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16. Abstract

The current AASHTO Guide for the Design of Pavement Structures was derived from the large-scale Road Test conducted by AASHTO in the 1950s. Being empirical in nature, the AASHTO pavement design guide reflects only the truck technology prevalent at the AASHTO Road Test. However, truck technology has advanced in many areas since the AASHTO Road Test. In that road test, average tire pressures of 75 to 80 psi were used, and the tires were of bias-ply construction. However, trucks today are normally operated with tire pressures of about 100 psi, and radial tires have essentially replaced bias-ply tires as the commonly used tire types. Moreover, in response to the increased trucking loads, a new truck fleet with different truck classes, new axle configurations, different axle spacings, different tire widths, and new truck suspension systems has emerged. To characterize the current truck configurations on Texas highways, in late 1999 and early 2000, a truck survey was conducted on major trucking routes throughout Texas. In this report, the newly collected truck configuration data are analyzed and presented. Mathematical models and theories employed for the survey design and data analysis are introduced. In-depth analysis of truck tire pressure is also conducted to identify the significant factors affecting tire pressures. Findings and conclusions based on the data analysis are presented.

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STUDY OF CURRENT TRUCK CONFIGURATIONS

by

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Research Report Number 0-1862-1

Research Project 0-1862
Synthesis Study of Current Truck Configurations Used in Texas

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION

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by the

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THE UNIVERSITY OF TEXAS AT AUSTIN

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IMPLEMENTATION

The data and predictive relationships presented and derived through this study can be immediately used by Texas Department of Transportation Pavement Design personnel. They provide reliable characterization of truck suspension configurations and, especially, tire pressures. The temperature–pressure relationship provides a means of assessing tire pressure change with ambient air temperatures.

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

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DISCLAIMERS

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SUMMARY

The current AASHTO Guide for the Design of Pavement Structures was derived from the large-scale Road Test conducted by AASHTO in the 1950s. Being empirical in nature, the AASHTO pavement design guide reflects only the truck technology prevalent at the AASHTO Road Test. However, truck technology has advanced in many areas since the AASHTO Road Test. In that road test, average tire pressures of 75 to 80 psi were used, and the tires were of bias-ply construction. However, trucks today are normally operated with tire pressures of about 100 psi, and radial tires have essentially replaced bias-ply tires as the commonly used tire types. Moreover, in response to the increased trucking loads, a new truck fleet with different truck classes, new axle configurations, different axle spacings, different tire widths, and new truck suspension systems has emerged. To characterize the current truck configurations on Texas highways, in late 1999 and early 2000, a truck survey was conducted on major trucking routes throughout Texas. In this report, the newly collected truck configuration data are analyzed and presented. Mathematical models and theories employed for the survey design and data analysis are introduced. In-depth analysis of truck tire pressure is also conducted to identify the significant factors affecting tire pressures. Findings and conclusions based on the data analysis are presented.

CHAPTER 1 INTRODUCTION

This study is expected to fulfill two interrelated research tasks: 1) to determine truck configurations, especially tire pressure values currently used by trucks traveling Texas highways; and 2) to identify the factors that differentiate truck fleet configurations in Texas. Obviously, research results addressing the above two questions will lead to a better understanding of current truck effects on pavements.

The current AASHTO Guide for the Design of Pavement Structures was derived from the large-scale Road Test conducted by AASHTO in the 1950s. Being empirical in nature, the AASHTO pavement design guide reflects only the truck technology prevalent at the AASHTO Road Test. However, truck technology has advanced in many areas since the AASHTO Road Test. In that road test, average tire pressures of 75 to 80 psi were used, and tires were of bias-ply construction. However, trucks today are normally operated with tire pressure of about 100 psi in some cases with tire pressures as high as 130 to 145 psi and radial-ply tires have essentially replaced bias-ply tires. Moreover, new truck axle configurations have emerged, with different tandem/tri-tandem axle usage, different axle spacings, different tire widths, and new truck suspension systems, which were not present at the AASHTO Road Test.

To characterize truck configurations on Texas highways, a survey on major trucking routes throughout Texas was designed to determine the distributions of tire usage, axle configurations, tire pressures, and other associated information. A survey plan was designed to produce a sample which was representative of all trucks traveling Texas highways and to guarantee accurate truck parameter estimation. In addition to providing accurate estimation of parameter means, the proposed survey also identified factors affecting the parameters of interest. It was assumed that the distribution of different commodity categories, the existence of NAFTA trucking corridors, and the presence of a large number of Mexican trucks in the border areas contributed to the differences in truck configurations. Comparisons of truck configurations, highway classes and directions, and commodity categories among different Texas areas constituted a major research task.

This report consists of eight chapters. In Chapter 1, “Introduction,” general introductions are given to both the research study and the report itself. Chapter 2, "Literature Review," justifies the research approach by providing relevant background information and citing previous research studies. Chapter 3, "Survey Design," introduces the survey plan design and presents the basic mathematical theories and models associated with the designed survey plan. Chapter 4, "Data Collection," briefly describes the whole data collection process, from the preparation to the execution of the designed survey. The collected truck data are processed and presented in Chapter 5, "Survey Results." In Chapter 6, "Analysis of Tire Pressure and Related Data," truck tire pressure data are analyzed in depth to identify tire pressure differences among geographic regions and vehicle classes. Chapter 7, "Relevant Studies," is a complement to Chapter 6 and presents more analysis related to tire pressure characteristics. Findings and conclusions based on the collected data and the data analysis are presented in Chapter 8.

CHAPTER 2 LITERATURE REVIEW

As mentioned in Chapter 1, the AASHTO Road Test in the 1950s established standards and equations for evaluating pavement performance. Although the established standards and equations are still being used in pavement design, many research studies have raised questions about the validity of the standards and equations, arguing that current truck technology has already differed from that of the AASHTO Road Test. In this chapter, the basic concepts of ESAL and EALF derived from the AASHTO Road Test are introduced. New changes and variations in truck technology are described, and truck technology surveys conducted by previous researchers are summarized.

ESAL AND EALF

Among all the factors that affect the condition and performance of pavements, the number of axle loads to which the pavements are subjected is the most important. Clearly, the accurate prediction of truck traffic is very important to the design of new pavements and the maintenance and rehabilitation of existing pavements. To represent various loading groups, the concept of equivalent single-axle loads (ESALs), as shown in Equation (1), is used to measure the effects of the axle loads on pavements (Huang, 1993). In Equation (1), m is the number of axle load groups, F_i is the equivalent axle load factor (EALF) for the i-th axle load group, and n_i is the number of passes of the i-th axle load group during the design life.

$$ESAL = \sum_{i=1}^{m} F_i n_i \qquad \text{(Eq. 1)}$$

The American Association of State Highway and Transportation Officials (AASHTO) conducted a large-scale road test in the 1950s and provided sets of ESAL values for single and tandem axles on various types of pavements. In 1972 empirical EALF equations were developed from the AASHTO Road Test data for single and tandem axles. In 1986 the empirical EALF equations were extended to tri-tandem axles.

The EALF regression models developed by AASHTO for flexible pavements are shown in Equations (2) and (3), in which W_{tx} is the number of x-axle load applications at the end of time t; W_{t18} is the number of 18 kip single-axle load applications until time t; L_x is the load in kip on one single axle, or one set of tandem axles, or one set of tri-tandem axles; L_2 is the axle code, 1 for single axle, 2 for tandem axles, and 3 for tri-tandem axles; SN is the structural number, which is a function of pavement structure; p_t is the terminal serviceability, which indicates the pavement conditions to be considered as failures; G_t is a function of p_t; and β_{18} is the value of β_x when L_x is equal to 18 and L_2 is equal to 1.

$$EALF = \frac{W_{t18}}{W_{tx}} \qquad \text{(Eq. 2)}$$

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79\log(19) - 4.79\log(L_x + L_2) + 4.33\log L_2 + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}} \qquad \text{(Eq. 3a)}$$

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right) \qquad \text{(Eq. 3b)}$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(SN+1)^{5.19} L_2^{3.23}} \qquad \text{(Eq. 3c)}$$

Obviously, pavement behavior and performance are closely related to the interactions between trucks and pavements, and therefore the above ESAL and EALF equations reflect the truck technology of the AASHTO Road Test in the 1950s. Naturally, the validity of these equations would be questioned when one takes into consideration both the changes and the variations in truck technology over the past 50 years.

CHANGES IN TRUCK CONFIGURATIONS

Because fuel cost per mile traveled does not vary proportionately with the weights of trucks, economic incentives often exceed the costs of overweighing in the minds of truckers and therefore have contributed to the increase in the average gross weight of trucks. As a result, since the AASHTO Road Test, the limits for axle weights have been increased from 18 kip to 20 kip for single axles and from 32 kip to 34 kip for tandem axles. Gross weights have increased from 73.28 kip to 80 kip, and dual trailer trucks (limited to 80 kip) have been permitted to operate nationwide (TxDOT, 1996). Along with the increase in axle weight limits, a truck fleet with new technology, which was not present at the AASHTO Road Test, has emerged (Ford et al., 1990; Sebaaly; 1992; and Yi et al., 1992).

Current flexible pavement designs are still based on the above ESAL and EALF models. However, truck technology has advanced in many areas since the AASHTO Road Test. Most importantly, the following concerns about the validity of the ESAL values have risen because of advances in truck technology:

1) Changes in the tires. In the AASHTO Road Test, all truck tires were of bias-ply construction. However, because they can endure higher trucking loads with better fuel mileages, radial-ply, heavy-duty truck tires now dominate the line-haul tire market share. Radial-ply tires usually have higher inflation pressures than bias-ply tires. In the AASHTO Road Test, tire pressures of 75 to 80 psi were used. However, trucks today are normally operated with tire pressures of about 100 psi, and in some cases with tire pressures as high as 130 to 145 psi (Yap, 1988; Tielking et al., 1994; and Hansen et al., 1989). Experimental results have shown that the bias-ply tire generates lower peak contact pressures than the radial-ply tire, approximately 12 percent less at the steering axles and 26 percent less at drive/trailer axles; therefore, the bias-ply tire also has less average contact pressure than the radial-ply tire (Ford et al., 1990). Furthermore, tires of new sizes are coming into use. The wide-base "super single" tires offer potential benefits affecting operating costs by providing greater payload to weight capability because of the reduction in the number of tires or wheels required and the improved fuel economy. However, the super singles' adverse effect on the pavement is the reduction in contact area and the increase in contact pressure. Experiments show that for a 17,000 lb axle load, the contact area under a 385/65R22.5 is 24 percent less than that of an 11R24.5 dual-tire assembly (Ford et al., 1990).

2) Changes in axle assembly. Deviations from the axle settings used in the AASHTO Road Test would make the EALF equations problematic. Therefore, information on current tandem and tri-tandem axle usage and axle spacing could be useful. Furthermore, trucks equipped with new suspension designs have also emerged. Leaf-spring suspensions are still widely used in today's commercial vehicles, but provide a rougher ride than air-spring suspensions. As a result of load leveling adjustments, careful cargo treatment, and better ride comfort, the air-spring suspension has become

more and more popular (Schonfeld et al., 1991). Dynamic tire force can cause severe pavement distress. Studies have shown that pavement stress may be increased by 159 percent because of the dynamic tire force in a leaf-spring suspension but only 82 percent with an air-spring suspension (Yi et al., 1992).

Clearly, along with the new technologies employed by the trucking industry, trucks today are significantly different from those of the 1950s. The increased trucking weight is one of the most important factors that led to the changes in truck technology over the past 50 years. However, trucks may be quite different from one another in terms of truck technology even within the same time period. As a matter of fact, there are many other factors that contribute to variations among trucks.

VARIATION OF TRUCK CONFIGURATIONS

Apart from the elevated axle load limits, many other factors may have contributed to variations in trucking configurations. Therefore, in addition to the primary research objectives of determining configurations of the truck fleet, the survey will address secondary research issues:

1) The road factor. Characteristics of trucks operating on highways in different geographical areas, in different highway classes, and in different highway directions are thought to be different from each other. A certain geographical area is generally characterized by the production and transportation of goods that are special to that area. Interstate highways are usually accessible to long-haul transports, while non-interstate highways usually serve local and short-distance transports. Even on the same highway, trucks traveling in opposite directions may differ from one another because of the existence of different cargo transportation patterns.

2) The border area factor. Of all the southern states, the state of Texas shares the longest land border with Mexico. El Paso, Laredo, and Brownsville are among the busiest ports in U.S.-Mexico border crossings and truck shipments (McCray et al., 1999). The presence of a large number of Mexican trucks in these border areas may have resulted in the difference between the truck fleet near the border areas and those trucks in other parts of the state. Again, information on the technology of the truck fleet in the border areas is also desirable for future pavement design considerations.

3) Commodity effects. It has been suspected that the commodities carried by trucks also have effects on the change of truck technology (Roberts et al., 1986). Possible relations between the commodity category and the truck technology are of special interest to this project.

4) The trucking corridor factor. It has been believed that the North American Free Trade Agreement (NAFTA) and the growth of trade among the U.S., Mexico, and Canada has resulted in the development of well-defined NAFTA truck highway corridors in the U.S. (McCray et al., 1999). These highway corridors are formed by trucks carrying products to and from major ports along the U.S.-Mexico and U.S.-Canada borders. Of course, future pavement designs will benefit from a good understanding of patterns of the truck technology associated with these trucking corridors.

Even though the importance of advances in truck technology and their impact on pavement design are well recognized, there are so far no reliable data that can accurately represent these changes in the truck population operating on Texas highways. Currently, efforts have been made under a TxDOT research project to investigate the validity of the 18 kip load equivalency concept because of the changes in truck technology. However, the real impacts that these changes have on Texas pavements cannot be properly evaluated if there are no accurate data about the distribution of tire types, axle configurations, suspension systems, and tire pressures for trucks operating on Texas highways. Therefore, there is an urgent need to conduct surveys on major trucking routes throughout Texas to determine the distribution of current truck configurations.

PREVIOUS SURVEYS

Several previous surveys of truck tire inflation pressure have been conducted since the 1980s. Roberts et al. conducted a tire pressure survey in Texas in 1982 and developed a finite element model of tires to estimate stress and strain in pavements when the tire is loaded and inflated to different air pressures. Bartholomev surveyed truck tire pressures in Colorado in 1986 and related the survey results to Asphalt Concrete Pavement mix design. Kim et al. made a tire pressure survey in Oregon in 1986 and examined the immediate pavement response using a four-layer linear model. In 1991, Elliott et al. conducted a survey of truck tire pressures in Arkansas and studied the effects of increased tire pressures on pavements by examining the distribution of tire-pavement contact pressures.

It is noticeable that none of the above surveys was aimed at truck configurations; they all were aimed only at tire pressures. Also noticeable is the fact that almost no documented research effort has been made to study the factors affecting the variability of truck configurations. Actually, almost no results from factorial experiment design and sample design could be retrieved from previous studies.

In summary, the proposed survey of trucks traveling Texas highways should consist of the following parameters, under the titles of "Primary research parameters" and "Secondary research parameters," respectively. Other relevant information, such as survey location, vehicle registration, and temperatures should also be included in the proposed survey plan.

