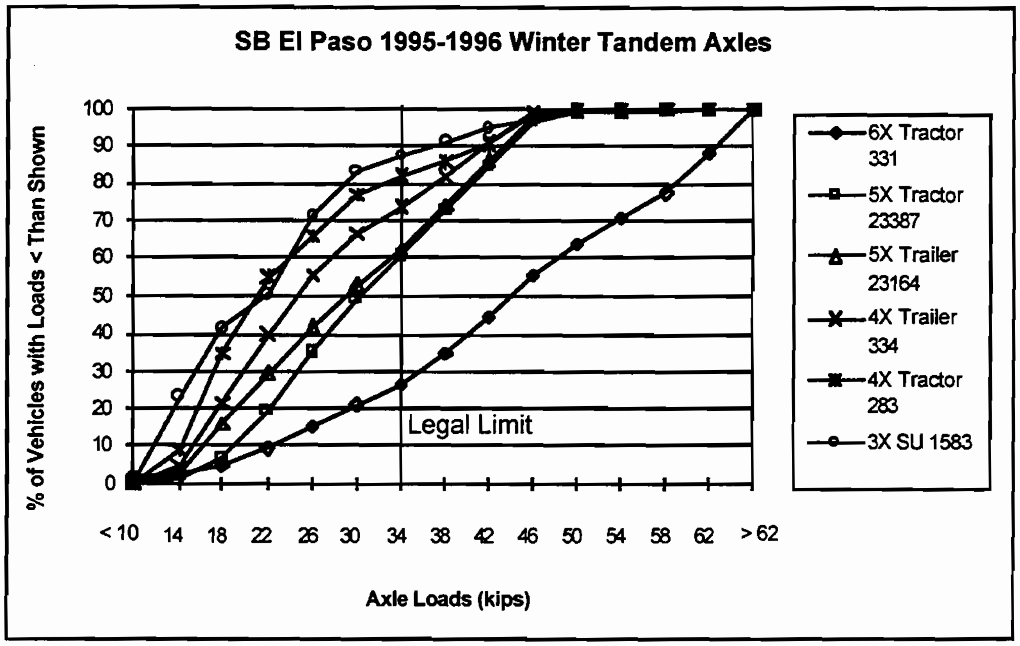

Figure 5.30 SB El Paso winter 1995-1996 tandem-axle loads

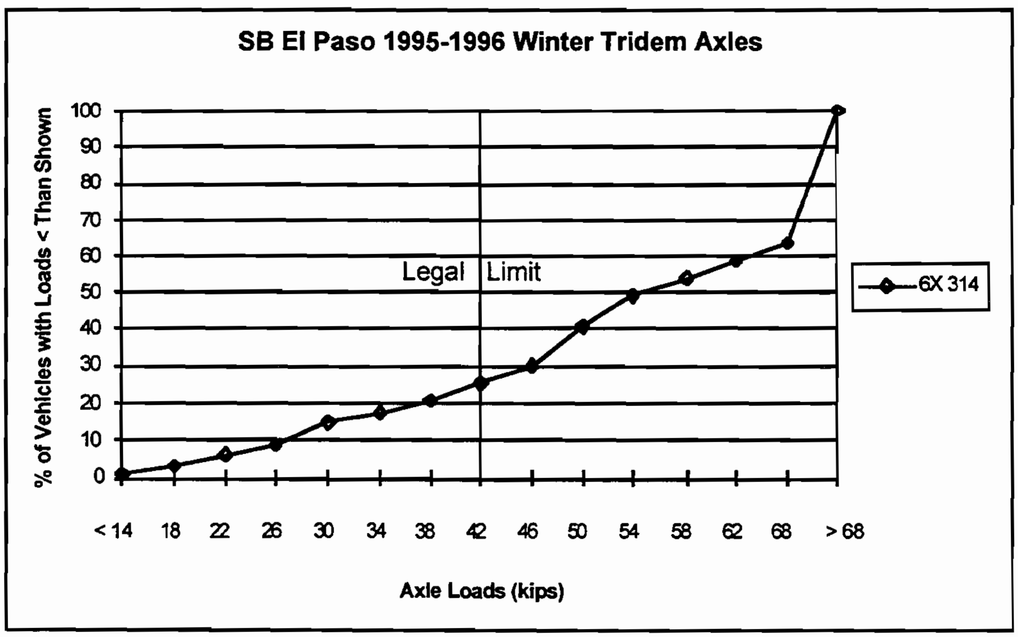

Figure 5.31 SB El Paso winter 1995-1996 tridem-axle loads

Figures 5.29–5.31 display the axle load, frequency distributions for the winter of 1995-1996, southbound El Paso. Figure 5.29 graphs the single-axle loads observed during the summer, where 25 percent of the 2S2 trucks exceeded the 20-kip limitation. The 3S1 and two-axle truck followed with 11 percent and 7 percent overloaded, respectively.

Figure 5.30 shows the 3S3 had 74 percent of its tandems exceeding the 34-kip limitation. The other vehicle tandems were overloaded as follows: 3S2 tractor (39 percent), 3S2 trailer (38 percent), 2S2 (26 percent), 3S1 (17 percent), and the three-axle (SU) truck (12 percent). Figure 5.31 shows the 3S3 tridems were 74 percent overloaded.

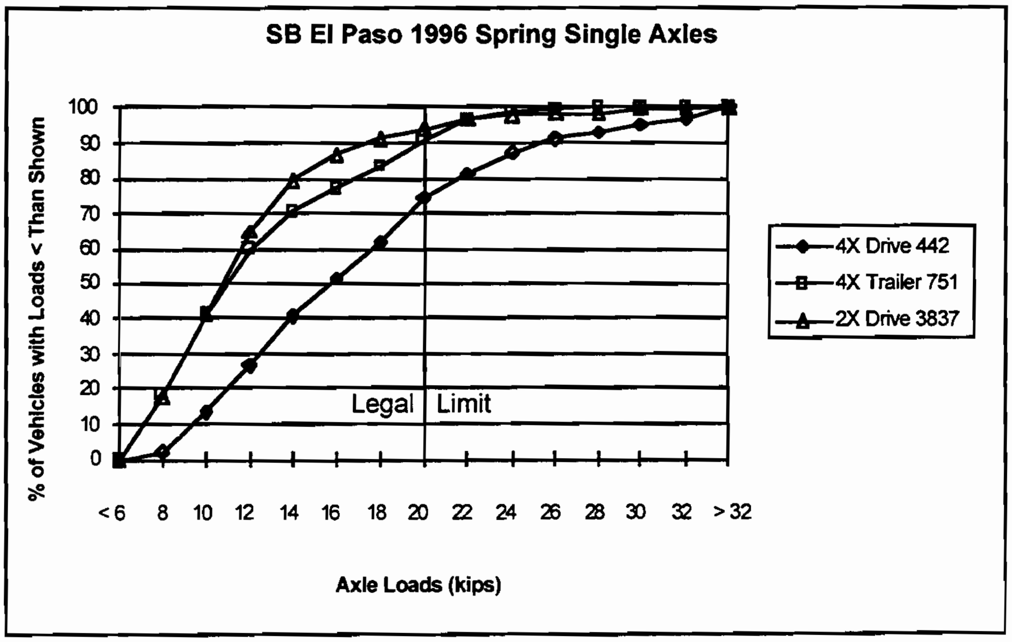

Figure 5.32 SB El Paso spring 1996 single-axle loads

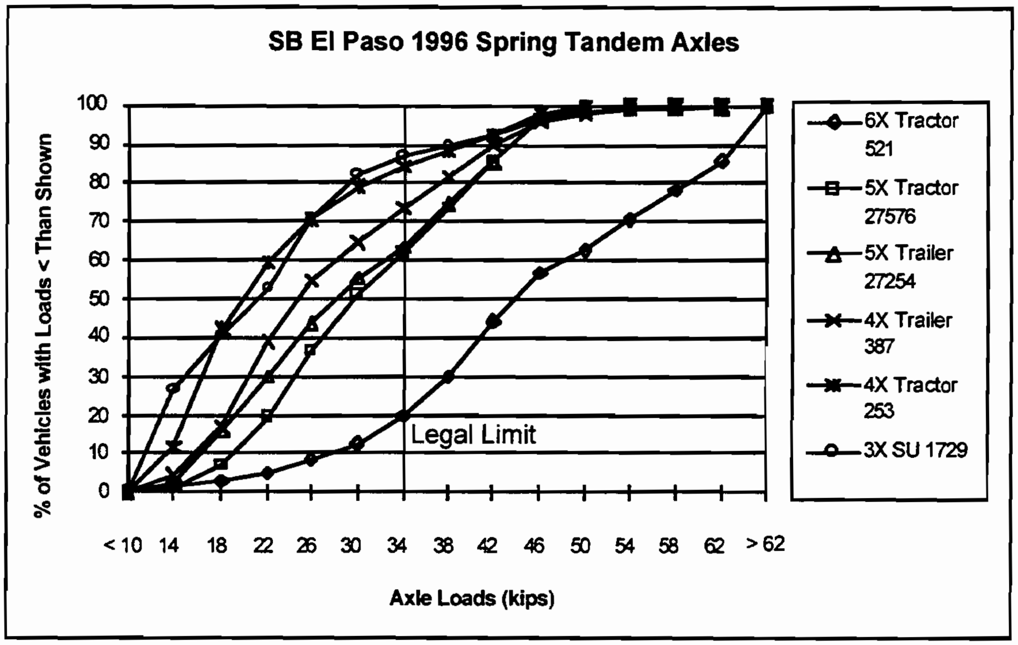

Figure 5.33 SB El Paso spring 1996 tandem-axle loads

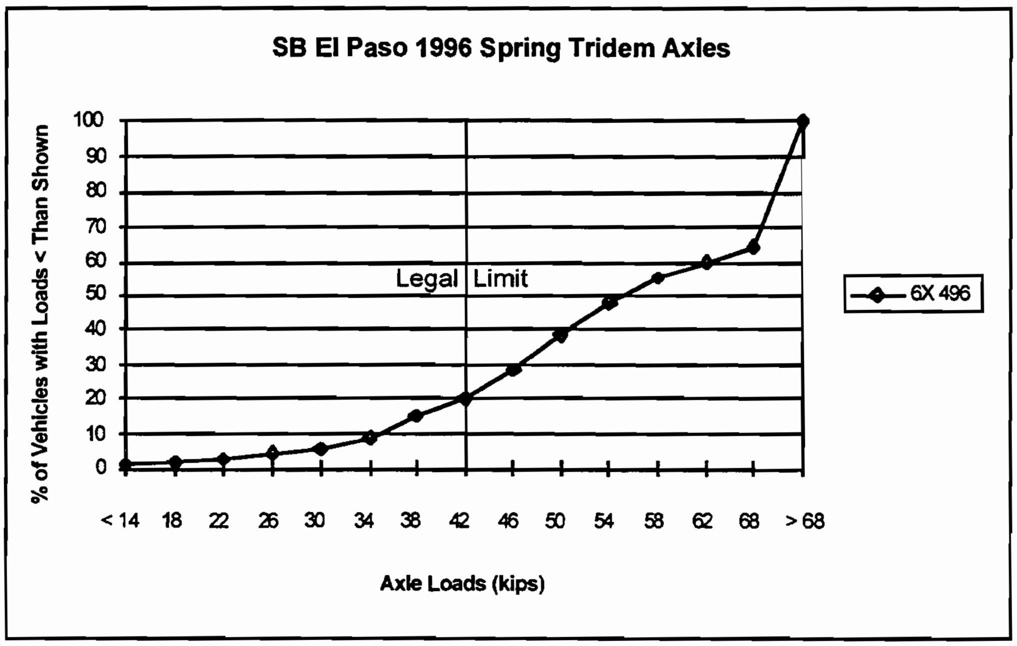

Figure 5.34 SB El Paso spring 1996 tridem-axle loads

Figures 5.31–5.34 display the axle load, frequency distributions for the spring of 1996, southbound El Paso. Figure 5.31 graphs the single-axle loads observed during the summer, where the single-axle loads that were overloaded past the 20-kip limitation were as follows: 2S2 (25 percent), 3S1 (10 percent), and the two-axle trucks (6 percent).