- **Primary research parameters**
  1. Composition of truck types
  2. Composition of truck suspension types
  3. Composition of tire types
  4. Distribution of tire pressures
  5. Distribution of tire sizes
  6. Distribution of axle spacings

- **Secondary research parameters**
  1. Truck trip origin/destination information
  2. Commodity category information
  3. Geographic information
  4. Highway class and direction information

With the parameters of interest determined, the proposed truck configuration survey was loaded with multiple survey parameters. As one of the major parameters to be surveyed for the study, tire pressure was included in the proposed truck configuration survey. Tire pressure was treated as most important among all the parameters of interest for the following two reasons.

1) Like increased truck weights, sizes, wheel loads, and axle loads, increased tire pressures are among the key loading factors that have been identified as contributing to accelerated pavement damage. Truck tire pressure is an important factor in pavement deterioration in new pavement and rehabilitation design (Pezo et al., 1989).

2) Research results of previous tire pressure surveys can serve as guidance to the proposed truck configuration survey. Variance estimates of previous tire pressure surveys can be used to determine the sample size for the proposed truck configuration survey.

SUMMARY

Therefore, a survey of truck configurations is justified for the state of Texas to have an accurate estimation of current truck technologies and to understand the factors affecting the changes and variations in truck technologies in the state. Through literature reviews, all the survey parameters have been determined, and a major design parameter, tire pressure, has been selected from the survey parameters. Naturally, the next step is the design of the survey for the parameter data to be collected, and that will be detailed in Chapter 3.

CHAPTER 3 SURVEY DESIGN

Characterizing current truck configurations and identifying underlying factors affecting the variations in Texas truck configurations constitute the two main research tasks. The survey plan was designed to fulfill these two tasks. In this chapter, sampling techniques are proposed to improve the sampling accuracy and efficiency and to minimize survey costs. In coincidence with the sampling design, a factorial experiment design is proposed to detect significant factors causing variations in the truck configurations. Sample size design, as well as equations and models associated with the survey design and employed to conduct data analysis, is discussed.

SELECTION OF DATA COLLECTION SITES

All trucks traveling on Texas highways constitute the population. The sampling process is to draw trucks from the traffic stream without interfering with other traffic; enforce complete stops of selected trucks at an available parking place; and conduct the required data collection. The weigh stations of the License and Weight Division of the Texas Department of Public Safety (DPS), located on various Texas highways, are the most ideal sites to perform data collections because the DPS officers working in the stations can enforce the truck stops. Meanwhile, facilities for signaling, weighing, and parking are available at the stations. The most reasonable way of collecting truck data is to work together with officers at the DPS weigh stations.

A stratified sampling method is better than a simple random sampling method for two reasons: 1) Generally speaking, stratified sampling tends to give a sample estimate with a smaller estimator variance than that of a simple random sampling. 2) If assumptions for the stratified method do not hold in reality, the stratified method will degrade at worst to a simple random method (Lohr, 1999).

It is believed that production and transportation of commodities are related to truck configuration and that, therefore, it would be reasonable to stratify the population according to the major commodity production structure and transportation pattern in each area. For practical purposes, the following factors are considered in population stratification: 1) Each stratum should be a geographical area that represents the production of certain major goods and certain transportation patterns; 2) To differentiate from other neighboring strata, a sampling stratum should have distinctly different production and transportation centers.

Because of the difficulty involved in obtaining county-level Texas commodity data, the data of "County Earnings, Total 1990" and "County Earnings, Percent Good-Related, Total 1990" (Geostat, 1994) were used to stratify Texas into six regions. The six Texas regions are Dallas, Houston, Austin/San Antonio, Corpus Christi, Midland/Lubbock, and El Paso, as shown in Figure 1.

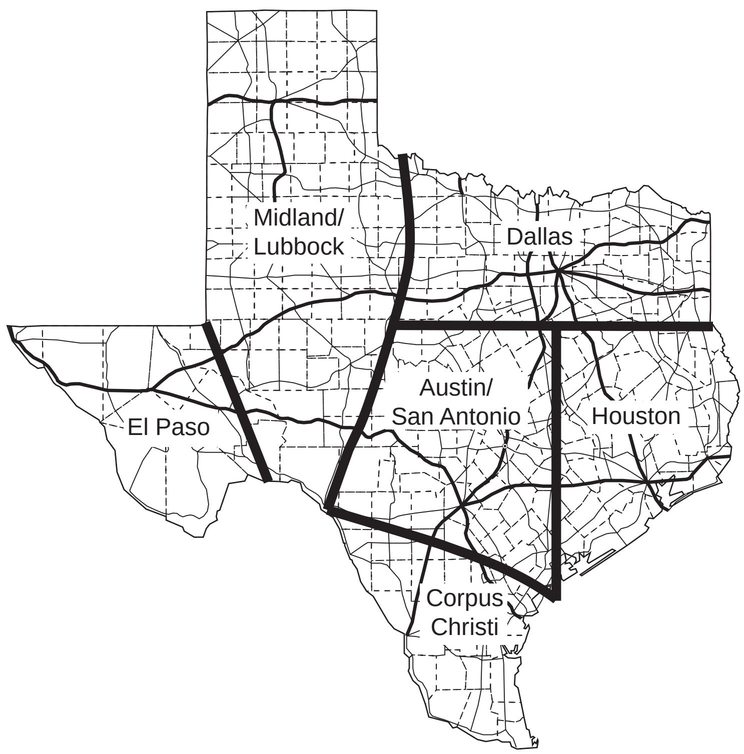


Figure 1 Division of Texas Areas

FACTORIAL DESIGN

In the preceding section, the state of Texas was divided into six strata. In the next step, DPS locations in each area were selected randomly within every stratum. This survey design was more complicated because factors affecting the parameters of interest were also taken into consideration when the data collection locations were selected.

Geographical region, highway class, and highway direction are the three, among many, underlying factors that might affect truck tire pressure and truck configurations. In order to test this assumption, and because the three factors are controllable in an experiment design, a three-factor factorial experiment design—with fixed effects of six geographical regions, two highway classes, and two highway directions in each factor, respectively—was proposed. The original experiment design is shown in Table 1. In the original design, highways were divided into two (interstate and non-interstate) classes, and truck tire pressures (proxy of truck configurations) in both highway directions were to be examined. Therefore, each geographical area was to have four locations to be taken with one location in each highway class and direction, and the overall design would be composed of twenty-four locations.

Table 1 Original Factorial Design for Data Collection Locations

		Area							
Hwy class	**Hwy dir**	Lubbock-Midland	Dallas	Houston	San Antonio /Austin	Corpus Christi	El Paso	Sum	Sum
Inter-state	EB/SB	1	1	1	1	1	1	6	12
	WB/NB	1	1	1	1	1	1	6	
State	EB/SB	1	1	1	1	1	1	6	12
	WB/NB	1	1	1	1	1	1	6	
Sum		4	4	4	4	4	4	24	24

Note: The number in each table cell is the number of DPS weigh stations for that cell.

To overcome the difficulty in scheduling available DPS weigh stations, and also to save money, pilot surveys were conducted in the weigh stations at San Marcos and Odessa. The purpose of the pilot surveys was to test the effect of highway direction on tire pressure values. Truck tire pressures in two opposite directions were collected at each of the two pilot survey locations, and their equality was tested using *t*- tests. More details about the direction equality test are provided in Chapter 6. Analysis of the collected data showed that for a 95 percent confidence level, no significant difference could be declared between the two opposite highway directions at the above two locations. Based on the pilot surveys, the original experiment design was revised to the one shown in Table 2. It is noticeable that the total number of survey sites decreased from twenty-four to eighteen, with most of the geographical areas having two or three sites. The imbalance between "Interstate" and "State" and two blank cells reflects the difficulty we had in finding suitable stations. Also noticeable is that data were collected at four border crossing sites, including two near El Paso and one each near Laredo and Brownsville; the area of "El Paso" was updated to "Border Area," which included the two locations in El Paso and the locations in Laredo and Brownsville.

Table 2 Revised Factorial Design for Data Collection Locations

	Area						
Hwy class	Lubbock-Midland	Dallas	Houston	San Antonio /Austin	Corpus Christi	Border Area	Sum
Interstate	2	2	2	2	1		9
State	1	1	1		2	2+2*	9
Sum	3	3	3	2	3	4	18

Notes: 1) The number in each table cell is the number of DPS weigh stations for that cell.
2) * Data collected from border crossing sites.

SAMPLE SIZE

Accurate estimation of the tire pressure mean for each sampling location, as well as for the overall population, is required. The minimum number of trucks to be surveyed in each survey location was determined by Equation (4):

$$n = \frac{K^2 V^2}{D^2} \qquad \text{(Eq. 4)}$$

where n = size of sample (minimum number of trucks at each location);

K = number of standard deviations for the chosen confidence level;

V = coefficient of variation of the random variable; that is, the sample standard deviation divided by the sample mean value; and

D = tolerable maximum relative error (percent).

The value selected for *K* determines the probability (confidence level) at which the sample estimate of the mean over the *n* observations in the sample will have a relative error no greater than $\pm D$. The value of *K* was chosen as 3.0 and *D* was selected to be 0.1, or 10 percent, to obtain a sample estimate of the mean that had a relative error within ±10 percent of the true mean tire pressure for 99.73 percent confidence.

To decide on an initial sample size, we reviewed similar surveys on tire pressures conducted by other researchers and looked at the value of *V*. From the tire pressure data collected by Kim et al. at Oregon State University and Elliott et al. at the University of Arkansas (Kim et al., 1989; Elliott et al., 1991), a standard deviation value of 15 psi was obtained for the estimated mean value of 80 psi. Therefore, based on the above settings, an initial sample size for each survey location was calculated as below:

$$n = \frac{K^2 V^2}{e^2} = \frac{(3^2)(15/80)^2}{(0.1)^2} \approx 32(trucks)$$

The above calculations signify that if the borrowed coefficient of variation *V* holds true for the proposed survey, a total of at least 32 trucks should be measured for each survey location to satisfy the mentioned probability significance and tolerable relative error levels.

Although it is desirable to take sample observations at many different locations in each area to better represent the area, in order to conduct the survey in a scientific and cost-effective way, the following issues regarding sample size were considered: 1) The sample estimate of the mean tire pressure of each data collection location is important for comparisons between highway directions and classes, and is required by the factorial design; 2) The difficulty in finding and scheduling suitable DPS weigh stations for the designed survey and the high cost involved in traveling to, from, and between sample sites leads one to conclude that the most logical survey design is to draw as many trucks as possible to the same available location; 3) Experience attained from practice in field trips before the real survey showed that an average truck takes about 10 minutes to finish all the required measurements, and a typical DPS weigh station would need to be open continuously for 6 to 7 hours one day. Taking into account the time needed for taking breaks and other necessary pauses, a typical sampling day can accommodate 30 to 35 trucks. This is how the sample size of 35 trucks at each location was determined.

Statistically speaking, different tires on the same truck are not as independent from one another as those on different trucks. Usually, tires of the same truck are inflated, serviced, and replaced by the same operator(s) at the same time, and therefore, statistically, the tires of the same truck are interrelated to one another. So it is easy to understand that the more interrelated the tires of the same truck are, the less information the said tires are contributing to the survey. In the design, a sampling unit is each truck drawn from the traffic stream, and an observation is each measured tire. In the survey design, all tires of each truck in the sample were measured, and the raw data table was composed of measurements of all tires of all trucks in the sample. Then, the collected tire pressure data of tires within each axle could be averaged to obtain a (axle average) pressure value representing that axle, and, similarly, collected data of tires within a truck could be averaged to get a (truck average) tire pressure value representing that truck. The resulting effects of the interrelation between tires of trucks will be detailed in Chapter 7.

FORMULAS AND MODELS

Estimation of Parameters

Below are the formulas used for estimating location tire pressure averages and the variance associated with the estimators.

$$\bar{y}_h = \frac{\sum_{j=1}^{n_h} y_{hj}}{n_h} \qquad \text{(Eq. 5)}$$

$$s_h^2 = \frac{\sum_{j=1}^{n_h} (y_{hj} - \bar{y}_h)^2}{n_h - 1} \qquad \text{(Eq. 6)}$$

$$\hat{V}(\bar{y}_h) = \frac{s_h^2}{n_h} \qquad \text{(Eq. 7)}$$

where $\bar{y}_h$ is the average tire pressure of the *h*-th location;

y_{hj} is the *j*-th tire pressure observation;

n_h is the total number of tires observed in the *h*-th location;

s_h^2 is the sample variance of observations in the h-th location;

$\hat{V}(\bar{y}_h)$ is the variance of the estimator of $\bar{y}_h$.

Similarly, the equations used for the calculation of the estimator of the grand average, the variance associated with the estimator, and the confidence interval (CI) are shown as follows.

$$\bar{y} = \frac{\sum_{h=1}^{N}\sum_{j=1}^{n_h} y_{hj}}{\sum_{h=1}^{N} n_h} \quad \text{(Eq. 8)}$$

$$s^2 = \frac{\sum_{h=1}^{N}\sum_{j=1}^{n_h} (y_{hj} - \bar{y})^2}{(\sum_{h=1}^{N} n_h) - 1} \quad \text{(Eq. 9)}$$

$$\hat{V}(\bar{y}) = \frac{s^2}{\sum_{h=1}^{N} n_h} \quad \text{(Eq. 10)}$$

$$CI = \left[\bar{y} - t_{\alpha/2}\sqrt{\hat{V}(\bar{y})}, \bar{y} + t_{\alpha/2}\sqrt{\hat{V}(\bar{y})} \right] \quad \text{(Eq. 11)}$$

where $\bar{y}$ is the grand mean of the sample observations;

s^2 is the variance of the sample observations;

$\hat{V}(\bar{y})$ is the variance of the estimator of the grand mean $\bar{y}$;

CI is the confidence interval for the grand mean $\bar{y}$;

N is the total number of survey locations;

$t_{\alpha/2}$ is the two-tailed t value according to the $(1-\alpha)$ confidence level.

Statistical Models

1) *t*-Test

Suppose that one assumes that the variances of samples of tire pressures were identical for **two** opposite highway directions. Then the appropriate test statistic to compare two opposite direction means is shown in Equation (12), where

$$t_0 = \frac{\bar{y}_1 - \bar{y}_2}{S_W\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \qquad \text{(Eq. 12)}$$

$\bar{y}_1$ and $\bar{y}_2$ are the sample means, n_1 and n_2 are the sample sizes, and S_W^2 is an estimate of the common variance $\sigma_1^2 = \sigma_2^2 = \sigma^2$ computed from Equation (13). S_1^2 and S_2^2 are the two individual sample variances. To determine whether to reject H_0: $\mu_1 = \mu_2$, one would compare the t_0 to the t distribution with $(n_1 + n_2 - 2)$ degrees of freedom.

$$S_W^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \qquad \text{(Eq. 13)}$$

If $|t_0| > t_{\alpha/2, n_1+n_2-2}$, where $t_{\alpha/2, n_1+n_2-2}$ is the upper $\alpha/2$ percentage point of the t distribution with (n_1+n_2-2) degrees of freedom, one would reject H_0 and conclude that the mean tire pressures of the two highway directions differ. Noticeably, when $(n_1 + n_2 - 2)$ is large enough (>30), then the t distribution with more than 30 degrees of freedom would be regarded as the same as a standard normal distribution, and $t_0 \cong Z$, where $Z \sim N(0,1)$.

2) One-Factor Fixed Effects ANOVA Model

Because the *t*-test is only good for comparing two means, it would become inefficient to use a *t*-test if the tire pressure means of the five non-border Texas areas are to be compared. In this case the one-factor fixed effects analysis of variance (ANOVA) can be used instead. The "one-factor" refers to the effect of geographical area on tire pressure. The "fixed effects" means that the five non-border areas, or five factor levels, or five treatments, are fixed but not random effects.

Suppose the fixed effects of a treatments or a levels of a single factor are to be compared. The observed response from each of the treatments is a random variable. One could use the term y_{ij} to represent the j-th observation under the i-th treatment, or the i-th factor level. There will be, in general, n observations under the i-th treatment. It is useful to describe the observations with a linear statistical model shown in Equation (14), where y_{ij} is the (ij)-th observation, μ is the overall mean, τ_i is a parameter unique to the

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij} \quad \begin{cases} i = 1,2,\ldots,a \\ j = 1,2,\ldots,n \end{cases} \qquad \text{(Eq. 14)}$$

i-th treatment called the *i*-th treatment effect, and ε_{ij} is a random error component. The objective is to test the equality of the *a* treatment means; that is,

$$H_0 : \mu_1 = \mu_2 = \cdots = \mu_a$$
$$H_1 : \mu_i \neq \mu_j \text{ for at least one pair (i, j)}$$

Let $y_{i.}$ represent the total of the observations under the *i*-th treatment and $\bar{y}_{i.}$ represent the average of the observations under the *i*-th treatment. Similarly, let $y_{..}$ represent the grand total of all the observations and $\bar{y}_{..}$ represent the grand average of all observations. Calculation of $y_{i.}$, $\bar{y}_{i.}$, $y_{..}$, and $\bar{y}_{..}$ is expressed symbolically in Equations (15) and (16), where $N = an$ is the total number of observations.

$$y_{i.} = \sum_{j=1}^{n} y_{ij}, \qquad \bar{y}_{i.} = y_{i.} / n \qquad \text{(Eq. 15)}$$

$$y_{..} = \sum_{i=1}^{a}\sum_{j=1}^{n} y_{ij}, \qquad \bar{y}_{..} = y_{..} / N \qquad \text{(Eq. 16)}$$

The analysis of variance (ANOVA) is derived from a partitioning of total variability into its component parts. The total corrected sum of squares can be partitioned into a sum of squares of the differences between the treatment averages and the grand average, plus a sum of squares of the differences of observations within treatments from the treatment average. The difference between the observed treatment averages and the grand average is a measure of the differences between treatment means, whereas the differences of observations within a treatment from the treatment average can be due only to random error. These relationships are expressed in Equations (17) through (20).

$$SS_T = SS_{Treatments} + SS_E \qquad \text{(Eq. 17)}$$

$$SS_T = \sum_{i=1}^{a}\sum_{j=1}^{n} (y_{ij} - \bar{y}_{..})^2 \qquad \text{(Eq. 18)}$$

$$SS_E = \sum_{i=1}^{a}\sum_{j=1}^{n} (y_{ij} - \bar{y}_{i.})^2 \qquad \text{(Eq. 19)}$$

$$SS_{Treatments} = n\sum_{i=1}^{a}(\bar{y}_{i.} - \bar{y}_{..})^2 \qquad \text{(Eq. 20)}$$

$SS_{Treatments}$ is called the sum of squares due to treatments (i.e., between treatments), and SS_E is called the sum of squares due to error (i.e., within treatments). There are $an = N$ total observations; thus SS_T has $(N-1)$ degrees of freedom. There are a levels of the factor (and a treatment means), so $SS_{Treatments}$ has $(a-1)$ degrees of freedom. Finally, within any treatment there are n replicates providing $n-1$ degrees of freedom with which to estimate the experimental error. Since there are a treatments, we have $a(n-1) = an-a$ degrees of freedom for error. Then the quantities

$$MS_{Treatments} = \frac{SS_{Treatments}}{a-1}$$

$$MS_E = \frac{SS_E}{an-a}$$

are called mean squares. And the ratio

$$F_0 = \frac{SS_{Treatments}/(a-1)}{SS_E/(an-a)} = \frac{MS_{Treatments}}{MS_E} \qquad \text{(Eq. 21)}$$

is distributed as F with $(a-1)$ and $(an-a)$ degrees of freedom. Equation (21) is the test statistic for the hypothesis of no differences in treatment means.

3) Two-Factor Factorial Design

If more than one factor is considered in the ANOVA analysis—for example, if the geographical area and the highway class are considered in the same time in the tire pressure data analysis—a two-factor factorial ANOVA should be used. To make simpler notions, the two factors, the geographical area and the highway class, are denoted as row factor A and column factor B, respectively, in the following several paragraphs. In a two-factor factorial design, the observations may be described by the linear statistical model shown in Equation (22), where μ is the overall mean effect, τ_i is the

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk} \quad \begin{cases} i = 1,2,\cdots,a \\ j = 1,2,\cdots,b \\ k = 1,2,\cdots,n \end{cases} \qquad \text{(Eq. 22)}$$

effect of the i-th level of the row factor A, β_j is the effect of the j-th level of column factor B, $(\tau\beta)_{ij}$ is the effect of the interaction between τ_i and β_j, and ε_{ijk} is a random error component. Both factors are fixed, and the treatment effects are defined as deviations from the overall mean, so $\sum_{i=1}^{a}\tau_i = 0$ and $\sum_{j=1}^{b}\beta_j = 0$. Similarly, the interaction effects are fixed and are defined such that $\sum_{i=1}^{a}(\tau\beta)_{ij} = \sum_{j=1}^{b}(\tau\beta)_{ij} = 0$. Because there are n replicates of the experiment, there are abn total observations.

In the two-factor factorial experiments, both row and column factors (or treatments) A and B are of equal interest. The objective of the two-factor ANOVA is to test the hypotheses about the equality of row treatment effects, or specifically the equality of tire pressure in different geographical areas

$$\begin{aligned} &H_0 : \tau_1 = \tau_2 = \cdots = \tau_a = 0 \\ &H_1 : \text{at least one } \tau_{\text{i}} \neq 0 \end{aligned} \qquad \text{(Eq. 23a)}$$

and the equality of column treatment effects, or specifically the equality of tire pressure in different highway classes

$$\begin{aligned} &H_0 : \beta_1 = \beta_2 = \cdots = \beta_b = 0 \\ &H_1 : \text{at least one } \beta_{\text{j}} \neq 0 \end{aligned} \qquad \text{(Eq. 23b)}$$

Let $y_{i..}$ denote the total of all observations under the i-th level of factor A. Let $y_{.j.}$ denote the total of all observations under the j-th level of factor B, $y_{ij.}$ denote the total of all observations in the (ij)-th cell, and $y_{...}$ denote the grand total of all observations. Define $\bar{y}_{i..}, \bar{y}_{.j.}, \bar{y}_{ij.}$, and $\bar{y}_{...}$ as the corresponding row, column, cell, and grand averages. Expressed mathematically,

$$\begin{aligned} &y_{i..} = \sum_{j=1}^{b}\sum_{k=1}^{n} y_{ijk}, && \bar{y}_{i..} = \frac{y_{i..}}{bn} && i = 1,2,\ldots,a \\ &y_{.j.} = \sum_{i=1}^{a}\sum_{k=1}^{n} y_{ijk} && \bar{y}_{.j.} = \frac{y_{.j.}}{an} && j = 1,2,\ldots,b \\ &y_{ij.} = \sum_{k=1}^{n} y_{ijk} && \bar{y}_{ij.} = \frac{y_{ij.}}{n} && \begin{cases} i = 1,2,\ldots,a \\ j = 1,2,\ldots,b \end{cases} \\ &y_{...} = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n} y_{ijk} && \bar{y}_{...} = \frac{y_{...}}{abn} \end{aligned} \qquad \text{(Eq. 24)}$$

Then, the total corrected sum of squares may be written as

$$\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n}(y_{ijk}-\bar{y}_{...})^2 = bn\sum_{i=1}^{a}(\bar{y}_{i..}-\bar{y}_{...})^2 + an\sum_{j=1}^{b}(\bar{y}_{.j.}-\bar{y}_{...})^2$$

$$+ \mathrm{n}\sum_{\mathrm{i}=1}^{\mathrm{a}}\sum_{\mathrm{j}=1}^{\mathrm{b}}(\bar{y}_{ij.} - \bar{y}_{i..} - \bar{y}_{.j.} + \bar{y}_{...})^2 \qquad \text{(Eq. 25)}$$

$$+ \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{n}(y_{ijk}-y_{ij.})^2$$

Shown in Equation (25), the sum of squares has been partitioned into a "rows" sum of squares or factor *A*, *(SS_A);* a "columns" sum of squares or factor *B*, *(SS_B);* an "interaction" sum of squares between factors *A* and *B*, *(SS_{AB});* and an "error" sum of squares, *(SS_E)*. So Equation (25) may be rewritten as

$$SS_T = SS_A + SS_B + SS_{AB} + SS_E \qquad \text{(Eq. 26)}$$

The number of degrees of freedom associated with each sum of squares is as follows:

Effects	Degrees of Freedom
A	*a–1*
B	*b–1*
AB interaction	*(a–1)(b–1)*
Error	*ab(n–1)*
Total	**abn–1**

Each sum of squares divided by its degrees of freedom is a mean square, producing quantities MS_A, MS_B, MS_{AB}, and MS_E. Therefore, to test the significance of both main effects and their interaction, the corresponding mean square is divided by the error mean square, shown as:

Mean Square	F_0
$MS_A = SS_A/(a-1)$	$F_0 = MS_A/MS_E$
$MS_B = SS_B/(b-1)$	$F_0 = MS_B/MS_E$
$MS_{AB} = SS_{AB}/((a-1)(b-1))$	$F_0 = MS_{AB}/MS_E$
$MS_E = SS_E/ab(n-1)$	

If the model (Equation 22) is assumed to be adequate and the error terms ε_{ijk} are assumed to be normally and independently distributed with constant variance σ^2, then each of the ratios of mean squares MS_A/MS_E, MS_B/MS_E, and MS_{AB}/MS_E are distributed as F with *(a–1), (b–1),* and *(a–1)(b–1)* numerator degrees of freedom, respectively, and *ab(n–1)* denominator degrees of freedom, and the critical region would be the upper tail of the *F* distribution.

4) Analysis of Covariance

There are many factors affecting truck tire pressures. As mentioned earlier, geographical area, highway class, and highway direction are all possible factors. Another factor that definitely affects tire pressure is tire temperature. However, tire temperature is different from the previously mentioned factors in that the tire temperature factor is uncontrollable while the other factors are controllable in experiment design. Analysis of covariance can be used to deal with the efforts of factors that cannot be controlled.

Analysis of covariance is another technique that is useful for improving the precision of an experiment. Suppose that in an experiment with a response variable *y* there is another variable *x*, and that *y* is linearly related to *x*. Furthermore, suppose that *x* cannot be controlled by the experimenter but can be observed along with *y*. The variable *x* is called a covariate or concomitant variable. Specifically, the response variable *y* is tire pressure and the covariate variable *x* is tire temperature. Tire temperature cannot be controlled in the experiment design but can be observed along with tire pressure. Furthermore, tire pressure is linearly related to tire temperature (detailed in Chapter 6). Therefore, the analysis of the covariance approach can be used to improve precision of the tire pressure data analysis.

The analysis of covariance involves adjusting the observed response variable for the effect of the concomitant variable. If such an adjustment is not performed, the concomitant variable could inflate the error mean square and make true differences in the response due to treatments harder to detect.

The analysis of covariance (ANOCA) model is shown in Equation (27) assuming there is a linear relationship between the response and the covariate.

$$y_{ij} = \mu + \tau_i + \beta(x_{ij} - \bar{x}_{..}) + \varepsilon_{ij} \quad \begin{cases} i = 1,2,\ldots,a \\ j = 1,2,\ldots,n \end{cases} \qquad \text{(Eq. 27)}$$

In Equation (27), y_{ij} (tire pressure) is the *j*-th observation on the response variable taken under the *i*-th treatment or level of the single factor (geographical area); x_{ij} (tire temperature) is the measurement made on the covariate variable corresponding to y_{ij}; $\bar{x}_{..}$ is the mean of the x_{ij} values; μ is an overall mean; τ_i is the effect of the *i*-th treatment, β is a linear regression coefficient indicating the dependency of y_{ij} on x_{ij}; and ε_{ij} is a random error component. The following conditions are self-evident and are assumed true for the tire pressure data analysis. The errors ε_{ij} are normally independently and identically distributed, i.e., $\varepsilon_{ij} \sim NID(0,\sigma^2)$; the slope $\beta \neq 0$ and the true relationship between y_{ij} and x_{ij} is linear; the regression coefficients for each treatment are identical; the treatment effects sum to zero ($\sum_{i=1}^{a} \tau_i = 0$); and the concomitant variable x_{ij} is not affected by the treatments.

To describe the analysis, the following notations were introduced.

$$S_{yy} = \sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij} - \bar{y}_{..})^2 \qquad \text{(Eq. 28)}$$

$$S_{xx} = \sum_{i=1}^{a}\sum_{j=1}^{n}(x_{ij} - \bar{x}_{..})^2 \qquad \text{(Eq. 29)}$$

$$S_{xy} = \sum_{i=1}^{a}\sum_{j=1}^{n}(x_{ij} - \bar{x}_{..})(y_{ij} - \bar{y}_{..}) \qquad \text{(Eq. 30)}$$

$$T_{yy} = \sum_{i=1}^{a}(\bar{y}_{i.} - \bar{y}_{..})^2 \qquad \text{(Eq. 31)}$$

$$T_{xx} = \sum_{i=1}^{a}(\bar{x}_{i.} - \bar{x}_{..})^2 \qquad \text{(Eq. 32)}$$

$$T_{xy} = \sum(\bar{x}_{i.} - \bar{x}_{..})(\bar{y}_{i.} - \bar{y}_{..}) \qquad \text{(Eq. 33)}$$

$$E_{yy} = \sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij} - \bar{y}_{i.})^2 = S_{yy} - T_{yy} \qquad \text{(Eq. 34)}$$

$$E_{xx} = \sum_{i=1}^{a}\sum_{j=1}^{n}(x_{ij} - \bar{x}_{i.})^2 = S_{xx} - T_{xx} \qquad \text{(Eq. 35)}$$

$$E_{xy} = \sum_{i=1}^{a}\sum_{j=1}^{n}(x_{ij} - \bar{x}_{i.})(y_{ij} - \bar{y}_{i.}) = S_{xy} - T_{xy} \qquad \text{(Eq. 36)}$$

Note that, in general, *S*= *T*+*E*, where the symbols *S, T,* and *E* are used to denote sums of squares and cross-products for total, treatments, and error, respectively.