Figure 5.33 shows the tandems exceeding the 34-kip limit for the following vehicle types: 3S3 (80 percent), 3S2 tractor (38 percent), 3S2 trailer (37 percent), 2S2 (26 percent), 3S1 (15 percent), and the three-axle (SU) trucks (12 percent). Figure 5.34 graphs the 3S3 tridems which had 80 percent exceeding the 42-kip limitation.

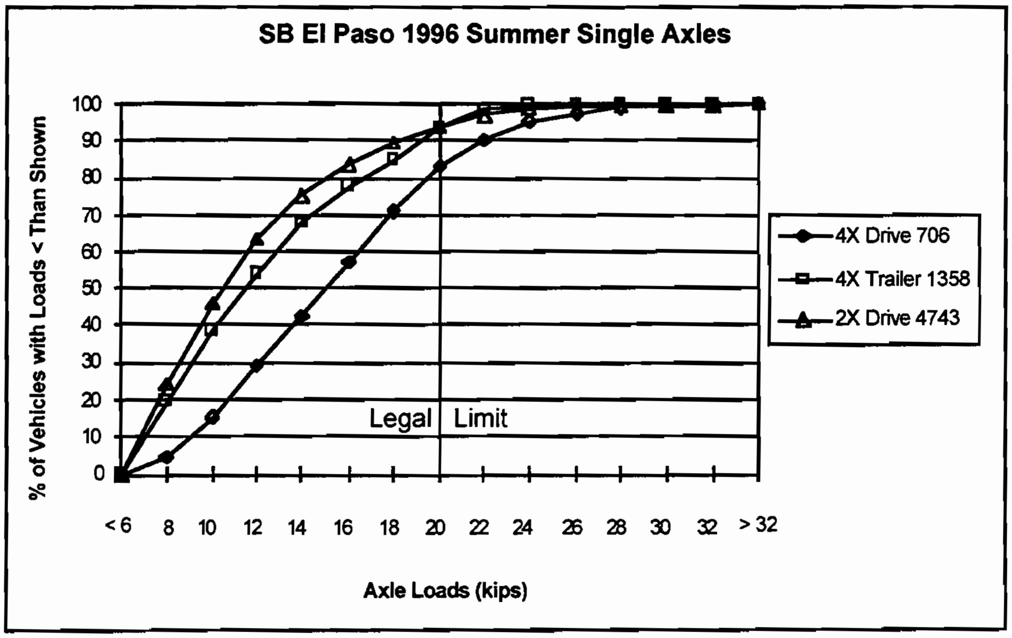

Figure 5.35 SB El Paso summer 1996 single-axle loads

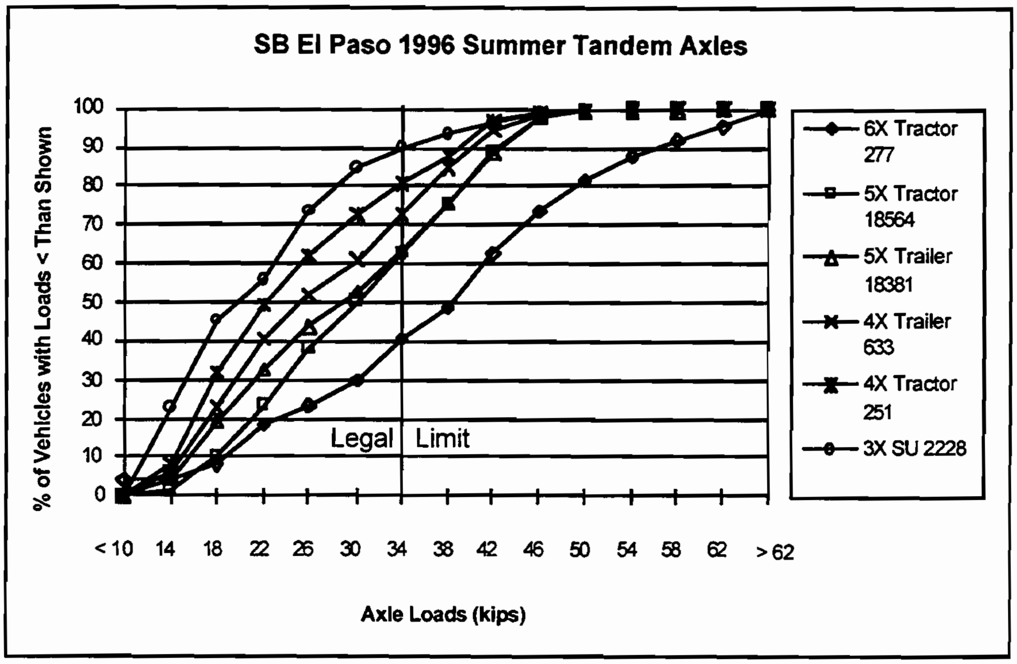

Figure 5.36 SB El Paso summer 1996 tandem-axle loads

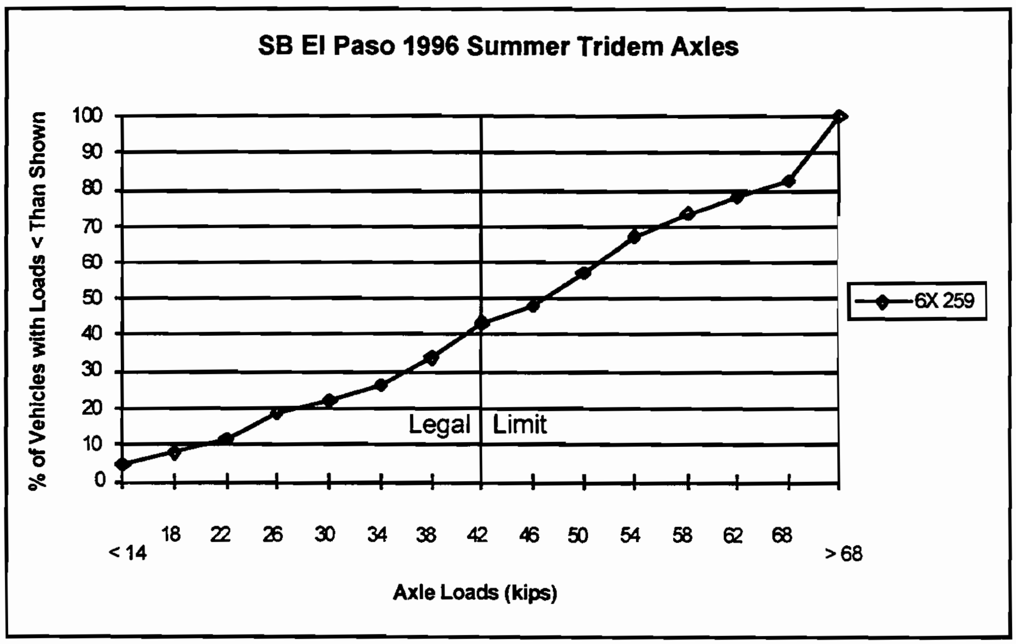

Figure 5.37 SB El Paso summer 1996 tridem-axle loads

Figures 5.34–5.37 display the axle load, frequency distributions for the summer of 1996, southbound El Paso. Figure 5.34 graphs the single-axle loads observed during the summer, where the single axle-load that were overloaded past the 20-kip limitation were as follows: 2S2 (18 percent), 3S1 (7 percent), and the two-axle trucks (7 percent).

Figure 5.33 shows the tandems exceeding the 34-kip limit for the following vehicle types: 3S3 (60 percent), 3S2 tractor (37 percent), 3S2 trailer (36 percent), 2S2 (27 percent), 3S1 (18 percent), and the three-axle (SU) trucks (10 percent). A noticeable change during the 1996 summer season was that the 3S3 tandem-axle loads had a smaller percentage overloaded.

Figure 5.34 graphs the 3S3 tridems which had 57 percent exceeding the 42-kip limitation. Another noticeable change during the 1996 summer season was that the 3S3 tridems had a much smaller percentage of overloaded tridems than the season before.

5.5 CONCLUSION

After examining all the data presented by seasons of the year in Chapter 5, most of the axle-load patterns for each season were similar. The data shown in these curves made it possible to assign rankings to the axle-types that had the highest percentage of overloads; however, consideration must also be given to the actual number of axles observed. The 3S3 trailer-tridems had the highest percentage of overloaded axles, followed by:

1. 3S3 trailer-tridems
2. 3S3 drive-tandems
3. 3S2 tractor-tandem
4. 3S2 trailer-tandem
5. 2S2 drive-single
6. 3S1 tractor-tandem
7. 2S2 trailer-tandem
8. three-axle (SU) truck, tandem
9. 3S1 trailer-single
10. two-axle truck, drive

There were times during which these rankings changed— for example in the autumn and winter of 1994, the three-axle (SU) trucks switched from an 8th ranking to a 6th ranking. For the most part, however, the rankings stayed in the same order.

Another main finding from this chapter was that the percentage of illegal axle-loads decreased over time. The two- , three- , and four-axle trucks stayed at their respective percentages. The more obvious change came from the 3S2 and 3S3 trucks. The 3S3 and 3S2 tridem- and tandem-axles had smaller percentages of overloaded axles from 1994 to 1996. This was an indication that axle-loads going southbound into Mexico gradually decreased in magnitude.

CHAPTER 6. RELATIVE HIGHWAY DAMAGE BY LOADED TRUCKS

When a vehicle passes over a pavement, its tire loads cause stresses and strains in the pavement structure which gradually cause cumulative damage. The extent of this damage can vary, as heavier trucks contributing higher loads cause more damage than lighter trucks with lesser loads. There needs to be some means of estimating the amount of damage that will be caused by all the different types of loaded axles that will use a road. For this purpose, equivalent single axle loads (ESALs) were calculated to show the relationship among the relative damaging effects of various axle arrangements on the observed truck types at Laredo and El Paso.

6.1 EQUIVALENT SINGLE AXLE LOADS

The chance of premature pavement wear-out increases every time overloaded tire forces are applied to a pavement. The damage these forces cause is relative to the amount of load and the successive spacings between each load. One way to express this damage is to calculate an equivalent single axle load (ESAL) factor. An ESAL factor is the number of repetitions of a standard axle-load, e.g., an 18-kip (80 kN) single axle load, to equal the damage caused to a particular pavement structure by an axle load of given magnitude on an axle type (e.g. single, tandem, or tridem). The ESAL factors calculated for every individual axle on a truck can be summed to give the number of standard axle loads (e.g., 18-kip, single) needed to equal the damage of one pass of that truck. By analyzing a set of observed data, a weighted-average ESAL factor for each truck type can be developed. If the pattern of loading on a particular truck type remains constant, or is assumed to do so, cumulative pavement damage can be estimated in terms of only the number of trucks of that type expected, and it will not be necessary to weigh each individual truck.

6.2 ESAL CHARACTERISTICS

The ESAL factors shown in Figures 6.1–6.5, have been calculated for each different loaded truck type. The lowest gross-vehicle weight to classify a two-axle truck as loaded was 12 kips. For three-axle trucks, the minimum gross-vehicle weight was 18 kips, 25 kips for four-axle trucks, 32 kips for five-axle trucks and 38 kips for six-axle trucks. The sum of the ESAL factors for each axle or axle group of a vehicle type were divided by the total number of axles of that kind in the data set for all trucks of that type. This gave a weighted average ESAL factor for each individual truck type. These results were plotted for the duration of the analysis period.