In Equation (27), the least squares estimators of μ, τ_i, and β are $\hat{\mu} = \bar{y}_{..}$,

$\hat{\tau}_i = \bar{y}_{i.} - \bar{y}_{..} - \hat{\beta}(\bar{x}_{i.} - \bar{x}_{..})$, and

$$\hat{\beta} = \frac{E_{xy}}{E_{xx}} \qquad \text{(Eq. 37)}$$

The error sum of squares in the model is

$$SS_E = E_{yy} - (E_{xy})^2 / E_{xx} \qquad \text{(Eq. 38)}$$

with $a(n-1) - 1$ degrees of freedom. The experimental error variance is estimated by

$$MS_E = \frac{SS_E}{a(n-1)-1} \qquad \text{(Eq. 39)}$$

Now suppose that there is no treatment effect. The model in Equation (27) would then be

$$y_{ij} = \mu + \beta(x_{ij} - \bar{x}_{..}) + \varepsilon_{ij} \qquad \text{(Eq. 40)}$$

and the least squares estimators of μ and β are $\hat{\mu} = \bar{y}_{..}$ and $\hat{\beta} = S_{xy} / S_{xx}$. The sum of squares for error in this reduced model is:

$$SS_E^{'} = S_{yy} - (S_{xy})^2 / S_{xx} \qquad \text{(Eq. 41)}$$

with $an - 2$ degrees of freedom. In Equation (41), the quantity $(S_{xy})^2/S_{xx}$ is the reduction in the sum of squares of *y* obtained from the linear regression of *y* against *x*. Then the quantity $SS'_E - SS_E$ is a reduction in the τ_i sum of squares. Therefore, the difference between SS'_E and SS_E provides a sum of squares with $a-1$ degrees of freedom for testing the hypothesis of no treatment effects. Consequently, to test H_0: $\tau_i = 0$, one would compute

$$F_0 = \frac{(SS_E^{'} - SS_E)/(a-1)}{SS_E / [a(n-1)-1]} \qquad \text{(Eq. 42)}$$

which, if the null hypothesis is true, is distributed as $F_{\alpha, a-1, a(n-1)-1}$.

5) Linear Regression Model

To obtain the coefficients associated with the linear relationship between tire pressure and tire temperature, one should establish a linear regression model for the relationship. In the following several paragraphs, y_i and x_i are standing for tire pressure and tire temperature, respectively, for the tire pressure data analysis.

If the sets of x_i and y_i data can be expressed in the following model, where α is the

$$y_i = \alpha + \beta \cdot x_i + \varepsilon_i \qquad i = 1,2,...,n \qquad \text{(Eq. 43)}$$

expected y value when $x = 0$; β is the expected increase in y for a one-unit increase in x; and ε_i is normally and independently distributed with a mean of 0 and a constant variance of σ^2, i.e, $\varepsilon_i \sim NID(0, \sigma^2)$; then the model shown in Equation (43) is the linear regression model of y on x, and the line $\alpha+\beta x$ is called the true regression line, which is available only if the entire population is included. However, the true regression line can be estimated by the Ordinary Least Squares (OLS) method. Suppose the estimated regression line is $a+bx$, where a and b are OLS estimators of α and β, respectively. Let $e_i = y_i - (a + bx_i)$ then the OLS estimators a and b are chosen to minimize $\sum_{i=1}^{n} e_i^2$, and they can therefore be derived as below:

$$\underset{a,b}{Min} \sum_{i=1}^{n} e_i^2 = \underset{a,b}{Min} \sum_{i=1}^{n} (y_i - (a + bx_i))^2 = \underset{a,b}{Min}\, S(a,b) \qquad \text{(Eq. 44)}$$

To minimize the function in Equation (44), derivatives with respect to a and b are set to 0, and then one solves for a and b, i.e.,

$$\begin{aligned} \frac{\partial}{\partial a} \sum_{i=1}^{n} (y_i - (a + bx_i))^2 &= 0 \\ \frac{\partial}{\partial b} \sum_{i=1}^{n} (y_i - (a + bx_i))^2 &= 0 \end{aligned} \qquad \text{(Eq. 45)}$$

One then solves a and b from Equation (45), and the OLS estimators of α and β are obtained as below, where $\bar{x}, \bar{y}$ are means of x and y data sets, respectively.

$$b = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \qquad \text{(Eq. 46)}$$

$$a = \overline{y} - b\overline{x} \qquad \text{(Eq. 47)}$$

It can be proved that *a* and *b* are both unbiased estimators of α and β, and the slope estimator *b* is distributed as:

$$b \sim N(\beta, \sigma_b^2 = \frac{\sigma^2}{\sum_{i=1}^{n}(x_i - \overline{x})^2}) \qquad \text{(Eq. 48)}$$

SUMMARY

All the elements required for a complete survey design are now ready. The parameters of interest have been determined, a practical survey plan has been designed, and the mathematical models associated with the survey design and the data analyses have been determined. The data collection process will be described in the next chapter.

CHAPTER 4 DATA COLLECTION

Now that the survey and the associated data analysis methods have been designed, the next step should be a detailed practical and executable data collection procedure. This chapter generally describes the data collection process. The first section describes preparation for the data collection, while the second section describes detailed data collection procedures; the whole data collection work is reviewed and summarized in the third section.

PREPARATION FOR DATA COLLECTION

Preparation before the real data collection included 1) tire pressure gauge calibration, 2) design of the data collection plan and data logging sheet, 3) field trips to practice and refine the data collection procedures, and 4) necessary adjustments to the original data collection plan.

Portable, inexpensive, easy to handle, and commonly used spring-type pressure gauges are very suitable for field use and therefore were employed for the pressure measurements. Several tire pressure gauges were tested against a reference gauge on different pressure levels, and the error correction curve for each gauge was plotted and recorded. Gauges with similar characteristics were so marked; ones with better precision were used first, and alternatives were reserved for use in case of gauge failure. Temperature was measured using both a thermo-couple meter and an infrared temperature gun. The thermo-couple was more accurate than the infrared gun, but the latter was much quicker in measurement response than the former. Therefore, the thermo-couple meter was used in air temperature measurement, and the infrared guns were used in pavement and tire temperature measurements.

The data collection/logging sheet was revised numerous times. The last update happened even after the start of the real survey. The final version is shown in Appendix A, and it includes the following blocks of information:

I. Identification data, such as truck license plate number, date, and location

II. Trip information including origin and destination and commodity type

III. Weather

IV. Pavement temperature and air temperature

V. Truck type

VI. Tire data, including the tire manufacturer type, size, pressure, and temperature

VII. Suspension type

VIII. Axle weight, axle spacing

IX. Comments

X. Identifications of inspectors and gauges

Before the actual survey, a field trip was arranged to the DPS weigh station on I-35 southbound at Devine in Medina County, Texas. The purposes of the trip were to check the preparation work and to finalize the data collection procedure. The data collection procedure was modified according to the field trip findings. Although axle weight data could be obtained from the weigh station scale, or even printed from the station computer, there was still a problem in matching the weight data with the actual truck being measured. Because of the distance between the tire data collection site and the axle weight scale, data collectors would need to go back and forth between the two locations, or have one person stay with the scale and relay the axle weight data via telecommunications. These difficulties, plus the fact that many measurements were made at rest areas and border crossings, where weighing is not possible, dictated that weight information could not be obtained for all measured trucks.

DATA COLLECTION PROCEDURE

Flashing lights and signboards written in both English and Spanish and located upstream of a typical DPS weigh station informed truck drivers of the oncoming enforcement activity. Once signaled, selected trucks executed lane changes and were diverted from the traffic stream to the weigh station with little interference to other traffic.

During the survey, trucks and drivers were first examined by DPS officers, who performed routine license and weight checks, and then were directed to the data collection site, about 100 to 150 ft. downstream of the weigh station. Once a truck was safely stopped and driver permission was obtained, the data collection was started. Usually, at least one more truck was backed up waiting to be measured. Having another waiting truck helped facilitate a continuous and efficient survey process. On the average, measurements on each truck took 7 to 10 minutes, and in most cases, truck drivers were cooperative.

A six-person team conducted the data collection, with three persons on each vehicle side. Generally, one person in each group was responsible solely for the tire pressure measurements; another person was taking tire temperature, tire type, tire size, axle spacing, and suspension measurements; and the third person was taking notes and collecting trip original destination (O/D) and commodity information by talking with the drivers. As indicated on the data collection sheet (Appendix A), axle spacing measurements included axle to axle distance for all axles on each surveyed truck. Two persons in the team were fluent in Spanish, guaranteeing no difficulty in serving Mexican drivers. Truck license numbers and start and finish times were recorded to help keep records in chronological order. Names of inspectors and gauges were also recorded for correcting personal and gauge errors.

OVERVIEW OF DATA COLLECTION

After careful design and repeated practice the survey program was carried out at eighteen locations throughout the state of Texas as indicated in Figure 2. Because of limitations in finding suitable DPS weigh stations to fit into the design, not all data were collected at DPS weigh stations. For example, the Mount Vernon data were collected at a rest area, and the Brownsville and Laredo data were collected at U.S. Customs border crossing sites. The overview of data collection is summarized in Table 3.

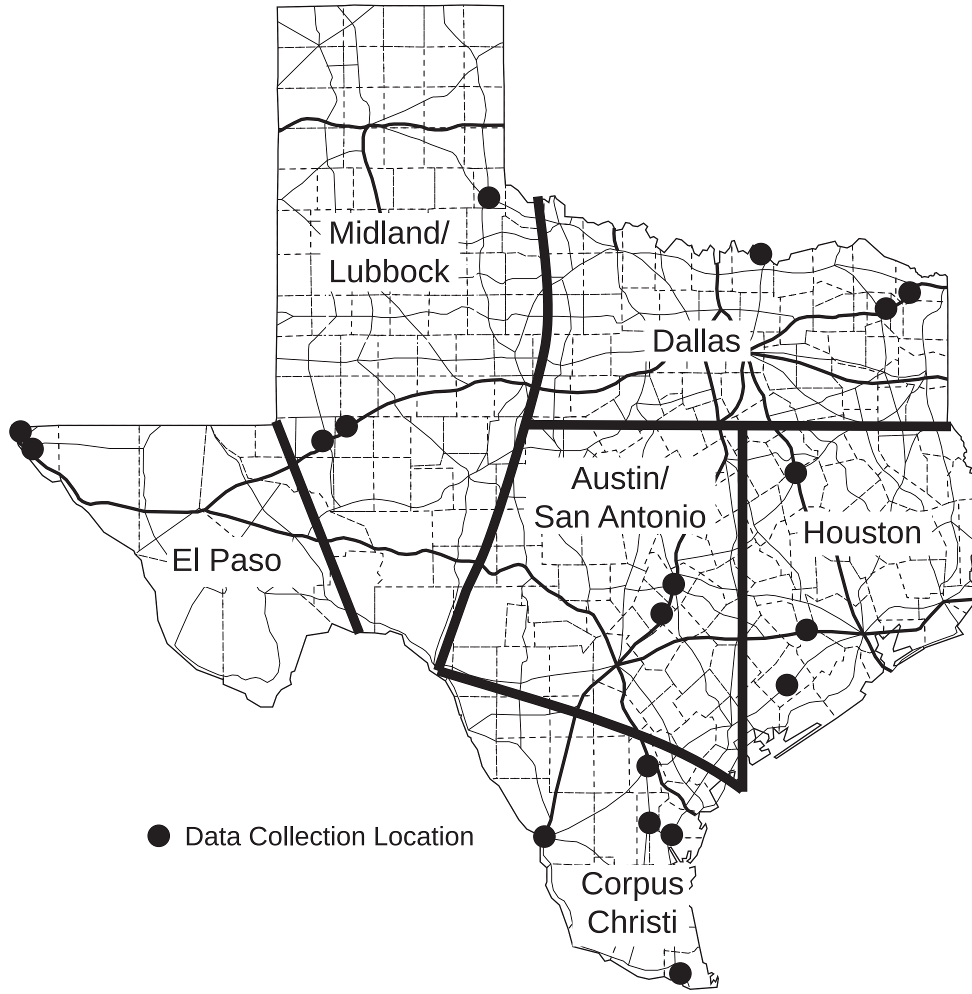


Figure 2 Data Collection Locations

Table 3 Overview of Data Collection

No.	Location	Hwy class	Hwy dir	Area	Sample size (trucks)	Note
1	Brownsville	Border St.	NB	Border	35	Border St.
2	Centerville	I-45	SB	Houston	35	WS 39
3	Childress	US 287	SB	Lubbock-Midland	35	WS 36
4	Denison	US 75	SB	Dallas	35	WS 1
5	El Paso	Loop 375	WB	Border	35	WS 34
6	El Paso	Loop 375	EB	Border	35	WS 33
7	Falfurrias	US 281	SB	Corpus Christi	35	WS 26
8	Katy	I-10	EB	Houston	35	WS 9
9	Laredo	Border St.	NB	Border	35	Border St.
10	Mt. Pleasant	I-30	WB	Dallas	35	WS 7
11	Mt. Vernon	I-30	EB	Dallas	35	Rest Area
12	Odessa	I-20	WB	Lubbock-Midland	35	WS 31
13	Odessa	I-20	EB	Lubbock-Midland	35	WS 32
14	Riviera	US 77	NB	Corpus Christi	35	WS 14
15	San Marcos	I-35	NB	San Antonio-Austin	33	WS 42
16	San Marcos	I-35	SB	San Antonio-Austin	30	WS 41
17	Three Rivers	I-37	SB	Corpus Christi	35	WS 29
18	Victoria	US 59	SB	Houston	35	WS 18

SUMMARY

This chapter has provided a description of the data collection plan and procedure. According to the designed survey plan, data were collected at eighteen locations over six different Texas areas, including Dallas, Houston, Corpus Christi, San Antonio/Austin, Lubbock/Midland, and border areas. Fourteen locations were at non-border Texas interstate/state highways, and four locations were at the U.S. Customs border crossing sites. Now that the data collection work has been finished, the collected data will be analyzed and discussed in the following three chapters.

CHAPTER 5 SURVEY RESULTS

From October 1999 through February 2000, a total of 623 trucks at eighteen locations in six geographic Texas areas were examined as part of the truck configuration survey. All tires of every selected truck were tested for tire pressure, temperature, size, and manufacturer name, making a total number of 9,600 tires and 2,870 axles. On rare occasions, tires were not tested because of inaccessibility of tire inflation stems on poorly serviced tires or because of automated inflation devices. Other truck configuration data such as truck classification, suspension system, axle spacing, trip origin and destination, and commodity information were also collected. With careful cross-verifications, all data were entered into Excel worksheets especially designed for data entry. In this chapter, distribution of tire pressures, truck suspensions, tire sizes and manufacturers, tandem/tri-tandem axle usage and spacings, truck classes, trucking commodity classes, and trip O/Ds are reported both for the overall sample and for non-border and border areas.

TIRE PRESSURE

For different study purposes, tire pressure estimates are reported on different population levels. First, tire pressure statistics based on the 9,600 sampled tire observations are desirable because the average and standard deviation of the sample represent the approximate level and variability in tire pressure of all the truck tires traveling Texas highways. Because many current pavement performance models use the number of axle load applications, the average and standard deviation of tire pressures for the sampled 2,870 axles were calculated for estimating the population of axles in Texas. Because trucks are more independent of one another than tires and axles are, estimates of tire pressure based on the 623 sampled trucks became important to us so we could compare the differences in truck configurations in different geographical areas, different highway classes, and different highway directions.

It has been widely accepted (Bartholomew, 1986) that tire pressures are higher in summer than in winter, simply as a result of higher summer temperatures. Because the survey was conducted in winter, tire pressures expected at a typical high summer pavement temperature, say 140 °F, were estimated using the derived relationship between tire pressure and tire temperature. The study of the relationship between tire pressure and tire temperature is detailed in Chapter 6.