Figure 6.1 graphs the average ESAL factor for two-axle loaded trucks. For northbound El Paso traffic, ESAL factors for the first nine months were considerably lower than in later periods. The two-axle truck average ESAL factor increased from about a 0.20 to 0.27 between August 1994 and April 1995, where it remained until June 1996. Southbound El Paso ESALs increased gradually from about 2.5 to 4.5 during the period. There were a few dips and peaks but southbound traffic averaged a 0.41 ESAL factor. There was a huge drop in the Laredo ESAL factor. This was perhaps due to the recent closing of an exiting bridge (May 20, 1996) which caused a lot of empty two- and three-axle trucks to cross the system that would not normally have to. These vehicles that normally would have taken the exit bridge are not heavily loaded and their ESAL values averaged into the mainstream of two- and three-axle trucks that were loaded, creating a drop in the overall ESAL factor.

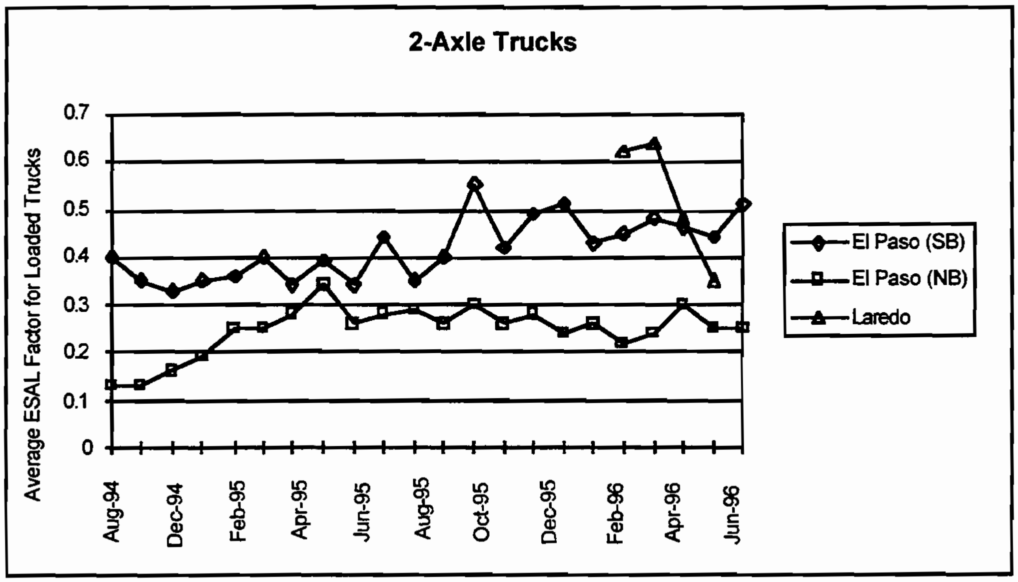

Figure 6.1 Average ESAL factors for two-axle trucks

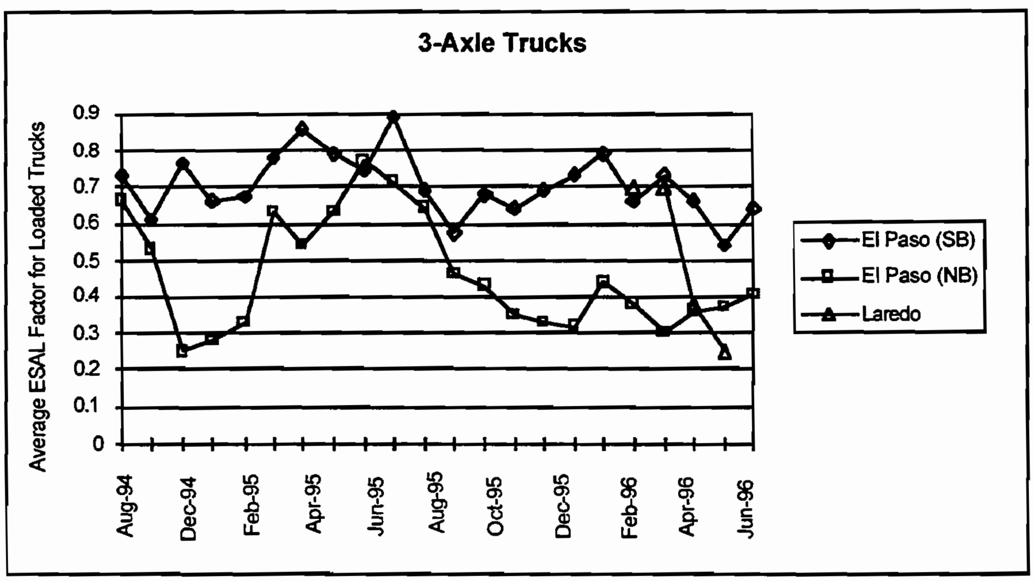

Figure 6.2 Average ESAL factors for three-axle trucks

Figure 6.2 shows that northbound El Paso has predominant peaks and valleys; there was no constant pattern found. Northbound El Paso had a high of 0.77 in June 1995 and there were lows of 0.25 and 0.3 in December 1994 and April 1996, respectively. Southbound El Paso had a pretty constant pattern with an average 0.71 ESAL factor. Laredo, once again, had an extreme drop with the three-axle truck ESAL factor as explained by the closing of the exiting bridge. Regardless of the drop, the three-axle trucks in Laredo averaged a 0.51 ESAL factor.

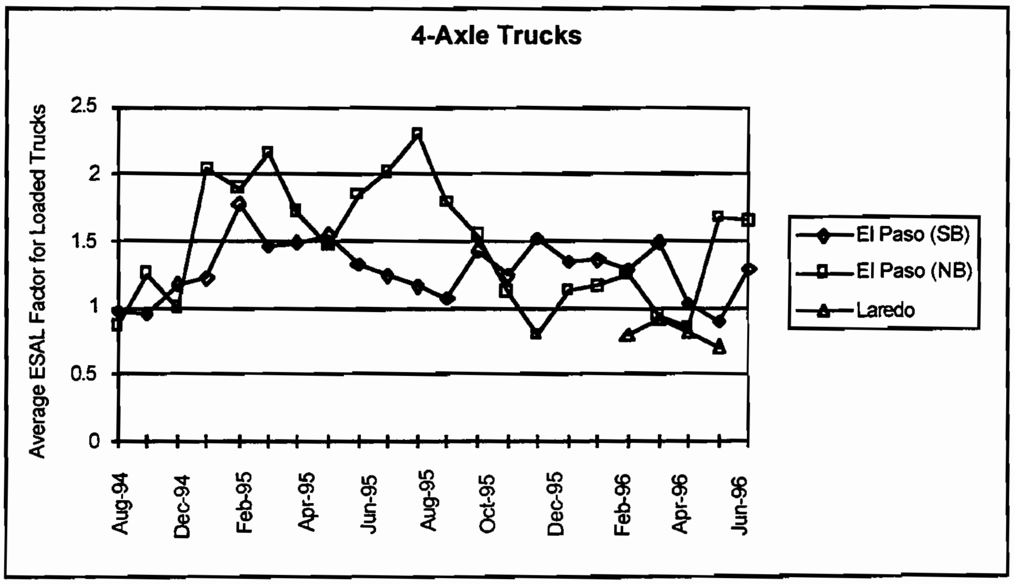

Figure 6.3 Average ESAL factors for four-axle trucks

In Figure 6.3, northbound El Paso traffic had low ESAL factors of 0.87 and 0.8 in August 1994 and December 1995, respectively. The high for northbound traffic was an ESAL factor of 2.29 in August 1995. Southbound traffic in El Paso was again reasonably constant as it had been in the previous figures as well. In Figure 6.3, there was an average ESAL factor of 1.28. Laredo did break away from repeating patterns shown for the first three figures. The four-axle trucks had a reasonable constant average ESAL factor of 0.81. There was no drop off as in the previous Laredo graphs because the closing of the bridge did not affect this vehicle class. There was no distinct pattern for four-axle truck traffic headed northbound; however, there was a pattern when comparing northbound traffic for all three figures for two-, three-, and four-axle truck ESAL factors (Figure 6.1, 6.2, and 6.3). The pattern seems to be very low ESAL factors in the months of 1994, and then they rise to a peak around May and June 1995. Then the ESAL factors steadily drop off through 1996.

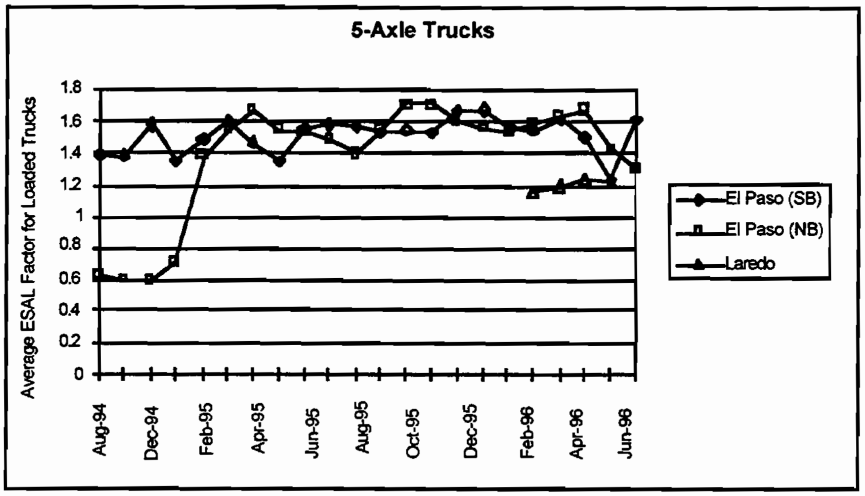

Figure 6.4 Average ESAL factors of five-axle trucks

In Figure 6.5, the northbound and southbound traffic in El Paso follow a very constant pattern with an average ESAL factor for both directions at 1.54 and 1.51, respectively. The first four months for northbound traffic are much lower with an average ESAL factor of 0.63. Laredo traffic had an average 1.20 ESAL factor.

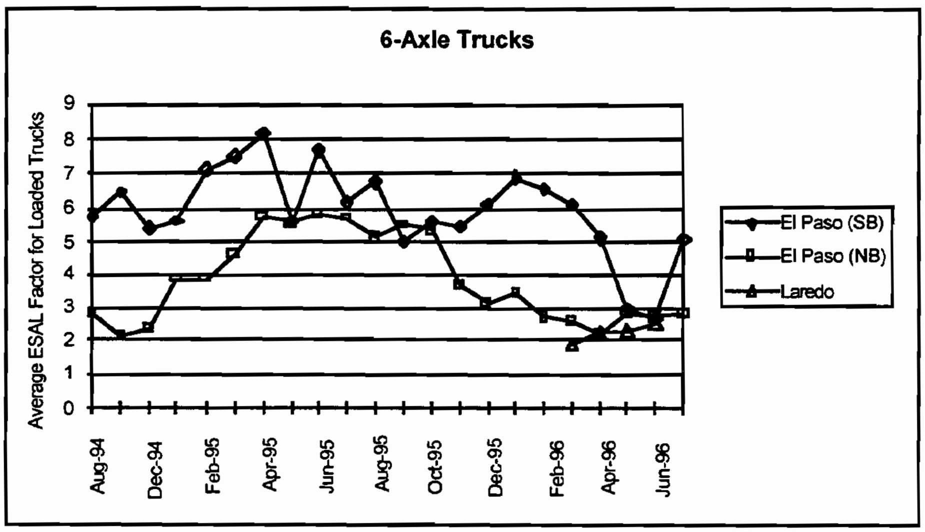

Figure 6.5 Average ESAL factors for six-axle trucks

With six-axle truck volumes so low, it was expected to find ESAL values to vary widely. Some parts of the curves had constant trends and then would change to peaks and valleys. The average ESAL factors for the six-axle trucks were 5.89 for El Paso southbound, 3.83 for El Paso northbound and 2.27 for Laredo.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

Records have been kept on the numbers of trucks that pass across the Texas-Mexico border, but their axle loads have never before been measured systematically. If NAFTA is implemented, concern about the potential damage to the highway infrastructure on both sides of the border will continue to grow. This concern comes partly from a lack of information about the axle-loads of trucks that cross the border. The installation of the WIM systems in Laredo and El Paso for this project are the first known attempt to record axle loads and spacings of trucks crossing the border in both directions.