Table 4 shows the averages and standard deviations of tire pressures of tires sampled in the eighteen locations. Column 1 lists the results calculated directly from raw field data; column 2 shows the data corrected for pressure gauge errors; and column 3 shows the averages and standard deviations expected in summertime at 140 °F. As shown in Table 4, gauge errors caused only minor differences between columns 1 and 2, and the summer data generally had a lower variability than the collected data, a phenomenon that is mainly due to the adjustment of tire temperature to a uniform 140 °F.

Table 4 Tire Pressure Averages (Tire Average) by Locations

Location	Collected Raw Data (1)			Corrected for Gauge Error (2)			Projected Summer Data (3)		
	# Tires	Tire mean (psi)	Tire stdev (psi)	# Tires	Tire avg (psi)	Tire stdev (psi)	# Tires	Tire avg (psi)	Tire stdev (psi)
Mt. Pleasant WB	550	101.78	15.09	550	101.70	14.98	550	111.76	14.58
Mt. Vernon EB	609	101.86	11.51	609	101.79	11.41	609	111.78	10.46
Denison SB	576	97.67	12.70	576	97.67	12.70	576	110.46	12.56
Katy EB	586	96.21	13.33	586	96.21	13.33	586	111.87	13.14
Victoria SB	523	91.78	13.59	523	91.78	13.59	523	104.07	13.24
Centerville SB	594	98.50	13.36	594	98.50	13.36	594	110.51	13.20
Three Rivers SB	581	102.70	14.44	581	102.60	14.30	581	113.88	13.87
Riviera NB	524	95.45	13.01	524	95.45	13.01	524	109.73	12.90
Falfurrias SB	510	98.27	12.65	510	98.25	12.63	510	110.94	12.47
San Marcos SB	472	98.35	12.77	472	98.35	12.77	472	106.96	13.01
San Marcos NB	498	95.29	14.94	498	95.29	14.94	498	105.44	15.26
Odessa WB	544	100.67	12.74	544	100.67	12.74	544	112.75	12.18
Odessa EB	573	100.87	12.07	573	100.87	12.07	573	112.38	12.31
Childress SB	580	101.09	11.72	580	101.09	11.72	580	113.28	11.55
El Paso WB	500	89.11	19.78	500	89.11	19.78	500	104.76	19.23
El Paso EB	473	90.22	18.75	473	90.22	18.75	473	104.10	18.99
Laredo	441	85.25	16.88	441	85.25	16.88	441	98.30	16.57
Brownsville	466	90.29	16.63	466	90.29	16.63	466	101.53	16.71
Overall	9,600	96.76	15.05	9,600	96.75	15.03	9,600	108.93	14.68

Figures 3 and 4 show the histograms of the sample of 9,600 tire pressures (corrected for gauge errors) and that of the 9,600 projected summer tire pressures.

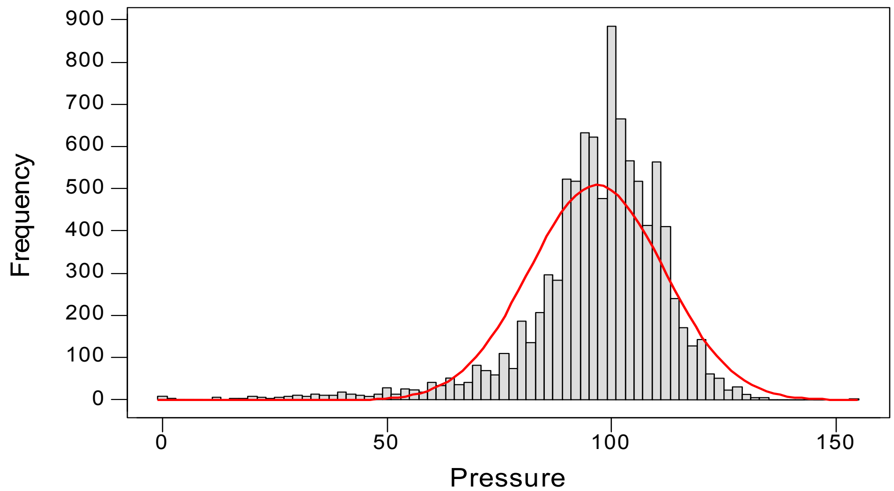


Figure 3 Histogram of Sampled Tire Pressures (corrected for gauge errors)

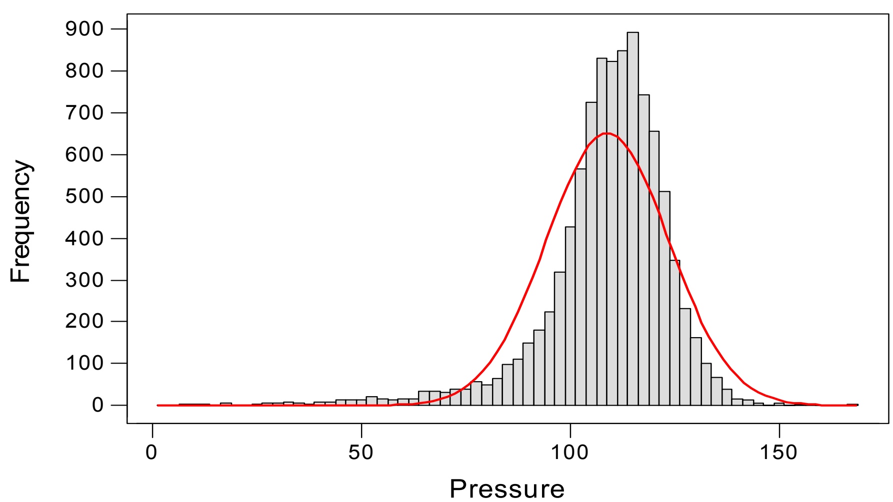


Figure 4 Histogram of Projected Summer Tire Pressures

Figures 3 and 4 show good normality in the distribution of both the collected and projected tire pressure data. Because of the lower variability, the projected summer tire pressures appear to be more nearly normally distributed than the collected data.

Tire pressure conditions in the samples of trucks and axles at the eighteen locations are summarized in Tables 5 and 6. The truck and axle samples both had noticeably lower variability than the tire sample. The reason for the decrease in variability was that each truck or axle estimate was obtained by averaging the pressure data of tires within the truck or axle. The number of tires within a truck or an axle was the controlling factor in the resulting sample variability. Therefore, the higher number of tires within a truck than in an axle would lead to variability in the average tire pressure estimates that was lower in trucks than in axles.

Table 5 Tire Pressure Averages (Axle Average) by Locations

	Collected Data (corrected)			**Projected Summer Data**		
Location	Axle avg (psi)	Axle stdev (psi)	# Axles	Axle avg (psi)	Axle stdev (psi)	# Axles
Mt. Pleasant WB	102.14	11.96	163	112.00	11.32	163
Mt. Vernon EB	102.35	8.78	175	112.15	7.48	175
Denison SB	98.21	10.33	171	110.78	10.05	171
Katy EB	97.13	11.04	168	112.62	10.55	168
Victoria SB	92.50	10.83	159	104.45	10.34	159
Centerville SB	98.62	12.27	169	110.54	12.05	169
Three Rivers SB	103.24	11.02	169	114.36	10.23	169
Riviera NB	96.13	9.33	160	110.18	8.94	160
Falfurrias SB	98.78	9.45	154	111.33	9.15	154
San Marcos SB	98.79	9.11	136	107.27	9.45	136
San Marcos NB	95.76	11.29	150	105.75	11.22	150
Odessa WB	101.14	10.95	168	113.01	9.98	168
Odessa EB	101.17	9.10	174	112.47	8.76	174
Childress SB	101.71	9.58	174	113.57	9.23	174
El Paso WB	89.02	16.53	154	104.55	15.81	154
El Paso EB	90.95	15.12	141	104.66	15.03	141
Laredo	86.31	12.82	135	99.14	12.26	135
Brownsville	90.04	13.95	150	101.19	14.07	150
Overall	97.17	12.39	2,870	109.17	11.80	2,870

Table 6 Tire Pressure Averages (Truck Average) by Locations

		Collected Data (corrected)		Projected Summer Data	
Location	# Trucks	Truck avg (psi)	Truck stdev (psi)	Truck avg (psi)	Truck stdev (psi)
Mt. Pleasant WB	35	100.28	11.18	110.30	11.00
Mt. Vernon EB	35	101.67	6.47	111.66	4.92
Denison SB	35	97.74	7.36	110.52	7.00
Katy EB	35	95.99	7.43	111.69	7.20
Victoria SB	35	91.09	6.64	103.22	7.00
Centerville SB	35	98.74	8.51	110.57	7.94
Three Rivers SB	35	102.55	7.18	113.77	6.69
Riviera NB	35	95.44	6.23	109.65	6.18
Falfurrias SB	35	97.99	6.51	110.55	6.16
San Marcos SB	30	98.15	4.56	106.78	5.06
San Marcos NB	33	96.14	8.73	106.30	8.76
Odessa WB	35	100.68	8.58	112.79	7.22
Odessa EB	35	100.71	6.24	112.24	6.23
Childress SB	35	101.04	7.07	113.17	6.73
El Paso WB	35	87.65	12.01	103.37	11.22
El Paso EB	35	90.07	11.85	104.15	11.90
Laredo	35	84.52	9.30	97.42	8.97
Brownsville	35	87.90	12.44	99.16	12.43
Overall	623	96.00	9.99	108.20	9.44

Tire pressure distributions over different truck classes are reported in descending order in Tables 7 through 9 for samples of tires, axles, and trucks, respectively.

Table 7 Tire Pressure Averages (Tire Average) of Truck Classes

Class	Collected data			Projected data		
	Average (psi)	Stdev (psi)	# Tires	Average (psi)	Stdev (psi)	# Tires
3-S1-2	102.80	7.62	83	114.10	8.29	83
2-S1-2	100.65	8.44	85	112.74	7.77	85
SU-4	99.08	18.65	12	107.99	14.60	12
3-S2	97.42	14.65	8,369	109.56	14.26	8,369
2-S2	96.00	12.08	115	106.98	11.51	115
3-S3	93.38	18.17	144	106.84	18.88	144
3-S1	93.09	11.06	69	106.98	10.88	69
4-S3	91.04	9.46	23	103.10	9.78	23
2-S1	90.80	18.05	45	103.40	17.97	45
SU-2	89.88	19.69	211	101.51	19.30	211
S-U3	88.06	17.28	444	101.21	17.49	444

Table 8 Tire Pressure Averages (Axle Average) of Truck Classes

Class	Collected Data			Projected Data		
	Avg (psi)	Stdev (psi)	#Axles	Avg (psi)	Stdev (psi)	#Axles
3-S1-2	103.47	6.34	24	114.59	6.81	24
2-S1-2	100.69	6.20	25	112.62	5.07	25
3-S2	97.89	11.90	2,479	109.85	11.24	2,479
SU-4	97.75	22.76	4	108.04	15.86	4
2-S2	96.06	10.45	36	106.94	9.55	36
3-S3	94.81	14.55	42	108.27	15.33	42
3-S1	94.04	10.40	20	107.60	9.80	20
4-S3	91.23	6.97	7	103.01	6.58	7
2-S1	90.20	18.11	15	102.50	17.96	15
SU-2	89.93	18.22	77	101.56	17.92	77
SU-3	89.14	13.21	141	101.98	13.31	141

Table 9 Tire Pressure Averages (Truck Average) of Truck Classes

Truck Class	Collected Data (corrected)			Projected Summer Data		
	Avg (psi)	Stdev (psi)	#Trucks	Avg (psi)	Stdev (psi)	#Trucks
3-S1-2	102.90	2.28	4	114.22	3.49	4
2-S1-2	100.74	5.75	5	112.80	3.84	5
SU-4	99.08	*	1	107.99	*	1
3-S2	97.29	8.89	500	109.44	8.19	500
2-S2	95.26	8.20	9	106.29	7.53	9
3-S3	93.78	8.21	7	107.26	9.70	7
3-S1	93.11	6.86	5	107.01	7.15	5
2-S1	91.15	9.49	5	103.85	8.97	5
4-S3	91.04	*	1	103.10	*	1
SU-2	89.65	16.46	39	101.30	15.90	39
SU-3	87.83	10.02	47	100.95	10.65	47

Clearly, the double-trailer vehicles found in the survey had the highest tire pressures, although only nine of them were observed. The 3-S2 trucks, the most common truck class, ranked fourth in tire pressure mean and SU-2 and SU-3 truck classes had the lowest tire pressures.

Tire pressure distributions in non-border and border areas are reported in Table 10 in samples of tires, axles, and trucks. Clearly, average tire pressure data in border areas were always lower than those of non-border areas.

Table 10 Tire Pressure Averages of Border and Non-border Areas

	Area	**Tires**			**Axles**			**Trucks**		
		Avg (psi)	Stdev (psi)	#Tires	Avg (psi)	Stdev (psi)	#Axles	Avg (psi)	Stdev (psi)	#Trucks
Collected	NB	98.69	13.45	7,720	99.20	10.80	2,290	98.46	7.98	483
	B	88.78	18.20	1,880	89.13	14.78	580	87.54	11.51	140
Projected	NB	110.55	13.21	7,720	110.87	10.33	2,290	110.28	7.62	483
	B	102.28	18.13	1,880	102.45	14.55	580	101.02	11.44	140

SUSPENSION USAGE

Tables 11 through 13 show the suspension system types used by sampled trucks. Air and leaf springs were the two most commonly used truck suspension systems. Air and leaf springs were mutually exclusive, never appearing together on the same axle; shock absorbers were often seen together with leaf springs. Air-spring systems were identified with the number of air springs in each suspension-axle combination, i.e., “Air spring” and “Dual air spring.” Leaf springs were further divided into “Semi-elliptic spring,” “Quarter-elliptic spring,” and “Monoleaf spring,” according to the shape of the spring. Please refer to Appendix B for suspension types.

Table 11 Distribution of Suspension Systems over the Sample of All Trucks

Suspension type	Steering Axles		Drive Axles		Trailer Axles	
	#Trucks	Percent	#Trucks	Percent	#Trucks	Percent
Air spring	2	0.33	382	61.81	178	33.71
Dual air spring	0	0.00	63	10.19	0	0.00
Semi-elliptic spring	610	99.67	151	24.43	294	55.68
Quarter-elliptic spring	0	0.00	19	3.07	27	5.11
Monoleaf spring	0	0.00	3	0.49	29	5.49
Shock absorber	598	97.71	436	70.55	179	33.90
Sum	612	100	618	100	528	100

As shown in Table 11, patterns in suspension usage existed in different combination axles. Leaf springs were predominantly used in steering axles in the 612 sampled axles, 98 percent of which had shock absorbers. In the 618 sampled drive combination axles, 72 percent were air springs, 28 percent were leaf springs, and 71 percent had shock absorbers. In contrast, only 34 percent of the 528 trailer combination axles used air springs, 66 percent of them used leaf springs, and only 34 percent of the trailer axles used shock absorbers.

Table 12 Distribution of Suspension Systems over Trucks in Non-border Areas

Suspension type	Steering Axles		Drive Axles		Trailer Axles	
	#Trucks	Percent	#Trucks	Percent	#Trucks	Percent
Air springs	2	0.42	342	71.25	162	36.90
Dual air springs	0	0.00	54	11.25	0	0.00
Semi-elliptic spring	472	99.58	68	14.17	234	53.30
Quarter-elliptic spring	0	0.00	13	2.71	22	5.01
Monoleaf spring	0	0.00	3	0.63	21	4.78
Shock absorber	469	98.95	385	80.21	162	36.90
Sum	474	100	480	100	439	100

Tables 12 and 13 are comparisons between non-border and border areas. Although there were steering axles, significantly different suspension usages were found in the drive and trailer axles for the border and non-border areas. It was more likely for non-border trucks to use air springs than for border trucks to use them.

Table 13 Distribution of Suspension Systems over Trucks in Border Areas

Suspension type	Steering Axles		Drive Axles		Trailer Axles	
	#Trucks	Percent	#Trucks	Percent	#Trucks	Percent
Air springs	0	0.00	40	28.99	16	17.98
Dual air springs	0	0.00	9	6.52	0	0.00
Semi-elliptic spring	138	100.00	83	60.14	60	67.42
Quarter-elliptic spring	0	0.00	6	4.35	5	5.62
Monoleaf spring	0	0.00	0	0.00	8	8.99
Shock absorber	129	93.48	51	36.96	17	19.10
Sum	138	100	138	100	89	100

TIRE MANUFACTURER AND SIZE

Major tire manufacturers sampled in the survey are listed in Table 14. Distributions of tire manufacturers over all trucks, 3-S2 trucks, and trucks in border and non-border areas are included in the table. The distribution of all trucks was very similar to that of the 3-S2 trucks because of the predominance of 3-S2s. Non-border and border trucks exhibited only small differences in tire manufacturer distributions.

Table 14 Distributions of Tire Manufacturers

Manufacturers		Armstrong, Kelly	Bridgestone	Continental	Dunlop, Cooper	Dayton	Firestone	Goodyear	General	BF Goodrich	Michelin	Sumitoma	Toyo	Yokahoma	Other	Sum
All trucks	Number	219	2770	162	490	30	481	1782	375	179	2295	44	257	431	636	10151
	Percent	2.16	27.29	1.60	4.83	0.30	4.74	17.55	3.69	1.76	22.61	0.43	2.53	4.25	6.27	100
3-S2 trucks	Number	204	2477	126	441	24	392	1500	336	148	2027	40	227	382	546	8870
	Percent	2.30	27.93	1.42	4.97	0.27	4.42	16.91	3.79	1.67	22.85	0.45	2.56	4.31	6.16	100
Nonborder	Number	176	2377	36	438	25	341	1333	300	130	1947	36	206	335	448	8128
	Percent	2.17	29.24	0.44	5.39	0.31	4.20	16.40	3.69	1.60	23.95	0.44	2.53	4.12	5.51	100
Border	Number	43	393	126	52	5	140	449	75	49	348	8	51	96	188	2023
	Percent	2.13	19.43	6.23	2.57	0.25	6.92	22.19	3.71	2.42	17.20	0.40	2.52	4.75	9.29	100

The tire size distributions are shown in Tables 15 and 16. Because drive and trailer axles usually have dual tires but steering axles do not, tire sizes in front axles and in axles other than front axles were studied separately over all trucks and over 3-S2s. The size 11R24.5 was most frequently used in steering axles, while 295-75R22.5 was most often seen in non-steering axles. Checks on tire width showed that most tires were 11 in. (275–280 mm) in width; very few “super single” tires of wide bases (425-65R22.5) were found in the sample. Refer to Appendix C for tire size specifications and sidewall codes. Roughly 98 percent of the front left and right tires were of the same size, and more than 96 percent of the dual tires in non-front axles were the same size.

Table 15 Distribution of Tire Sizes in Front and Non-front Axles

Tire size		9R22.5	11R22.5	11R24.5	255-70R22.5	275-80R22.5	275-80R24.5	285-75R24.5	295-75R22.5	425-65R22.5	10-20Bias	Other Bias	Other	Sum
All Trucks	#Front tires	0	250	295	2	97	56	201	276	3	8	15	21	1224
	Percent	0.00	20.42	24.10	0.16	7.92	4.58	16.42	22.55	0.25	0.65	1.23	1.72	100
	#Other tires	10	1494	1903	164	815	402	1353	2314	3	114	108	168	8848
	Percent	0.11	16.89	21.51	1.85	9.21	4.54	15.29	26.15	0.03	1.29	1.22	1.90	100
3-S2	#Front tires	0	178	246	0	88	54	179	233	0	2	4	2	986
	Percent	0.00	18.05	24.95	0.00	8.92	5.48	18.15	23.63	0.00	0.20	0.41	0.20	100
	#Other tires	8	1238	1685	128	733	370	1245	2150	3	94	67	94	7815
	Percent	0.10	15.84	21.56	1.64	9.38	4.73	15.93	27.51	0.04	1.20	0.86	1.20	100

As shown in Table 16, tire size usages in border and non-border Texas areas were very similar. Actually, the results for the border and non-border areas were not significantly different.

Table 16 Distribution of Tire Sizes in Border and Non-border Areas

Tire size		9R22.5	11R22.5	11R24.5	255-70R22.5	275-80R22.5	275-80R24.5	285-75R24.5	295-75R22.5	425-65R22.5	10-20Bias	Other Bias	Other	Sum
Non-border	# tires	8	1326	1756	154	804	390	1282	2175	6	56	22	77	8056
	Percent	0.10	16.46	21.80	1.91	9.98	4.84	15.91	27.00	0.07	0.70	0.27	0.96	100
Border	#tires	2	418	442	12	108	68	272	415	0	66	101	112	2016
	Percent	0.10	20.73	21.92	0.60	5.36	3.37	13.49	20.59	0.00	3.27	5.01	5.56	100
All trucks	#tires	10	1744	2198	166	912	458	1554	2590	6	122	123	189	10072
	Percent	0.10	17.32	21.82	1.65	9.05	4.55	15.43	25.71	0.06	1.21	1.22	1.88	100

TANDEM/TRI-TANDEM AXLES

As shown in Table 17, tandem combination axles were widely used in truck configurations, while tri-tandem combination axles were uncommon. Comparisons between axles in border and non-border areas indicated similar results in tandem/tri-tandem axle usage.

Table 17 Usage of Tandem/Tri-tandem Axles

Items	All	Non-border	Border
Total # of axles surveyed	2,892	2,307	585
# of 2-axle tandem sets	2040	1640	400
Percent	70.54	71.09	68.38
# of triple axle tandem sets	27	18	9
Percent	0.93	0.78	1.54
Sum of tandem and tri-tandem axles	2,067	1,658	409
Percent	71.47	71.87	69.91

Table 18 shows very similar statistical descriptions of tandem/tri-tandem spacings found in all sampled trucks and trucks in non-border and border areas. A slightly higher average spacing was found for the tandem/tri-tandem axles in border areas than for those in non-border areas. As indicated in Chapter 4, spacings among all axles of each sampled truck were measured and are included in Appendix G.

Table 18 Description of Tandem/Tri-tandem Spacings

	Average (ft)	StDev (ft)	Number	Maximum (ft)	Minimum (ft)
All	4.23	0.22	1,034	6.0	3.08
Non-border	4.22	0.22	829	5.83	3.08
Border	4.25	0.23	205	6.0	3.42

VEHICLE CLASS

Tables 19 and 20 list breakdowns of the truck classes for all sampled trucks and for trucks in border and non-border areas. In each case, 3-S2 was the most common truck type traveling on Texas highways. A higher percentage of 3-S2s was observed in non-border areas than in border areas.

Table 19 Distribution of Truck Classes (overall)

Class	#Axles	#Trucks	Truck percentage
3-S2	2,500	500	80.3
SU-3	141	47	7.5
SU-2	78	39	6.3
2-S2	36	9	1.4
3-S3	42	7	1.1
2-S1	15	5	0.8
2-S1-2	25	5	0.8
3-S1	20	5	0.8
3-S1-2	24	4	0.6
4-S3	7	1	0.2
SU-4	4	1	0.2
Sum	2,892	623	100.0

Table 20 Distribution of Truck Classes (border and non-border areas)

Non-border				**Border**			
Class	#Axles	#Trucks	Truck percentage	Class	#Axles	#Trucks	Truck percentage
3-S2	2,075	415	85.9	3-S2	425	85	60.7
SU-2	46	23	4.8	SU-3	96	32	22.9
SU-3	45	15	3.1	SU-2	32	16	11.4
2-S2	32	8	1.7	3-S3	18	3	2.1
2-S1-2	25	5	1.0	2-S1	6	2	1.4
3-S1	16	4	0.8	2-S2	4	1	0.7
3-S1-2	24	4	0.8	3-S1	4	1	0.7
3-S3	24	4	0.8	Sum	585	140	100.0
2-S1	9	3	0.6				
4-S3	7	1	0.2				
SU-4	4	1	0.2				
Sum	2,307	483	100.0				

COMMODITY CATEGORY

Table 21 shows the commodity distribution for all sampled trucks and for the trucks in non-border and border areas. Interestingly, 28 percent of the sampled trucks were found empty or carrying empty containers. Detailed commodity counts with commodities coded in STCCC (Standard Transportation Commodity Classification Code) are attached in Appendix D.

Table 21 Distribution of Commodity Categories

	Farm products	Crude oil/gas	Ordnance	Food	Textile products	Lumber and paper products	Chemical/petro products	Clay/concrete/glass/stone	Metal/electr/misc products	Waste	Containers/returned empty	Commodity unknown	Misc freight	Sum
Non-border	25	14	4	53	11	42	41	53	97	12	102	8	9	471
Percent	5.31	2.97	0.85	11.25	2.34	8.92	8.70	11.25	20.59	2.55	21.66	1.70	1.91	100
Border	2	7	0	5	5	8	6	0	17	2	67	0	14	133
Percent	1.50	5.26	0.00	3.76	3.76	6.02	4.51	0.00	12.78	1.50	50.38	0.00	10.53	100
All	27	21	4	58	16	50	47	53	114	14	169	8	23	604
Percent	4.47	3.48	0.66	9.60	2.65	8.28	7.78	8.77	18.87	2.32	27.98	1.32	3.81	100

Figure 5 shows the comparison of commodity distributions in non-border and border areas. Significantly different distribution patterns exist for the two areas.

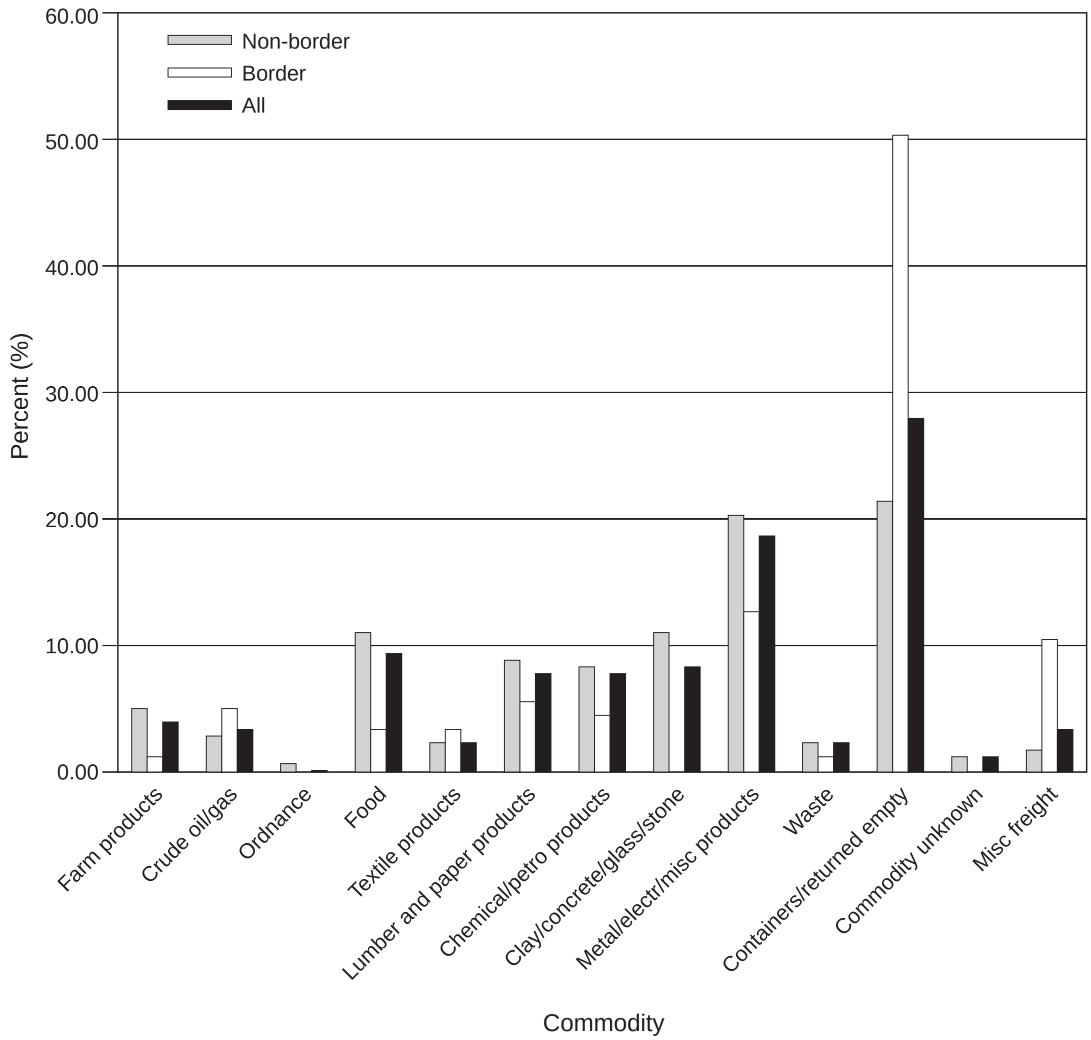


Figure 5 Distribution of Commodities

TRIP O/D CATEGORY

Table 22a shows the distribution of trip origin and destinations in non-border and border areas. Trips were categorized by whether they originated from or were bound for Texas, or originated or were bound for a destination out of Texas but still in the U.S. (including Canada) or Mexico.

Table 22b shows the distribution of trips by origins and destinations in non-border and border areas, and for the overall sample. Trips were categorized as (1) both origin and destination in Texas, (2) origin in Texas and a destination in the U.S. other than Texas, or origin in the U.S. other than Texas and a destination in Texas, (3) origin and destination both in the U.S. out of Texas, and (4) either origin or destination in Mexico.

Table 22a Distribution of Trip Origins and Destinations (1)

Trip Category		Origin			Destination		
		Texas	U.S.	Mexico	Texas	U.S.	Mexico
Non-border	Number	282	162	0	351	92	1
	Percent	63.51	36.49	0.00	79.05	20.72	0.23
Border	Number	54	9	77	91	1	48
	Percent	38.57	6.43	55.00	65.00	0.71	34.29

Table 22b Distribution of Trip Origins and Destinations (2)

Trip Category		Type (1)	Type (2)	Type (3)	Type (4)	Sum
Non-border	Number	222	186	34	1	443
	Percent	50.1	42.0	7.7	0.2	100.0
Border	Number	13	2	1	124	140
	Percent	9.3	1.4	0.7	88.6	100.0
Overall	Number	235	188	35	125	583
	Percent	40.3	32.2	6.0	21.4	100

As shown in Table 22b, in non-border areas 50 percent of the truck trips had both origin and destination in Texas, implying short travel distances; 42 percent of the truck trips were either from other U.S. states to Texas, or from Texas to other U.S. states, implying longer travel distances than those of the first type. However, 7.7 percent of the trips had both origin and destination in U.S. states other than Texas, probably with longer travel distances than the second type, and almost no Mexico-based trips were observed in the non-border areas. However, in the border areas percentages of trip types 1, 2, 3, and 4 were calculated to be 9.3 percent, 1.4 percent, 0.7 percent, and 88.6 percent, respectively, demonstrating a significant departure from the non-border areas.