The axle data recorded for northbound trucks in Laredo and El Paso from August 1994 to July 1996 was consistent and reliable as most trucks moved smoothly over the WIM-system sensors without stopping. The data recorded for southbound traffic in El Paso, however, was affected adversely by trucks queuing to pay Mexican bridge toll and stopping over the sensors. The addition of a supplementary vehicle-presence sensor and a software program to interpret the recorded data made it possible to identify individual trucks and extract valuable axle-load data for these southbound trucks.

From all the collected data, there were three major focuses of analysis. The first focus centered on the number of trucks that passed over the WIM sensors in Laredo and El Paso. Figure 7.1 shows an average daily count of the various truck types as they passed over the WIM sensors.

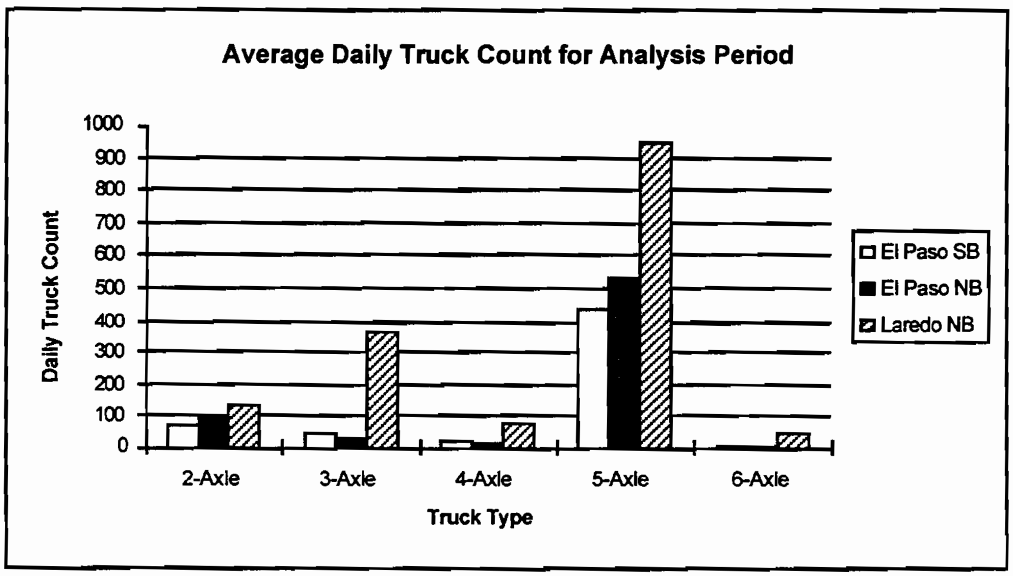

Figure 7.1 Average daily truck count, 1994–1996

It is apparent from Figure 7.1 that five-axle trucks were the dominant truck-type analyzed in this research. They averaged about 950 northbound trucks per month in Laredo, 540 northbound trucks per month in El Paso and about 440 southbound trucks per month in El Paso. Three-axle trucks had the second highest average monthly count going northbound in Laredo with about 360 per month, but the northbound and southbound three-axle trucks in El Paso ranked third with the two-axle northbound and southbound trucks in El Paso ranking second with about 88 and 74 vehicles per month, respectively. The four- and six-axle trucks followed in as forth and fifth for the average monthly vehicle counts.

The second major vehicle characteristic analyzed was axle loads. This was split up in Chapter 5 by seasons. The material in Chapter 5 showed that the six-axle trucks were the most overloaded vehicles by percentage. Some seasons had at least 80 percent of the six-axle trucks overloaded on either the tandem or tridem axle group. The five-axle truck tandems ranked second with their percentages exceeding the U.S. load limitations. The three- and four-axle truck tandems alternated for the third and fourth ranked spots. Some seasons, the three-axle trucks would have larger percentages of their tandem-axles being overloaded and other seasons would have four-axle trucks having larger percentages of their tandem-axles being overloaded. The two-axle trucks followed last, ranking fifth, with the lowest percentage of their single-axles exceeding the U.S. axle-load limitations. The curves showing these differences have been graphed in Chapter 5. Another major focus of this section was to reveal if there was any pattern with seasonal change. Table 7.1 shows the differences among the seasons, highlighting which seasons had more overloaded axles past U.S. legal limitations.

Table 7.1 Seasonal differences with axle loads

	Autumn 1994	Winter 1994	Spring 1995	Summer 1995	Autumn 1995	Winter 1995	Spring 1996	Summer 1996
El Paso SB	Heavy	Medium	Heavy	Heavy	Lighter	Medium	Heavy	Very Light
El Paso NB						Light	Very Light	Very Light
Laredo								Light

One noticeable trend was apparent when comparing the season of one year with the same season of another year (e.g. winter 1995 vs. winter 1996). The percentage of trucks with overloaded axles past the U.S. legal limitations decreased over time. Comparing autumn of 1994 and 1995 for southbound El Paso traffic, the percentage of overloaded axles was lower in 1995. The same happened for the summer and winter seasons. However, the one season that stood out for southbound El Paso traffic was the spring season. A large percentage of axles, in the spring, remained heavily loaded regardless of the year. The northbound traffic in El Paso and Laredo did not have enough data to compare the seasons of different years; however, when compared to the southbound trucks in El Paso, the overall percentages of trucks with overloaded axles were much lower.

The last major characteristic analyzed for this project was the ESAL factors of the various truck types that crossed the border. There was no real surprise with the results. The six-axle trucks had the highest number of overloaded axles and this directly related to their high calculated ESAL factors. Five-axle trucks ranked in second, four-axle, three-axle, and two-axle trucks followed in third through fifth, respectively. Figure 7.2 gives a graphical representation of the ESAL factors recorded throughout the project duration.

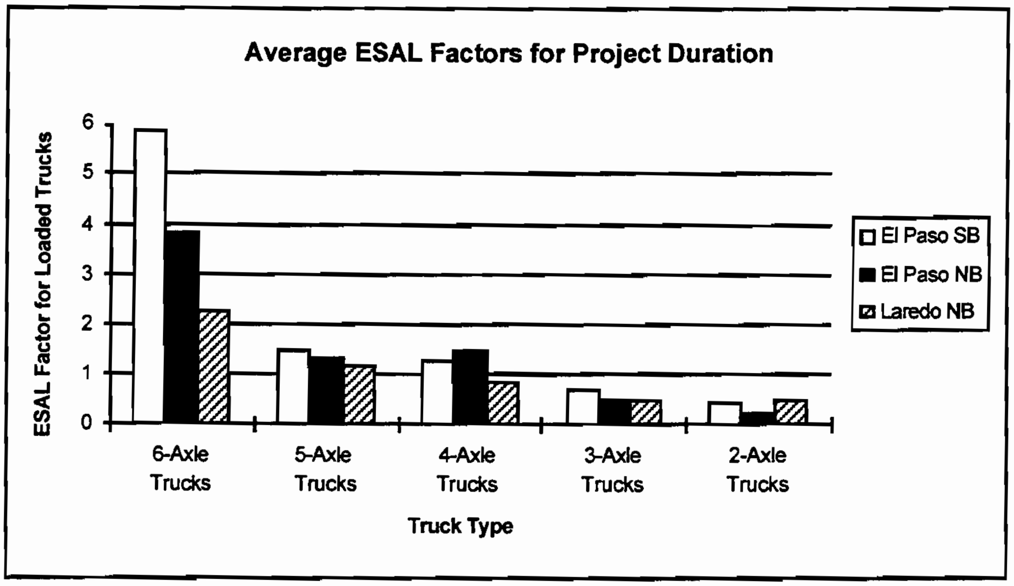

Figure 7.2 Average ESAL factor for project duration

The data recorded from the WIM sensors were very informative. One was able to determine the spacing between each axle, the speed of the vehicle, the time of day that the vehicle passed, and the load applied by each passing axle. From this information, an analyst was able to determine the truck type, ESAL factors, and seasonal patterns. The one area for improvement would be to solve the problems encountered with recording queued data in the southbound direction. This can be eliminated if WIM sensors would be placed on the opposite side of the bridge (in Mexico) where the vehicle characteristics can be recorded as they exit the border crossings. This would make the southbound system as efficient as it was for northbound traffic. Strict enforcement of pavement markings would also be of great benefit. The zero load recordings found in the data came from vehicles rolling out of the designated pavement markings and if this could be corrected, there would be even fewer errors. If these corrections are not possible, use of the reclassifying program would improve on the data set, but placing the sensors in Mexico, as the vehicles pass through the station, would provide the most reliable data for examination.

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[2] Sanchez-Ruiz, L. A. (1996). "Heavy Vehicle Characteristics Under NAFTA: The Texas-Mexico Border." MS thesis in Civil Engineering, The University of Texas at Austin.

[3] Garner, J. E. and Lee, C. E. (1994). "Augmented Weigh-in-Motion System for Traffic Data Collection and Analysis," Transportation Research Record 1501, Center for Transportation Research, The University of Texas at Austin.

[4] PAT (1993). PAT Traffic Corporation, "DAW100 Operation Manual," Chambersburg, PA.

[5] Lee, C. E. (1994). "Specifications for Infrared Vehicle Sensor at El Paso, Texas," Center for Transportation Research, The University of Texas.

APPENDIX

RECLASSIFYING PROGRAM

"C"-Language Reclassifying Program

```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <ctype.h>

#define BAD_RECORD    -99
#define BAD_SPEED     10
#define RECORD_SIZE   600
#define MAXIMUM_AXLES  11
#define MAXIMUM_FIELDS MAXIMUM_AXLES*20+7
#define TRUE          1
#define FALSE         0
#define TANDEM_MIN     3
#define TANDEM_MAX     7
#define TRACTOR_MIN    7
#define TRACTOR_MAX   21
#define TRAILER       20

#define STEER_MIN          4
#define STEER_MAX          7
#define DRIVE_3_AXLE_E_MIN  2
#define DRIVE_3_AXLE_E_MAX  3.5
#define DRIVE_E_MIN        3
#define DRIVE_E_MAX        5
#define TRAILER_E_MIN      3
#define TRAILER_E_MAX      5
#define DRIVE_3_AXLE_L_MIN  3.6
#define DRIVE_3_AXLE_L_MAX  6
#define DRIVE_L_MIN        5.1
#define DRIVE_L_MAX        16
#define TRAILER_L_MIN      5.1
#define TRAILER_L_MAX      16
#define TWO_AXLE_MIN        1.5
#define TWO_AXLE_MAX        4

#define SPACING_TEST   0
#define WEIGHT_TEST    1

#define FILE_NAME_NC 250

/* global variables */
FILE *input_file_ptr;
FILE *log_file_ptr;
FILE *output1_file_ptr;
FILE *output2_file_ptr;
FILE *error_file_ptr;
int   gsiv_next_record_read;
int   gsiv_vehicles;

/* structure definitions */
```

```
typedef struct
{
  int ssiv_day;
  int ssiv_hour;
  int ssiv_minute;
  int ssiv_second;
} TimeStamp;
typedef struct
{
  double sdfv_left;
  double sdfv_right;
  double sdfv_spacing;
} AxleData;
typedef struct
{
  int       ssiv_recordNumber ;
  int       ssiv_line;
  TimeStamp stdv_time;
  int       ssiv_speed;
  AxleData  stda_axleData[MAXIMUM_FIELDS-7];
} FileRecord;

/* function prototypes */
void shift_axles
(
  AxleData ptda_axle_record[],
  int      psiv_this_many,
  int      psiv_max
);
int is_it_a_2
(
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
);
int is_it_a_3
(
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
);
int is_it_a_4
(
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
);
int is_it_a_5
(
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
);
int is_it_a_6
(
```

```
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
);
void print_record
 (
FileRecord *ptdv_fileRecord_ptr,
int psiv_axles
 );
void process_record
 (
FileRecord *ptdv_fileRecord_ptr,          /* data to be processed */
int        psiv_first_axle,              /* first axle in array (0 based) */
int        psiv_last_axle                /* last axle in array (0 based) */
 );

int read_record
 (
FileRecord *ptdv_fileRecord_ptr,
int        *psiv_last_axle_ptr,
int        *psiv_axles_ptr
 );

int read_axle
 (
char     *pcza_record_ptr,  /* character data                 */
AxleData *ptdv_axleData_ptr  /* structure to return axle data */
 );

int find_field_locations
 (
char *pcza_record_ptr,         /* character data with comma separated
fields */
int   psia_field_location[]   /* character positions for start of fields
*/
 );

void main
(
  int  psiv_argc     ,
  char *pcza_argv_ptr[]
)
{
  FileRecord ltdv_fileRecord;
  int       lsiv_read_again;
  int       lsiv_axles;      /* number of axles in just read record   */
  int       lsiv_records     = 0;
  int       lsiv_bad_records = 0;
  int       lsiv_first_axle;
  int       lsiv_last_axle;
  int       lsiv_last_processed_axle;
  char        lcza_input_file[FILE_NAME_NC];
  char        lcza_log_file[FILE_NAME_NC];
  char        lcza_output1_file[FILE_NAME_NC];
  char        lcza_output2_file[FILE_NAME_NC];
```

```
char       lcza_error_file[FILE_NAME_NC];
char       lcza_file_prefix[FILE_NAME_NC];
char       lcza_temp[FILE_NAME_NC];
int        lsiv_day;
int        lsiv_year;
int        lsiv_month;
int        lsia_last_day[13] = {0,31,28,31,30,31,30,31,31,30,31,30,31};
if ( psiv_argc >= 1 )
{
  if ( sscanf ( pcza_argv_ptr[1],"%d",&lsiv_month ) != 1 )
  {
    goto month_error;
  }
  if ( ( lsiv_month < 0 ) || ( lsiv_month > 12 ) )
  {
    goto month_error;
  }
}
else
{
  goto month_error;
}
if ( psiv_argc >= 2 )
{
  if ( sscanf ( pcza_argv_ptr[2],"%d",&lsiv_year ) != 1 )
  {
    goto year_error;
  }
  if ( ( lsiv_year < 90 ) || ( lsiv_year > 99 ) )
  {
    goto year_error;
  }
}
else
{
  goto year_error;
}
if ( psiv_argc >= 3 )
{
   strncpy (lcza_file_prefix,pcza_argv_ptr[3],FILE_NAME_NC-1);
}
else
{
   lcza_file_prefix[0] = '\0';
}
strncpy ( lcza_error_file,lcza_file_prefix,FILE_NAME_NC-1 );
sprintf ( lcza_temp, "ERROR%2.2d.%2.2d",
         lsiv_month,lsiv_year );
strncat ( lcza_error_file,lcza_temp,FILE_NAME_NC-strlen(lcza_error_file)-1 );
error_file_ptr  = fopen ( lcza_error_file,"w" );
if ( error_file_ptr == NULL )
{
  printf  ( "Error when opening error file \"%s\"\n",lcza_error_file );
  exit (3);
}
```

```
strncpy ( lcza_log_file,lcza_file_prefix,FILE_NAME_NC-1 );
sprintf ( lcza_temp, "LOG%2.2d.%2.2d",
        lsiv_month,lsiv_year );
strncat ( lcza_log_file,lcza_temp,FILE_NAME_NC-strlen(lcza_log_file)-1   );
log_file_ptr  = fopen ( lcza_log_file,"w" );
if ( log_file_ptr == NULL )
{
  printf ( "Error when opening processing log file\"%s\"\n",lcza_log_file );
  exit (3);
}
for ( lsiv_day = 1; lsiv_day <= lsia_last_day[lsiv_month]; lsiv_day++ )
{
  strncpy ( lcza_input_file,lcza_file_prefix,FILE_NAME_NC-1 );
  sprintf ( lcza_temp, "V010%2.2d%2.2d.%2.2d",
          lsiv_month,lsiv_day,lsiv_year );
  strncat ( lcza_input_file,lcza_temp,FILE_NAME_NC-strlen(lcza_input_file)-1   );
  input_file_ptr  = fopen ( lcza_input_file,"r" );
  if ( input_file_ptr == NULL )
  {
    printf  ( "Error when opening input file \"%s\"\n",lcza_input_file);
    fprintf ( log_file_ptr,"Error when opening input file\"%s\"\n",lcza_input_file );
    continue;
  }

  strncpy ( lcza_output1_file,lcza_file_prefix,FILE_NAME_NC-1 );
  sprintf ( lcza_temp, "VF15%2.2d%2.2d.%2.2d",
          lsiv_month,lsiv_day,lsiv_year );
  strncat ( lcza_output1_file,lcza_temp,FILE_NAME_NC-strlen(lcza_output1_file)-1 );
  output1_file_ptr = fopen ( lcza_output1_file,"w" );
  if ( output1_file_ptr == NULL )
  {
    printf  ( "Error when opening output file\"%s\"\n",lcza_output1_file );
    fprintf ( log_file_ptr,"Error when opening output file\"%s\"\n",lcza_output1_file );
    exit (4);
  }

  strncpy ( lcza_output2_file,lcza_file_prefix,FILE_NAME_NC-1 );
  sprintf ( lcza_temp, "VF18%2.2d%2.2d.%2.2d",
          lsiv_month,lsiv_day,lsiv_year );
  strncat ( lcza_output2_file,lcza_temp,FILE_NAME_NC-strlen(lcza_output2_file)-1 );
  output2_file_ptr = fopen ( lcza_output2_file,"w" );
  if ( output2_file_ptr == NULL )
  {
    printf  ("Error when opening output file\"%s\"\n",lcza_output2_file );
    fprintf (log_file_ptr,"Error when opening output file\"%s\"\n",lcza_output2_file );
    exit (4);
  }
  printf  ( "Input file is \"%s\"\n", lcza_input_file );
  fprintf ( log_file_ptr,"Input file is \"%s\"\n", lcza_input_file );
  printf  ( "Output files are \"%s\" and\"%s\"\n",lcza_output1_file,lcza_output2_file );
  fprintf ( log_file_ptr,"Output files are \"%s\" and\"%s\"\n",lcza_output1_file,lcza_output2_file );
  printf  ( "Error file is \"%s\"\n",lcza_error_file );
  fprintf ( log_file_ptr,"Error file is \"%s\"\n",lcza_error_file );
  gsiv_vehicles    = 0;
```

```
lsiv_records     = 0;
lsiv_bad_records = 0;

gsiv_next_record_read = FALSE;
while ( TRUE )
{
  lsiv_read_again         = TRUE;
  lsiv_first_axle         =  0;
  lsiv_last_axle          = -1;
  lsiv_last_processed_axle = -1;
  while ( lsiv_read_again )
  {
    lsiv_read_again = read_record ( &ltdv_fileRecord,
                                    &lsiv_last_axle,
                                    &lsiv_axles  );
    if ( lsiv_axles == -1 )
    {
      /* found end of file EOF */
      printf  ( "End of File found\n" );
      fprintf ( log_file_ptr,"End of File found\n" );
      printf  ( "%d records processed, including %d bad records\n",lsiv_records,
              lsiv_bad_records );
      fprintf ( log_file_ptr,"%d records processed, including %d bad records\n",lsiv_records,
              lsiv_bad_records );
      printf  ( "%d vehicles processed\n",gsiv_vehicles );
      fprintf ( log_file_ptr,"%d vehicles processed\n",gsiv_vehicles );
      goto end;
    }
    ++lsiv_records;
    if ( lsiv_axles == BAD_RECORD )
    {
      /* record has data that can't be processed  go to next record */
      ++lsiv_bad_records;
      continue;
    }
  }
  process_record ( &ltdv_fileRecord,
                   lsiv_first_axle,
                   lsiv_last_axle );
}
end:
fclose ( input_file_ptr );
fclose ( output1_file_ptr );
fclose ( output2_file_ptr );
}
printf ( "Processing log file is \"%s\"\n",lcza_log_file );
exit (0);

month_error:
printf  ( "Error reading month from command line\n" );
fprintf ( log_file_ptr,"Error reading month from command line\n" );
exit (1);

year_error:
printf  ( "Error reading year from command line\n" );
```

```
    fprintf ( log_file_ptr,"Error reading year from command line\n" );
    exit (2);
}


int read_record
  (
FileRecord  *ptdv_fileRecord_ptr,
int        *psiv_last_axle_ptr,
int        *psiv_axles_ptr
  )
{
  AxleData     *ltdv_axleData_ptr;
  int          lsiv_line;
  int          lsiv_axle;
  int          lsiv_fields;
  int            lsia_field_locations[MAXIMUM_FIELDS-7];
  static char  scza_record[RECORD_SIZE];
  int          lsiv_return;
  int          lsiv_i;
  int          lsiv_j;

  /* read a record and put data into fields                      */
  /* return number of axles in record, or -1 if EOF, or BAD_RECORD */

  if ( !gsiv_next_record_read )
  {
    /* read a record into character array */
    if ( fgets ( scza_record,RECORD_SIZE-1,input_file_ptr ) == NULL )
    {
      fgetc ( input_file_ptr );
     *psiv_axles_ptr = -1;
     return FALSE;
    }
/*    fgetc ( input_file_ptr );   */