As shown in Table 22a and Figure 6, very different trip O/D patterns were observed for non-border and border areas. While 55 percent and 34 percent of the trucks in border areas originated from and were bound for Mexico, respectively, only a few trucks in non-border areas had origins or destinations in Mexico. It was interesting to notice that most of the trucks in non-border areas had either an origin or a destination within Texas.

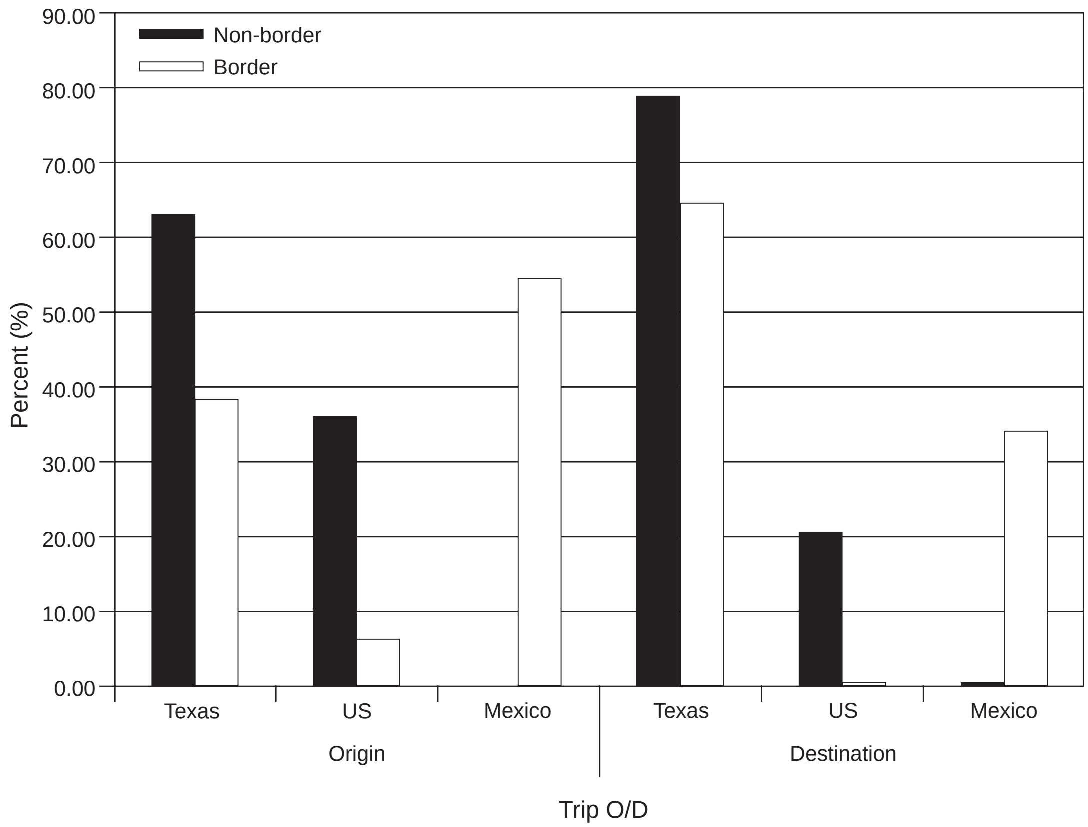


Figure 6 Distribution of Trip O/D

SUMMARY

Chapter 5 has presented general descriptions of all truck configuration parameters identified in Chapter 2. However, as the most important truck parameter among the collected data, truck tire pressure was given more detailed analysis. Therefore, in-depth tire pressure data analysis will be presented in Chapter 6.

CHAPTER 6 ANALYSIS OF TIRE PRESSURE AND RELATED DATA

Of all truck configuration parameters mentioned in Chapter 5, tire pressure is the most important because it is now increasingly recognized that truck tire pressure is an important factor in pavement deterioration (Pezo et al., 1989). The rate of highway pavement deterioration has been observed to be accelerating over the last 50 years (Eisenmann et al., 1987). A variety of loading factors, including increased truck weights, sizes, wheel loads, and axle loads, have been identified as contributing to the accelerated rate of pavement damage. The trend of increasing truck tire inflation pressure, and its effect on pavements, are also believed to have contributed to increased pavement deterioration.

In this chapter, the collected tire pressure data were corrected for temperature variability and analyzed in different ways to enable the researchers to conduct truck configuration comparisons. The relationship between tire pressure and temperature was characterized through lab experiments on truck tires and correlation analyses. The equality of average tire pressure in opposite highway directions was proved by data collected through the pilot surveys. Factors and parameters affecting tire pressure were studied by ANOVA, ANOCA, multiple comparisons, and linear regression.

TEMPERATURE EFFECTS

One objective of this research was to verify if factors such as geographical area, highway class, and highway direction are related to tire pressure. Testing the significance of these factors and comparing multiple levels within factors are the main topics of this chapter. However, tire temperature, a variable closely related to tire pressure, became the nuisance factor in the proposed analysis. Many variables, such as air and pavement temperatures, traveled distance, axle load, and road surface condition, could contribute to tire temperature changes, resulting in much variability in tire pressure observations. Tire temperature was measured but was uncontrollable, and the resulting variability might complicate the study of interest. Therefore, characterizing the relationship between tire pressure and tire temperature, and correcting the collected tire pressure data to standard temperatures could reduce the variability caused by tire temperature. In the following sections, tire pressure data collected from the field will be corrected for tire temperature by converting the data already corrected for gauge errors to new tire pressure values based on a 140 °F tire temperature representing the critical summer conditions. All the incoming tests and comparisons will be based on the manipulated data rather than on the raw data or the data corrected only for gauge errors.

Amonton's law and the ideal gas law, shown in Equations (49) and (50), respectively, can be employed to help us find the relationship between gas pressure and gas temperature. In Equation (49), P_i and T_i are gas pressure and absolute gas temperature. In Equation (50), R is the ideal gas constant, P is gas pressure in atmospheres, T is absolute gas temperature in degrees Kelvin, V is gas volume in liters, and n is the number of gas molecules in moles.

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} \qquad \text{(Eq. 49)}$$

$$PV = nRT \qquad \text{(Eq. 50)}$$

Equation (49) can be derived from Equation (50), letting *V, n,* and *R* be constant.

Let: $\Delta P = P_2 - P_1$, $\Delta T = T_2 - T_1$, and $\alpha = \frac{P_1}{T_1}$, then

$$\Delta P = \frac{\Delta T}{T_1} P_1 = \alpha.\Delta T \qquad \text{(Eq. 51)}$$

$$P_2 = P_1 + \alpha.\Delta T \qquad \text{(Eq. 52)}$$

$$\alpha = \frac{P_1}{T_1} = \frac{nR}{V} \qquad \text{(Eq. 53)}$$

Obviously, α is a constant if n and V are kept constant. In the case of a truck tire, the amount of air confined in the tire and the volume of the tire could be treated as approximately constant as long as the truck tire was operated in normal conditions. Therefore, if the tire pressure P_1 and the tire temperature T_1 under which P_1 is measured are obtained, then the projected tire pressure under a higher tire temperature T_2 is obtained simply by adding the product of the increase in temperature ΔT and the coefficient α to P_1.

As shown in Equation (53), the coefficient α, representing the tire pressure change per unit tire temperature change, is governed by the volume of the truck tire *(V)* and the amount of air contained in the tire *(n)*, implying different α*'s* for different tires. However, because the *V* is linearly related to *n*, a constant α might be assumed for all truck tires. Furthermore, the constancy of α is also dependent on the validity of the assumed linear relationship of *V* and *n*. To test the distribution of α, correlation and regression analyses were conducted for the collected tire pressure and temperature data, and the results are shown in the following MINITAB printouts in Table 23.

Table 23 Tire Pressure and Temperature Correlation Analysis

1) Descriptive Statistics: pressure

```
Variable            N         N*       Mean     Median     TrMean      StDev
pressure        9,600      5,033     96.748     99.000     97.828     15.029

Variable      SE Mean    Minimum    Maximum         Q1         Q3
pressure        0.153      0.000    154.000     90.000    106.000
```

2) Descriptive Statistics: temperature

```
Variable            N         N*       Mean     Median     TrMean      StDev
tempera         9,600      5,033     84.621     84.000     84.381     16.516

Variable      SE Mean    Minimum    Maximum         Q1         Q3
tempera         0.169      0.000    155.000     73.000     95.000
```

3) Correlations: pressure, temperature

		PRESSURE	TEMPERAT
PRESSURE	Pearson Correlation	1.000	.216**
	Sig. (2-tailed)	.	.000
	N	9600	9600
TEMPERAT	Pearson Correlation	.216**	1.000
	Sig. (2-tailed)	.000	.
	N	9600	9600

**. Correlation is significant at the 0.01 level (2-tailed).

4) Regression Analysis: pressure versus tempera

```
The regression equation is
pressure = 80.1 + 0.197 tempera

9,600 cases used 5,033 cases contain missing values
Predictor        Coef     SE Coef          T        P
Constant      80.0898      0.7818     102.44    0.000
tempera      0.196854    0.009068      21.71    0.000

S = 14.67      R-Sq = 4.7 percent      R-Sq(adj) = 4.7 percent

Analysis of Variance
Source            DF          SS          MS          F        P
Regression         1     101,469     101,469     471.25    0.000
```

Residual Error	9,598	2,066,624	215
Total	9,599	2,168,093	

To obtain the slope coefficient of α, tire pressure change per unit tire temperature change, an inflated truck tire was tested at different controlled oven temperatures in lab experiments. Refer to Appendix E for the detailed lab experiment procedure and data. The average α of the lab experiments was found to be 0.22 psi per degree F. Because the above regression found $\alpha \sim N(0.1969, 0.0091^2)$, the 99.7 percent confidence interval for α is (0.1697, 0.2241), in which 0.22 was included. Therefore, Equation (52) with an α of 0.22 was used to convert all collected tire pressure data to a critical summer pressure level, with the tire temperature assumed to be 140 °F. Most standard deviations were reduced after the tire temperature variability correction. However, the projected tire pressure data should be used with caution for the following reasons:

1) The conversion did not consider the variation of α among tires, but assumed identical values for the whole sample. However, the following analyses were all based on the data averaged from tire groups, and it would be intuitively correct to assume an identical α if a group of tires were pooled together.

2) The conversion would not be valid if the tire pressures were regulated intentionally. Talks with truck drivers showed that truck drivers inflated truck tires only when it was necessary to do so. However, it would still be intuitively correct to expect higher truck tire pressures in summer than in winter.

3) The regression did not consider the difference in geographical areas, highway classes, or highway directions because it assumed identical regression coefficients over all data sets. Actually, the coefficient of "constant" in the regression model could change for different geographical areas, highway classes, or highway directions, even with α, the coefficient of slope, kept constant.

DIRECTION COMPARISONS

To test the equality of truck configurations and tire pressures for opposite highway directions, we collected pilot survey data for southbound and northbound directions of I-35 near San Marcos, and for eastbound and westbound directions of I-20 at Odessa. The collected data were corrected both for gauge errors and for tire temperature effects. Data analysis results of the two locations indicated no significant differences, which not only negated the need for further highway direction testing, saving time and cost, but also helped solve the difficulty in finding enough DPS weigh stations where both directions were operational.

1) Analysis of San Marcos Data

The test was carried out in two steps. First, every tire was treated as an independent observation, and southbound and northbound tire pressure means were compared. The results of this step for southbound and northbound tire pressure data are described in Table 24.

Table 24 Tire Pressures, Northbound (NB) and Southbound (SB) along I-35 near San Marcos (sample of tires)

Direction	# of Tires	Minimum	Maximum	Mean	Std. Deviation
Tires SB	472	27.88	142.80	106.96	13.01
Tires NB	498	7.26	137.50	105.44	15.26

The numbers of tires in the two directions were 472 and 498, well above the minimum size of 30. Therefore, normal distributions for SB and NB tire pressures were assumed. The following hypothesis and test were conducted.

$\mathrm{H}_0 : \bar{y}_1 = \bar{y}_2$ (Mean tire pressures are equal for opposite directions)

$$S_w^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}$$

$$t = \frac{\bar{y}_1 - \bar{y}_2}{S_w \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$\mathrm{n}_1 = 472,\ \bar{y}_1 = 106.96,\ \mathrm{S}_1^2 = 13.01^2$

$\mathrm{n}_2 = 498,\ \bar{y}_2 = 105.44,\ \mathrm{S}_2^2 = 15.26^2$

then

$S_w^2 = 14.2^2$

$t = 1.67 < Z_{2.5\%} = 1.96$

So, the null hypothesis H_0 cannot be rejected at a 95 percent confidence level.

Based on the above analysis, for a 95 percent confidence level, there was not a significant difference between tire pressure means of southbound and northbound tires. However, the possible homogeneity of tires within individual trucks might have invalidated the above test results because of the possible violation of the assumption of independent tire observations. Therefore, the above test procedure was conducted again for samples of trucks, which could hold the independent assumption with more certainty.

Secondly, the average tire pressure of each truck was treated as an independent observation to compare the (truck average) tire pressure means of southbound and northbound trucks. Average tire pressures of trucks are described in Table 25.

Table 25 Truck Average Tire Pressures, Northbound (NB) and Southbound (SB) along I-35 near San Marcos (sample of trucks)

Direction	# of Trucks	Minimum	Maximum	Mean	Std. Deviation
TRUCK_SB	30	97.10	119.74	106.78	5.06
TRUCK_NB	33	79.69	119.99	106.30	8.76
Valid N (listwise)	30				

A similar hypothesis test was conducted for the truck average pressures.

$H_0 : \bar{y}_1 = \bar{y}_2$

then,

$n_1 = 30,\ \bar{y}_1 = 106.78,\ S_1^2 = 5.06^2$

$n_2 = 33,\ \bar{y}_2 = 106.30,\ S_2^2 = 8.76^2$

then,

$S_w^2 = 7.24^2$

$t = 0.263 < Z_{2.5\%} = 1.96$

So, again the null hypothesis H_0 cannot be rejected at a 95 percent confidence level.

Based on the above analysis, for a 95 percent confidence level, there was no significant difference between the truck-average tire pressures of southbound and northbound trucks on I-35 near San Marcos.

2) Analysis of Odessa Data

The Odessa data characterizing eastbound versus westbound trucks on I-20 did not show any significant difference between highway directions, either on the tire or on the truck level. The test procedure for truck average tire pressures is described in Table 26.