  }
  /* remove imbedded blanks */
  lsiv_i = 0;
  while ( lsiv_i < RECORD_SIZE )
  {
    if ( scza_record[lsiv_i] == '\0' )
    {
      break;
    }
    if ( isspace(scza_record[lsiv_i]))
    {
      lsiv_j = lsiv_i;
      while ( (scza_record[lsiv_j] = scza_record[1+lsiv_j++]) != '\0' );
    }
    if ( scza_record[lsiv_i] == '\0' )
    {
      break;
    }
    ++lsiv_i;
  }
```

```
gsiv_next_record_read = FALSE;
lsiv_fields = find_field_locations ( scza_record,lsia_field_locations );

if ( lsiv_fields  < 9 )
{
  /* there is not at least one axle in the record */
  *psiv_axles_ptr = BAD_RECORD;
  return FALSE;
}
if ( *psiv_last_axle_ptr != -1 )
{
  /* the last read found MAXIMUM_AXLES             */
  /* this read may replace header and append axles */
  lsiv_line = ptdv_fileRecord_ptr->ssiv_line;
  lsiv_return = sscanf ( &scza_record[lsia_field_locations[1]],
                        "%d",
                        &ptdv_fileRecord_ptr->ssiv_line );
 if ( lsiv_return != 1 )
 {
   ptdv_fileRecord_ptr->ssiv_line = lsiv_line;
   *psiv_axles_ptr = BAD_RECORD;
   return FALSE;
 }
 if ( lsiv_line != ptdv_fileRecord_ptr->ssiv_line )
 {
   /* for this record, line is not same as line of previous record */
   /* don't merge this one with the previous one                   */
   gsiv_next_record_read        = TRUE;
   ptdv_fileRecord_ptr->ssiv_line = lsiv_line;
   return FALSE;
 }
}
lsiv_return = sscanf ( scza_record,
                      "%d,%d,%d,%d,%d,%d,",
                      &ptdv_fileRecord_ptr->ssiv_recordNumber,
                      &ptdv_fileRecord_ptr->ssiv_line,
                      &ptdv_fileRecord_ptr->stdv_time.ssiv_day,
                      &ptdv_fileRecord_ptr->stdv_time.ssiv_hour,
                      &ptdv_fileRecord_ptr->stdv_time.ssiv_minute,
                      &ptdv_fileRecord_ptr->stdv_time.ssiv_second );
if ( lsiv_return != 6 )
{
  *psiv_axles_ptr = BAD_RECORD;
  return FALSE;
}

lsiv_return = sscanf ( &scza_record[lsia_field_locations[6]],
                      "%d,",&ptdv_fileRecord_ptr->ssiv_speed );
if ( lsiv_return  != 1 )
{
  ptdv_fileRecord_ptr->ssiv_speed = BAD_SPEED;
r }
for ( lsiv_axle = 0; lsiv_axle < (lsiv_fields-6)/3; lsiv_axle++ )
{
```

```
    if ( ( lsia_field_locations[8+lsiv_axle*3] -
           lsia_field_locations[7+lsiv_axle*3] ) == 1 )
   {
     /* zero width field, last axle has been read */
     *psiv_axles_ptr = lsiv_axle;
     if ( lsiv_axle == MAXIMUM_AXLES )
    {
      return TRUE;
    }
    else
    {
      return FALSE;
    }
   }
    ltdv_axleData_ptr =
                  &ptdv_fileRecord_ptr->stda_axleData[*psiv_last_axle_ptr+1];
    lsiv_return =  read_axle (&scza_record[lsia_field_locations[7+lsiv_axle*3]],
                         ltdv_axleData_ptr );
   if ( lsiv_return == BAD_RECORD )
   {
     *psiv_axles_ptr = BAD_RECORD;
     return FALSE;
   }
    ++*psiv_last_axle_ptr;
  }
  *psiv_axles_ptr = lsiv_axle;
  if ( lsiv_axle == MAXIMUM_AXLES )
  {
   return TRUE;
  }
  else
  {
   return FALSE;
  }
}


int read_axle
(
  char     *pcza_record_ptr,   /* character data               */
  AxleData *ptdv_axleData_ptr  /* structure to return axle data */
)
{
  int lsiv_return;
  float lflv_left;
  float lflv_right;
  float lflv_spacing;

  /* read data for one axle                                  */
  /* left weight, right weight, spacing from this axle to previous axle
*/

  lsiv_return = sscanf ( pcza_record_ptr,"%f,%f,%f,",
                       &lflv_left,&lflv_right,&lflv_spacing );
  if ( lsiv_return != 3 )
```

```
 {
   return BAD_RECORD;
 }
  ptdv_axleData_ptr->sdfv_left    = lflv_left;
  ptdv_axleData_ptr->sdfv_right   = lflv_right;
  ptdv_axleData_ptr->sdfv_spacing = lflv_spacing;
  return 0;
}


int  find_field_locations
(
  char *pcza_record_ptr,       /* character data with comma separated
fields */
  int   psia_field_location[]  /* character positions for start of fields
*/
)
{
  int lsiv_current_character;
  int lsiv_current_field;

  /* find the character position of the start of each field */
  /* first field is field 0  first character position is 0  */

  lsiv_current_field     = 0;
  psia_field_location[0] = 0;
  for ( lsiv_current_character = 0; lsiv_current_character <
RECORD_SIZE;
        lsiv_current_character++ )
 {
   /* look for field separating commas */
   if ( (pcza_record_ptr[lsiv_current_character] == '\n') ||
        (pcza_record_ptr[lsiv_current_character] == '\0') )
   {
     /* end of this record */
     return lsiv_current_field;
   }
   if (  pcza_record_ptr[lsiv_current_character] == ',' )
   {
     /* end of the current field */
     if ( (pcza_record_ptr[lsiv_current_character+1] == '\n') ||
          (pcza_record_ptr[lsiv_current_character+1] == '\0') )
     {
       /* current field is the last non-empty field */
       return lsiv_current_field;
     }
     /* start of new field */
     if (lsiv_current_field >= MAXIMUM_FIELDS )
     {
       return lsiv_current_field;
     }
       psia_field_location[++lsiv_current_field] = lsiv_current_character+1;
   }
 }
  return lsiv_current_field;
```

```
}

void process_record
 (
FileRecord *ptdv_fileRecord_ptr,          /* data to be processed */
int        psiv_first_axle,               /* first axle in array (0 based) */
int        psiv_last_axle                 /* last axle in array (0 based) */
 )
{
 int       lsiv_axles;

 lsiv_axles = psiv_last_axle - psiv_first_axle + 1;
/* if ( lsiv_axles > MAXIMUM_FIELDS-7 )
 {
   printf ( "Record %d has first,last,axles = %d %d %d\n",
           ptdv_fileRecord_ptr->ssiv_recordNumber,psiv_first_axle,
psiv_last_axle,lsiv_axles);
 }*/

 if ( lsiv_axles < 6 )
 {
    print_record ( ptdv_fileRecord_ptr,lsiv_axles );
   return;
 }
 if ( lsiv_axles == 10 )
 {
    print_record ( ptdv_fileRecord_ptr,5 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],5,lsiv_axles );
   lsiv_axles -= 5;
r     print_record ( ptdv_fileRecord_ptr,5 );
   return;
 }
 loop:
 if ( lsiv_axles < 2 )
 {
   if ( lsiv_axles == 1 )
   {
      print_record ( ptdv_fileRecord_ptr,lsiv_axles+100 );
   }
   lsiv_axles = 0;
   return;
 }
 if ( is_it_a_6 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
                SPACING_TEST ) )
 {
    print_record ( ptdv_fileRecord_ptr,6 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],6,lsiv_axles );
   lsiv_axles -= 6;
   goto loop;
 }
 if ( is_it_a_5 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
                SPACING_TEST ) )
 {
    print_record ( ptdv_fileRecord_ptr,5 );
```

```
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],5,lsiv_axles );
   lsiv_axles -= 5;
  goto loop;
}
 if ( is_it_a_4 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
              SPACING_TEST ) )
{
    print_record ( ptdv_fileRecord_ptr,4 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],4,lsiv_axles );
   lsiv_axles -= 4;
  goto loop;
}
 if ( is_it_a_3 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
              SPACING_TEST ) )
{
    print_record ( ptdv_fileRecord_ptr,3 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],3,lsiv_axles );
   lsiv_axles -= 3;
  goto loop;
}
 if ( is_it_a_2 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
              SPACING_TEST ) )
{
    print_record ( ptdv_fileRecord_ptr,2 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],2,lsiv_axles );
   lsiv_axles -= 2;
  goto loop;
}
 if ( is_it_a_6 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
              WEIGHT_TEST ) )
{
    print_record ( ptdv_fileRecord_ptr,6 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],6,lsiv_axles );
   lsiv_axles -= 6;
  goto loop;
}
 if ( is_it_a_5 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
              WEIGHT_TEST ) )
{
    print_record ( ptdv_fileRecord_ptr,5 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],5,lsiv_axles );
   lsiv_axles -= 5;
  goto loop;
}
 if ( is_it_a_4 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
              WEIGHT_TEST ) )
{
    print_record ( ptdv_fileRecord_ptr,4 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],4,lsiv_axles );
   lsiv_axles -= 4;
  goto loop;
}
 if ( is_it_a_3 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
              WEIGHT_TEST ) )
{
```

```
    print_record ( ptdv_fileRecord_ptr,3 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],3,lsiv_axles );
   lsiv_axles -= 3;
   goto loop;
  }
  if ( is_it_a_2 ( &ptdv_fileRecord_ptr->stda_axleData[0],lsiv_axles,
                WEIGHT_TEST ) )
  {
    print_record ( ptdv_fileRecord_ptr,2 );
    shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],2,lsiv_axles );
   lsiv_axles -= 2;
   goto loop;
  }
  if ( lsiv_axles < 2 )
  {
   /* this is going to the error file */
   if ( lsiv_axles == 1 )
   {
     print_record ( ptdv_fileRecord_ptr,lsiv_axles+100 );
   }
   lsiv_axles = 0;
   return;
  }
  print_record ( ptdv_fileRecord_ptr,1+100 );
  shift_axles ( &ptdv_fileRecord_ptr->stda_axleData[0],1,lsiv_axles );
  lsiv_axles -= 1;
  goto loop;
}


void shift_axles
(
  AxleData ptda_axle_record[],
  int      psiv_this_many,
  int      psiv_max
)
{
  int lsiv_i;

  for ( lsiv_i = 0; lsiv_i < psiv_max; lsiv_i++ )
  {
    ptda_axle_record[lsiv_i] =
ptda_axle_record[lsiv_i+psiv_this_many];
  }
  return;
}


int is_it_a_2
(
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
)
{
```

```
 if ( psiv_axles < 2 )
 {
   return FALSE;
 }
 if ( psiv_test == SPACING_TEST )
 {
   if ( ( ( ptda_axle_record[1].sdfv_spacing >= TRACTOR_MIN ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
       ( ( ptda_axle_record[1].sdfv_spacing <= TRACTOR_MAX ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) )  )
   {
    if ( psiv_axles == 2 )
    {
      return TRUE;
    }
     else if ( ( ptda_axle_record[2].sdfv_spacing >=  20 )  || (
ptda_axle_record[2].sdfv_spacing == 0 ) )
    {
      return TRUE;
    }
    else
    {
      return FALSE;
    }
   }
   else
   {
    return FALSE;
   }
 }
 else  if ( psiv_test == WEIGHT_TEST )
 {
   if ( ( ( ( ptda_axle_record[0].sdfv_left  >= TWO_AXLE_MIN )   && (
ptda_axle_record[0].sdfv_left  <= TWO_AXLE_MAX    ) ) &&
         ( ( ptda_axle_record[0].sdfv_right >= TWO_AXLE_MIN )   && (
ptda_axle_record[0].sdfv_right <= TWO_AXLE_MAX    ) )  ) &&
       ( ( ( ptda_axle_record[1].sdfv_left  >= TWO_AXLE_MIN )   && (
ptda_axle_record[1].sdfv_left  <= TWO_AXLE_MAX    ) ) &&
         ( ( ptda_axle_record[1].sdfv_right >= TWO_AXLE_MIN )   && (
ptda_axle_record[1].sdfv_right <= TWO_AXLE_MAX    ) ) ) )
   {
    return TRUE;
   }
   else
   {
    return FALSE;
   }
 }
 else
 {
   return FALSE;
 }
}
```

```
int is_it_a_3
(
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
)
{
  if ( psiv_axles < 3 )
  {
    return FALSE;
  }
  if ( psiv_test == SPACING_TEST )
  {
    if (
         /* 3A */
         ( ( ( ptda_axle_record[1].sdfv_spacing >= TRACTOR_MIN ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
           ( ( ptda_axle_record[1].sdfv_spacing <= TRACTOR_MAX ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
           ( ( ptda_axle_record[2].sdfv_spacing >= TANDEM_MIN  ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) ) &&
           ( ( ptda_axle_record[2].sdfv_spacing <= TANDEM_MAX  ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) )  ) ||
         /* 2s-1 */
         ( ( ( ptda_axle_record[1].sdfv_spacing >= TRACTOR_MIN ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
           ( ( ptda_axle_record[1].sdfv_spacing <= TRACTOR_MAX ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
           ( ( ptda_axle_record[2].sdfv_spacing >= TRAILER     ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) )  ) )
    {
      if ( psiv_axles == 3 )
      {
        return TRUE;
      }
      else if ( ( ptda_axle_record[3].sdfv_spacing >=  20 )  || (
ptda_axle_record[3].sdfv_spacing == 0 ) )
      {
        return TRUE;
      }
      else
      {
        return FALSE;
      }
    }
    else
    {
      return FALSE;
    }
  }
  else  if ( psiv_test == WEIGHT_TEST )
  {
    if ( (
           /* steering axle */
           ( ( ( ptda_axle_record[0].sdfv_left  >= STEER_MIN        ) && (
```

```
ptda_axle_record[0].sdfv_left  <= STEER_MAX          ) ) &&
          ( ( ptda_axle_record[0].sdfv_right >= STEER_MIN          ) && (
ptda_axle_record[0].sdfv_right <= STEER_MAX          ) )  ) &&
        /* 3A  loaded */
         ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_3_AXLE_L_MIN )
&& ( ptda_axle_record[1].sdfv_left  <= DRIVE_3_AXLE_L_MAX ) ) &&
          ( ( ptda_axle_record[1].sdfv_right >= DRIVE_3_AXLE_L_MIN )
&& ( ptda_axle_record[1].sdfv_right <= DRIVE_3_AXLE_L_MAX ) ) &&
          ( ( ptda_axle_record[2].sdfv_left  >= DRIVE_3_AXLE_L_MIN )
&& ( ptda_axle_record[2].sdfv_left  <= DRIVE_3_AXLE_L_MAX ) ) &&
          ( ( ptda_axle_record[2].sdfv_right >= DRIVE_3_AXLE_L_MIN )
&& ( ptda_axle_record[2].sdfv_right <= DRIVE_3_AXLE_L_MAX ) )  ) ||
        /* 3A  empty */
         ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_3_AXLE_E_MIN )
&& ( ptda_axle_record[1].sdfv_left  <= DRIVE_3_AXLE_E_MAX ) ) &&
          ( ( ptda_axle_record[1].sdfv_right >= DRIVE_3_AXLE_E_MIN )
&& ( ptda_axle_record[1].sdfv_right <= DRIVE_3_AXLE_E_MAX ) ) &&
          ( ( ptda_axle_record[2].sdfv_left  >= DRIVE_3_AXLE_E_MIN )
&& ( ptda_axle_record[2].sdfv_left  <= DRIVE_3_AXLE_E_MAX ) ) &&
          ( ( ptda_axle_record[2].sdfv_right >= DRIVE_3_AXLE_E_MIN )
&& ( ptda_axle_record[2].sdfv_right <= DRIVE_3_AXLE_E_MAX ) )  ) ||
        /* 2s-1  loaded */
         ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_3_AXLE_L_MIN )
&& ( ptda_axle_record[1].sdfv_left  <= DRIVE_3_AXLE_L_MAX ) ) &&
          ( ( ptda_axle_record[1].sdfv_right >= DRIVE_3_AXLE_L_MIN )
&& ( ptda_axle_record[1].sdfv_right <= DRIVE_3_AXLE_L_MAX ) ) &&
          ( ( ptda_axle_record[2].sdfv_left  >= TRAILER_L_MIN       ) &&
( ptda_axle_record[2].sdfv_left  <= TRAILER_L_MAX        ) ) &&
          ( ( ptda_axle_record[2].sdfv_right >= TRAILER_L_MIN       )
&& ( ptda_axle_record[2].sdfv_right <= TRAILER_L_MAX        ) )  ) ||
        /* 2s-1  empty */
         ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_3_AXLE_E_MIN )
&& ( ptda_axle_record[1].sdfv_left  <= DRIVE_3_AXLE_E_MAX ) ) &&
          ( ( ptda_axle_record[1].sdfv_right >= DRIVE_3_AXLE_E_MIN )
&& ( ptda_axle_record[1].sdfv_right <= DRIVE_3_AXLE_E_MAX ) ) &&
          ( ( ptda_axle_record[2].sdfv_left  >= TRAILER_E_MIN       ) &&
( ptda_axle_record[2].sdfv_left  <= TRAILER_E_MAX        ) ) &&
          ( ( ptda_axle_record[2].sdfv_right >= TRAILER_E_MIN       )
&& ( ptda_axle_record[2].sdfv_right <= TRAILER_E_MAX        ) ) ) ) )
    {
      return TRUE;
    }
    else
    {
      return FALSE;
    }
  }
  else
  {
    return FALSE;
  }
}


int is_it_a_4
```

```
(
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
)
{
  if ( psiv_axles < 4 )
  {
    return FALSE;
  }
  if ( psiv_test == SPACING_TEST )
  {
    if ( ( ( ( ptda_axle_record[1].sdfv_spacing >= TRACTOR_MIN ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
          ( ( ptda_axle_record[1].sdfv_spacing <= TRACTOR_MAX ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
          ( ( ptda_axle_record[2].sdfv_spacing >= TANDEM_MIN  ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) ) &&
          ( ( ptda_axle_record[2].sdfv_spacing <= TANDEM_MAX  ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) ) &&
          ( ( ptda_axle_record[3].sdfv_spacing >= TRAILER     ) || (
ptda_axle_record[3].sdfv_spacing == 0 ) )   ) ||
        ( ( ( ptda_axle_record[1].sdfv_spacing >= TRACTOR_MIN ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
          ( ( ptda_axle_record[1].sdfv_spacing <= TRACTOR_MAX ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
          ( ( ptda_axle_record[2].sdfv_spacing >= TRAILER     ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) ) &&
          ( ( ptda_axle_record[3].sdfv_spacing >= TANDEM_MIN  ) || (
ptda_axle_record[3].sdfv_spacing == 0 ) ) &&
          ( ( ptda_axle_record[3].sdfv_spacing <= TANDEM_MAX  ) || (
ptda_axle_record[3].sdfv_spacing == 0 ) )   ) )
    {
      if ( psiv_axles == 4 )
      {
        return TRUE;
      }
      else if ( ( ptda_axle_record[4].sdfv_spacing >=  20 ) || (
ptda_axle_record[4].sdfv_spacing == 0 ) )
      {
        return TRUE;
      }
      else
      {
        return FALSE;
      }
    }
    else
    {
      return FALSE;
    }
  }
  else  if ( psiv_test == WEIGHT_TEST )
  {
    if ( ( ( ( ( ptda_axle_record[0].sdfv_left  >= STEER_MIN )     && (
```

```
ptda_axle_record[0].sdfv_left  <= STEER_MAX     ) ) &&
          ( ( ptda_axle_record[0].sdfv_right >= STEER_MIN )    && (
ptda_axle_record[0].sdfv_right <= STEER_MAX     ) )  ) &&
        ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_L_MIN )  && (
ptda_axle_record[1].sdfv_left  <= DRIVE_L_MAX    ) ) &&
          ( ( ptda_axle_record[1].sdfv_right >= DRIVE_L_MIN )   && (
ptda_axle_record[1].sdfv_right <= DRIVE_L_MAX    ) ) &&
          ( ( ptda_axle_record[2].sdfv_left  >= DRIVE_L_MIN )  && (
ptda_axle_record[2].sdfv_left  <= DRIVE_L_MAX    ) ) &&
          ( ( ptda_axle_record[2].sdfv_right >= DRIVE_L_MIN )   && (
ptda_axle_record[2].sdfv_right <= DRIVE_L_MAX    ) ) &&
          ( ( ptda_axle_record[3].sdfv_left  >= TRAILER_L_MIN ) && (
ptda_axle_record[3].sdfv_left  <= TRAILER_L_MAX ) ) &&
          ( ( ptda_axle_record[3].sdfv_right >= TRAILER_L_MIN ) && (
ptda_axle_record[3].sdfv_right <= TRAILER_L_MAX ) )  ) ||
        ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_E_MIN )   && (
ptda_axle_record[1].sdfv_left  <= DRIVE_E_MAX    ) ) &&
          ( ( ptda_axle_record[1].sdfv_right >= DRIVE_E_MIN )   && (
ptda_axle_record[1].sdfv_right <= DRIVE_E_MAX    ) ) &&
          ( ( ptda_axle_record[2].sdfv_left  >= DRIVE_E_MIN )   && (
ptda_axle_record[2].sdfv_left  <= DRIVE_E_MAX    ) ) &&
          ( ( ptda_axle_record[2].sdfv_right >= DRIVE_E_MIN )   && (
ptda_axle_record[2].sdfv_right <= DRIVE_E_MAX    ) ) &&
          ( ( ptda_axle_record[3].sdfv_left  >= TRAILER_E_MIN ) && (
ptda_axle_record[3].sdfv_left  <= TRAILER_E_MAX ) ) &&
          ( ( ptda_axle_record[3].sdfv_right >= TRAILER_E_MIN ) && (
ptda_axle_record[3].sdfv_right <= TRAILER_E_MAX ) )  ) ||
        ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_L_MIN )   && (
ptda_axle_record[1].sdfv_left  <= DRIVE_L_MAX    ) ) &&
          ( ( ptda_axle_record[1].sdfv_right >= DRIVE_L_MIN )   && (
ptda_axle_record[1].sdfv_right <= DRIVE_L_MAX    ) ) &&
          ( ( ptda_axle_record[2].sdfv_left  >= TRAILER_L_MIN ) && (
ptda_axle_record[2].sdfv_left  <= TRAILER_L_MAX ) ) &&
          ( ( ptda_axle_record[2].sdfv_right >= TRAILER_L_MIN ) && (
ptda_axle_record[2].sdfv_right <= TRAILER_L_MAX ) ) &&
          ( ( ptda_axle_record[3].sdfv_left  >= TRAILER_L_MIN ) && (
ptda_axle_record[3].sdfv_left  <= TRAILER_L_MAX ) ) &&
          ( ( ptda_axle_record[3].sdfv_right >= TRAILER_L_MIN ) && (
ptda_axle_record[3].sdfv_right <= TRAILER_L_MAX ) )  ) ||
        ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_E_MIN )   && (
ptda_axle_record[1].sdfv_left  <= DRIVE_E_MAX    ) ) &&
          ( ( ptda_axle_record[1].sdfv_right >= DRIVE_E_MIN )   && (
ptda_axle_record[1].sdfv_right <= DRIVE_E_MAX    ) ) &&
          ( ( ptda_axle_record[2].sdfv_left  >= TRAILER_E_MIN ) && (
ptda_axle_record[2].sdfv_left  <= TRAILER_E_MAX ) ) &&
          ( ( ptda_axle_record[2].sdfv_right >= TRAILER_E_MIN ) && (
ptda_axle_record[2].sdfv_right <= TRAILER_E_MAX ) ) &&
          ( ( ptda_axle_record[3].sdfv_left  >= TRAILER_E_MIN ) && (
ptda_axle_record[3].sdfv_left  <= TRAILER_E_MAX ) ) &&
          ( ( ptda_axle_record[3].sdfv_right >= TRAILER_E_MIN ) && (
ptda_axle_record[3].sdfv_right <= TRAILER_E_MAX ) ) ) ) )
  {
    return TRUE;
  }
  else
```

```
    {
      return FALSE;
    }
  }
  else
  {
    return FALSE;
  }
}


int is_it_a_5
(
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
)
{
  if ( psiv_axles < 5 )
  {
    return FALSE;
  }
  if ( psiv_test == SPACING_TEST )
  {
    if ( ( ( ptda_axle_record[1].sdfv_spacing >= TRACTOR_MIN ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[1].sdfv_spacing <= TRACTOR_MAX ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[2].sdfv_spacing >= TANDEM_MIN  ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[2].sdfv_spacing <= TANDEM_MAX  ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[3].sdfv_spacing >= TRAILER     ) || (
ptda_axle_record[3].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[4].sdfv_spacing >= TANDEM_MIN  ) || (
ptda_axle_record[4].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[4].sdfv_spacing <= TANDEM_MAX  ) || (
ptda_axle_record[4].sdfv_spacing == 0 ) )   )
    {
      if ( psiv_axles == 5 )
      {
        return TRUE;
      }
      else if  ( ( ptda_axle_record[5].sdfv_spacing >=  7 ) || (
ptda_axle_record[5].sdfv_spacing == 0 ) )
      {
        return TRUE;
      }
      else
      {
        return FALSE;
      }
    }
    else
    {
```

```
    return FALSE;
   }
  }
  else  if ( psiv_test == WEIGHT_TEST )
  {
    if ( ( ( ( ( ptda_axle_record[0].sdfv_left  >= STEER_MIN )     && (
ptda_axle_record[0].sdfv_left  <= STEER_MAX     ) ) &&
            ( ( ptda_axle_record[0].sdfv_right >= STEER_MIN )     && (
ptda_axle_record[0].sdfv_right <= STEER_MAX     ) )  ) &&
          ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_L_MIN )   && (
ptda_axle_record[1].sdfv_left  <= DRIVE_L_MAX   ) ) &&
            ( ( ptda_axle_record[1].sdfv_right >= DRIVE_L_MIN )   && (
ptda_axle_record[1].sdfv_right <= DRIVE_L_MAX   ) ) &&
            ( ( ptda_axle_record[2].sdfv_left  >= DRIVE_L_MIN )   && (
ptda_axle_record[2].sdfv_left  <= DRIVE_L_MAX   ) ) &&
            ( ( ptda_axle_record[2].sdfv_right >= DRIVE_L_MIN )   && (
ptda_axle_record[2].sdfv_right <= DRIVE_L_MAX   ) ) &&
            ( ( ptda_axle_record[3].sdfv_left  >= TRAILER_L_MIN ) && (
ptda_axle_record[3].sdfv_left  <= TRAILER_L_MAX ) ) &&
            ( ( ptda_axle_record[3].sdfv_right >= TRAILER_L_MIN ) && (
ptda_axle_record[3].sdfv_right <= TRAILER_L_MAX ) ) &&
            ( ( ptda_axle_record[4].sdfv_left  >= TRAILER_L_MIN ) && (
ptda_axle_record[4].sdfv_left  <= TRAILER_L_MAX ) ) &&
            ( ( ptda_axle_record[4].sdfv_right >= TRAILER_L_MIN ) && (
ptda_axle_record[4].sdfv_right <= TRAILER_L_MAX ) )  ) ||
          ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_E_MIN )   && (
ptda_axle_record[1].sdfv_left  <= DRIVE_E_MAX   ) ) &&
            ( ( ptda_axle_record[1].sdfv_right >= DRIVE_E_MIN )   && (
ptda_axle_record[1].sdfv_right <= DRIVE_E_MAX   ) ) &&
            ( ( ptda_axle_record[2].sdfv_left  >= DRIVE_E_MIN )   && (
ptda_axle_record[2].sdfv_left  <= DRIVE_E_MAX   ) ) &&
            ( ( ptda_axle_record[2].sdfv_right >= DRIVE_E_MIN )   && (
ptda_axle_record[2].sdfv_right <= DRIVE_E_MAX   ) ) &&
            ( ( ptda_axle_record[3].sdfv_left  >= TRAILER_E_MIN ) && (
ptda_axle_record[3].sdfv_left  <= TRAILER_E_MAX ) ) &&
            ( ( ptda_axle_record[3].sdfv_right >= TRAILER_E_MIN ) && (
ptda_axle_record[3].sdfv_right <= TRAILER_E_MAX ) ) &&
            ( ( ptda_axle_record[4].sdfv_left  >= TRAILER_E_MIN ) && (
ptda_axle_record[4].sdfv_left  <= TRAILER_E_MAX ) ) &&
            ( ( ptda_axle_record[4].sdfv_right >= TRAILER_E_MIN ) && (
ptda_axle_record[4].sdfv_right <= TRAILER_E_MAX ) ) ) ) )
    {
      return TRUE;
    }
    else
    {
      return FALSE;
    }
  }
  else
  {
    return FALSE;
  }
}
```

```
int is_it_a_6
(
  AxleData ptda_axle_record[],
  int      psiv_axles,
  int      psiv_test
)
{
 if ( psiv_axles < 6 )
 {
   return FALSE;
 }
 if ( psiv_test == SPACING_TEST )
 {
   if ( ( ( ptda_axle_record[1].sdfv_spacing >= TRACTOR_MIN ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[1].sdfv_spacing <= TRACTOR_MAX ) || (
ptda_axle_record[1].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[2].sdfv_spacing >= TANDEM_MIN  ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[2].sdfv_spacing <= TANDEM_MAX  ) || (
ptda_axle_record[2].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[3].sdfv_spacing >= TRAILER     ) || (
ptda_axle_record[3].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[4].sdfv_spacing >= TANDEM_MIN  ) || (
ptda_axle_record[4].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[4].sdfv_spacing <= TANDEM_MAX  ) || (
ptda_axle_record[4].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[5].sdfv_spacing >= TANDEM_MIN  ) || (
ptda_axle_record[5].sdfv_spacing == 0 ) ) &&
        ( ( ptda_axle_record[5].sdfv_spacing <= TANDEM_MAX  ) || (
ptda_axle_record[5].sdfv_spacing == 0 ) )   )
   {
     if ( psiv_axles == 6 )
     {
       return TRUE;
     }
      else if  ( ( ptda_axle_record[6].sdfv_spacing >= 20 ) || (
ptda_axle_record[6].sdfv_spacing == 0 ) )
     {
       return TRUE;
     }
     else
     {
       return FALSE;
     }
   }
   else
   {
     return FALSE;
   }
 }
 else  if ( psiv_test == WEIGHT_TEST )
 {
```

```
    if ( ( ( ( ( ptda_axle_record[0].sdfv_left  >= STEER_MIN )     && (
ptda_axle_record[0].sdfv_left  <= STEER_MAX      ) ) &&
           ( ( ptda_axle_record[0].sdfv_right >= STEER_MIN )     && (
ptda_axle_record[0].sdfv_right <= STEER_MAX      ) )  ) &&
         ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_L_MIN )   && (
ptda_axle_record[1].sdfv_left  <= DRIVE_L_MAX    ) ) &&
           ( ( ptda_axle_record[1].sdfv_right >= DRIVE_L_MIN )   && (
ptda_axle_record[1].sdfv_right <= DRIVE_L_MAX    ) ) &&
           ( ( ptda_axle_record[2].sdfv_left  >= DRIVE_L_MIN )   && (
ptda_axle_record[2].sdfv_left  <= DRIVE_L_MAX    ) ) &&
           ( ( ptda_axle_record[2].sdfv_right >= DRIVE_L_MIN )   && (
ptda_axle_record[2].sdfv_right <= DRIVE_L_MAX    ) ) &&
           ( ( ptda_axle_record[3].sdfv_left  >= TRAILER_L_MIN ) && (
ptda_axle_record[3].sdfv_left  <= TRAILER_L_MAX ) ) &&
           ( ( ptda_axle_record[3].sdfv_right >= TRAILER_L_MIN ) && (
ptda_axle_record[3].sdfv_right <= TRAILER_L_MAX ) ) &&
           ( ( ptda_axle_record[4].sdfv_left  >= TRAILER_L_MIN ) && (
ptda_axle_record[4].sdfv_left  <= TRAILER_L_MAX ) ) &&
           ( ( ptda_axle_record[4].sdfv_right >= TRAILER_L_MIN ) && (
ptda_axle_record[4].sdfv_right <= TRAILER_L_MAX ) ) &&
           ( ( ptda_axle_record[5].sdfv_left  >= TRAILER_L_MIN ) && (
ptda_axle_record[5].sdfv_left  <= TRAILER_L_MAX ) ) &&
           ( ( ptda_axle_record[5].sdfv_right >= TRAILER_L_MIN ) && (
ptda_axle_record[5].sdfv_right <= TRAILER_L_MAX ) ) ) ||
         ( ( ( ptda_axle_record[1].sdfv_left  >= DRIVE_E_MIN )   && (
ptda_axle_record[1].sdfv_left  <= DRIVE_E_MAX    ) ) &&
           ( ( ptda_axle_record[1].sdfv_right >= DRIVE_E_MIN )   && (
ptda_axle_record[1].sdfv_right <= DRIVE_E_MAX    ) ) &&
           ( ( ptda_axle_record[2].sdfv_left  >= DRIVE_E_MIN )   && (
ptda_axle_record[2].sdfv_left  <= DRIVE_E_MAX    ) ) &&
           ( ( ptda_axle_record[2].sdfv_right >= DRIVE_E_MIN )   && (
ptda_axle_record[2].sdfv_right <= DRIVE_E_MAX    ) ) &&
           ( ( ptda_axle_record[3].sdfv_left  >= TRAILER_E_MIN ) && (
ptda_axle_record[3].sdfv_left  <= TRAILER_E_MAX ) ) &&
           ( ( ptda_axle_record[3].sdfv_right >= TRAILER_E_MIN ) && (
ptda_axle_record[3].sdfv_right <= TRAILER_E_MAX ) ) &&
           ( ( ptda_axle_record[4].sdfv_left  >= TRAILER_E_MIN ) && (
ptda_axle_record[4].sdfv_left  <= TRAILER_E_MAX ) ) &&
           ( ( ptda_axle_record[4].sdfv_right >= TRAILER_E_MIN ) && (
ptda_axle_record[4].sdfv_right <= TRAILER_E_MAX ) ) &&
           ( ( ptda_axle_record[5].sdfv_left  >= TRAILER_E_MIN ) && (
ptda_axle_record[5].sdfv_left  <= TRAILER_E_MAX ) ) &&
           ( ( ptda_axle_record[5].sdfv_right >= TRAILER_E_MIN ) && (
ptda_axle_record[5].sdfv_right <= TRAILER_E_MAX ) ) ) ) )
    {
      return TRUE;
    }
    else
    {
      return FALSE;
    }
  }
  else
  {
    return FALSE;
```

```
 }
}


void print_record
 (
FileRecord *ptdv_fileRecord_ptr,
int psiv_axles
 )
{
 FILE      *file_ptr;
  AxleData  *ltda_axleData_ptr;
 int       lsiv_i;
 if ( psiv_axles >= 100 )
 {
   psiv_axles -=100;
   file_ptr = error_file_ptr;
 }
 else
 {
   if ( ptdv_fileRecord_ptr->ssiv_line == 1 )
   {
      file_ptr = output1_file_ptr;
   }
   else
   {
      file_ptr = output2_file_ptr;
   }
   gsiv_vehicles += 1;
 }
  fprintf ( file_ptr,"%d,%d,%d,%d,%d,%d,%d",
           ptdv_fileRecord_ptr->ssiv_recordNumber,
           ptdv_fileRecord_ptr->ssiv_line,
           ptdv_fileRecord_ptr->stdv_time.ssiv_day,
           ptdv_fileRecord_ptr->stdv_time.ssiv_hour,
           ptdv_fileRecord_ptr->stdv_time.ssiv_minute,
           ptdv_fileRecord_ptr->stdv_time.ssiv_second,
          ptdv_fileRecord_ptr->ssiv_speed );
 for ( lsiv_i = 0; lsiv_i <= psiv_axles -1; lsiv_i++)
 {
    ltda_axleData_ptr = &ptdv_fileRecord_ptr->stda_axleData[lsiv_i];
    fprintf (file_ptr,",%.1f",(float)ltda_axleData_ptr->sdfv_left);
    fprintf (file_ptr,",%.1f",(float)ltda_axleData_ptr->sdfv_right);
    fprintf (file_ptr,",%.1f",(float)ltda_axleData_ptr->sdfv_spacing);
 }
 fprintf ( file_ptr,"\n" );
}
```