Table 26 Truck Average Tire Pressures, Eastbound (EB) and Westbound (WB) along I-20 near Odessa (sample of trucks)

Direction	# of Trucks	Minimum	Maximum	Mean	Std. Deviation
TRUCK_WB	35	103.29	132.92	112.79	7.22
TRUCK_EB	35	98.64	126.38	112.24	6.23
Valid N (listwise)	35				

$n_1 = 35,\ \bar{y}_1 = 112.79,\ S_1^2 = 7.22^2$

$n_2 = 35, \bar{y}_2 = 112.24,\ S_2^2 = 6.23^2$

then,

$S_w^2 = 6.74^2$

$t = 0.34 < Z_{2.5\%} = 1.96$

So, the null hypothesis cannot be rejected at a 95 percent confidence level

Based on the above analysis, there was no significant difference between eastbound and westbound truck-average tire pressure means on I-20 near Odessa.

3) Conclusions

1. For a 95 percent confidence level, there was no significant difference in average tire pressure between southbound and northbound trucks on I-35 near San Marcos, on both the tire level and the truck level.
2. For a 95 percent confidence level, there was no significant difference of average tire pressure between westbound and eastbound trucks on I-20 near Odessa, on both the tire level and the truck level.
3. There was some risk in assuming every tire to be an independent observation. The sample units were NOT randomly selected from the whole tire population. The dependence and interrelation between observation units could contribute to overestimation or underestimation and invalidate the hypothesis test.
4. Odessa and San Marcos were two randomly and independently selected pilot survey locations hundreds of miles apart in two different geographical areas. Therefore, the above test results are likely valid, and the equality of truck tire pressure configurations between opposite highway directions can be concluded and extended to other locations.

ANOVA AND FACTORIAL EFFECTS

In Chapter 2, two experimental designs were proposed. The original design included three factors—geographical areas, highway classes, and highway directions—with six, two, and two levels in each factor, respectively. With pilot surveys conducted at San Marcos and Odessa, the highway direction factor was dropped from the design, and the original plan was revised to have two factors. The effective data for the revised factorial design are described in Table 27. Truck tire pressure configuration data (obtained by averaging all tires of each truck) corrected for tire temperature variability were input for a two-way ANOVA using the factors "area" and "hwyclass." The MINITAB printouts for the 4×2 factorial design are shown in Table 28.

Table 27 Data Arrangement for the Two-Factor Experiment

<table>
<tr><th rowspan="2">Hwy class</th><th colspan="4">Area</th></tr>
<tr><td>Lubbock-Midland</td><td>Dallas</td><td>Houston</td><td>Corpus Christi</td></tr>
<tr><td rowspan="2">Inter-state</td><td>Odessa
I-20WB</td><td>Mt. Pleasant
I-30WB</td><td>Katy
I-10EB</td><td rowspan="2">Three Rivers
I-37SB</td></tr>
<tr><td>Odessa
I-20EB</td><td>Mt. Vernon
I-30EB</td><td>Centerville
I-45 SB</td></tr>
<tr><td rowspan="2">State</td><td rowspan="2">Childress
US287SB</td><td rowspan="2">Denison
US75SB</td><td rowspan="2">Victoria
US59SB</td><td>Riviera
US77NB</td></tr>
<tr><td>Falfurrias
US281SB</td></tr>
</table>

Table 28 Two-way ANOVA Analysis of Tire Pressure for Factors of Geographical Area and Highway Class

General Linear Model: press versus area, hwyclass

```
Factor     Type Levels Values
area      fixed      4 Corpus  Dallas  Houston Mid-Lub
hwyclass  fixed      2 interstate state

Analysis of Variance for press, using Adjusted SS for Tests
Source          DF     SEq. SS     Adj SS     Adj MS      F      P
area             3    1,003.26    1,763.47   587.82   11.58  0.000
hwyclass         1      748.63      748.63   748.63   14.74  0.000
area*hwyclass    3    1,030.89    1,030.89   343.63    6.77  0.000
Error          412   20,921.93   20,921.93    50.78
Total          419   23,704.71
```

The F-test and P-value in the ANOVA results showed that the main factors "area" and "hwyclass" and the interaction factor "area*hwyclass" were all significant, meaning that 1) trucks in different geographical areas had different tire pressures; 2) trucks in different highway classes had different tire pressures; and 3) interaction between the above two factors existed. The ANOVA also showed that the main factor "hwyclass" ranked first in significance, the main factor "area" second, and the interaction factor "area*hwyclass" last.

ANOCA for the collected tire pressure data (corrected for gauge errors but uncorrected for tire temperature) along with tire temperature data was also conducted, as shown in the MINITAB printout in Table 29.

Table 29 Two-way ANOCA Analysis of Tire Pressure and Tire Temperature for Factors of Geographical Area and Highway Class

General Linear Model: press versus area, hwyclass

```
Factor     Type Levels Values
area      fixed      4 Corpus  Dallas  Houston Lub-Mid
hwyclass  fixed      2 interstate state

Analysis of Variance for press, using Adjusted SS for Tests
Source          DF     SEq. SS     Adj SS     Adj MS       F       P
temp             1    4,106.72    2,956.18   2,956.18   58.64  0.000
area             3      887.44    1,574.36     524.79   10.41  0.000
hwyclass         1      776.32      720.64     720.64   14.30  0.000
area*hwyclass    3      994.56      994.56     331.52    6.58  0.000
Error          411   20,717.80   20,717.80      50.41
Total          419   27,482.84

Term                  Coef   SE Coef       T       P
Constant            78.131     2.688    29.07  0.000
temp               0.24009   0.03135     7.66  0.000
```

As expected, the ANOCA analysis showed almost the same results as the previous ANOVA; plus it showed that "temp" had a significant effect, which was already known. It is not surprising that the two analyses showed the same results. Actually, the idea of correcting tire pressure for tire temperature variability was borrowed from the ANOCA. The ANOCA also showed the order of significance of the factors. The "temp" covariate variable of tire pressure ranked first in significance. The main factors "hwyclass" and "area" ranked second and third, respectively, and the interaction factor "area*hwyclass" was the least significant.

Interestingly, the ANOCA also gave another estimate of the tire pressure–tire temperature slope α, i.e., $\alpha \sim N(0.241, 0.03^2)$. The null hypothesis of $\alpha = 0.22$ could not be rejected for 95 percent confidence, because

$$t = \left|\frac{\alpha - \mu}{\sigma}\right| = \left|\frac{0.22 - 0.241}{0.03}\right| = 0.7 < Z_{0.025} = 1.96\,.$$

So the validity of $\alpha = 0.22$ was again proved.

Figures 7 through 9 show the effects of the test factors. Figure 7 shows the difference in average tire pressure in different areas. San Antonio/Austin was not included in the ANOVA test because of the lack of data collected on a state-class highway in that area. However, the geographical effect will be discussed later in detail. In Figure 8, the main factor "hwyclass" showed a higher tire pressure mean for interstate highways than for state highways. Although the interaction of the two main factors leads to non-parallelism of the effect curves, effects in Figure 9 show that trucks on interstate highways tend to have more uniform tire pressures through all geographical regions than trucks on non-interstate routes do.

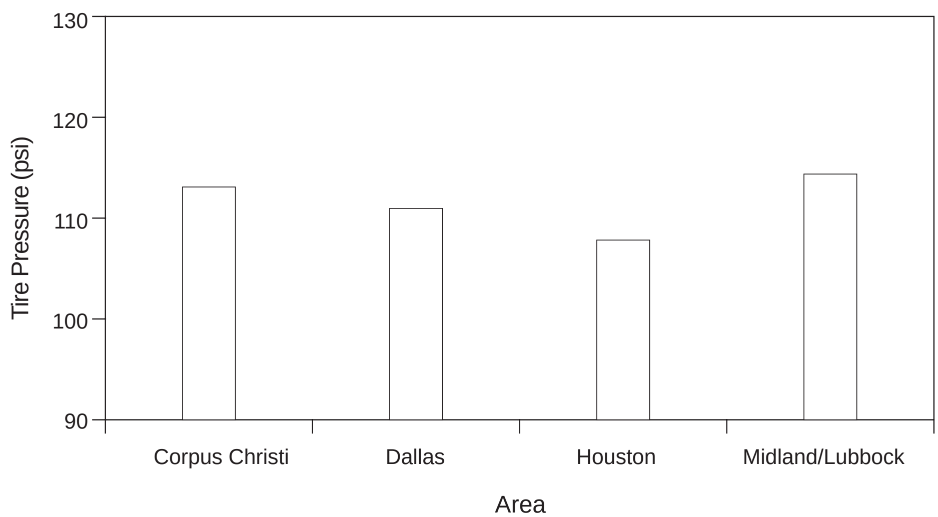


Figure 7 Tire Pressures versus Texas Geographical Areas

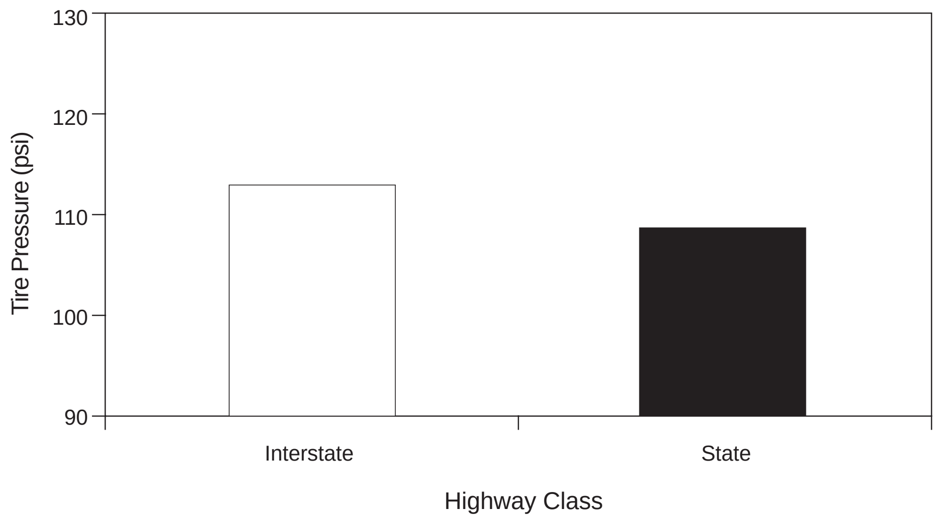


Figure 8 Tire Pressures versus Highway Classes

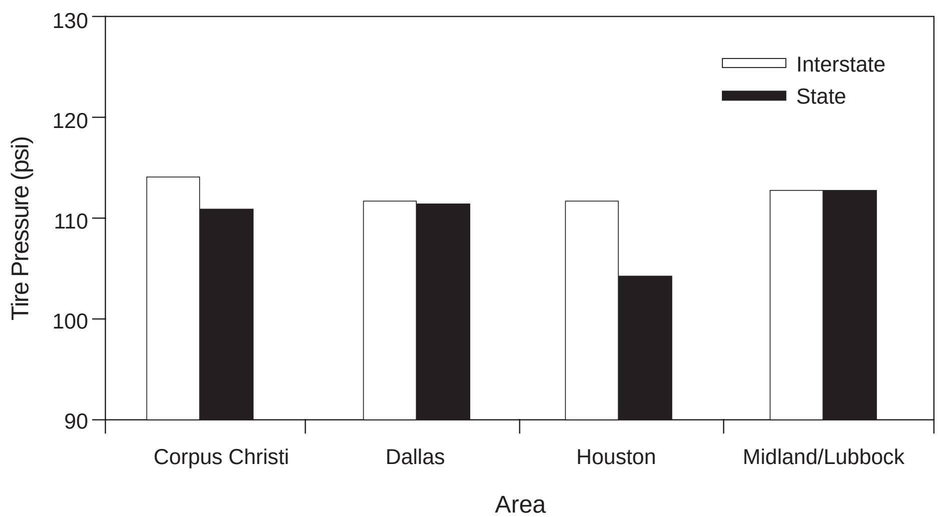


Figure 9 Interaction of Geographical Areas and Highway Classes

TEXAS AREA COMPARISONS

The preceding section conducted a factorial test of tire pressure configuration variation across geographical areas and highway classes. In this section, special attention will be given to comparisons among geographical areas.

Table 2 in Chapter 3 is rewritten in Table 30 with the factor "highway class" removed. Truck tire pressure data (obtained by averaging all the tires of each truck) corrected for tire temperature were compared using the one-way ANOVA of the factor "area." MINITAB printouts for the one-way test are shown in Table 31.

Table 30 Data Arrangement for the One-Factor Experiment

	Area					
	Dallas	Houston	Corpus	Aus/San	Mid-Lub	Border
Location	Mt. Pleasant I-30 WB	Katy I-10 EB	Three Rivers I-37 SB	San Marcos I-35 SB	Odessa I-20 WB	El Paso Lp 375 WB
	Mt. Vernon I-30 EB	Victoria US 59 SB	Riviera US 77 NB	San Marcos I-35 NB	Odessa I-20 EB	El Paso Lp 375 EB
	Denison US 75 SB	Centerville I-45 SB	Falfurrias US 281 SB		Childress US 287 SB	Laredo
						Brownsville
# of Locations	3	3	3	2	3	4
# of Trucks	105	105	105	63	105	140

Table 31 One-way ANOVA of Tire Pressure for Factor of Geographical Areas

Descriptive Statistics: Dallas, Houston, Corpus, Aus-San, Mid-Lub, Border

Variable	N	Mean	Median	TrMean	StDev	SE Mean
Dallas	105	110.81	111.00	111.16	7.93	0.77
Houston	105	108.49	108.00	108.63	8.26	0.81
Corpus	105	111.37	111.00	111.32	6.51	0.64
Aus-San	63	106.54	107.00	106.84	7.19	0.91
Mid-Lub	105	112.77	112.00	112.40	6.68	0.65
Border	140	101.00	101.00	101.25	11.43	0.97

Variable	Minimum	Maximum	Q1	Q3
Dallas	72.00	130.00	106.00	115.50
Houston	87.00	126.00	103.50	115.00
Corpus	92.00	132.00	107.00	116.00
Aus-San	80.00	120.00	102.00	111.00
Mid-Lub	99.00	133.00	108.00	116.50
Border	61.00	127.00	94.25	109.00

One-way ANOVA: Dallas, Houston, Corpus, Aus-San, Mid-Lub, Border

Analysis of Variance for press

Source	DF	SS	MS	F	P
area	5	11405.2	2281.0	31.93	0.000
Error	617	44073.1	71.4		
Total	622	55478.3			

```
                                   Individual 95 percent CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  --+---------+---------+---------+----
Aus-San     63    106.54      7.19                (----*-----)
Border     140    101.00     11.43   (---*--)
Corpus     105    111.37      6.51                            (---*---)
Dallas     105    110.81      7.93                           (---*---)
Houston    105    108.49      8.26                     (---*---)
Mid-Lub    105    112.77      6.68                                (---*---)
                                    --+---------+---------+---------+----
Pooled StDev =     8.45           100.0     104.0     108.0     112.0
```

Turkey's pairwise comparisons

Family error rate = 0.0500

Individual error rate = 0.00452

Critical value = 4.03

Intervals for (column level mean) - (row level mean)

	Aus-San	Border	Corpus	Dallas	Houston
Border	1.886 9.194				
Corpus	-8.670 -0.994	-13.481 -7.262			
Dallas	-8.108 -0.432	-12.919 -6.700	-2.762 3.886		
Houston	-5.784 1.892	-10.595 -4.376	-0.438 6.210	-1.000 5.648	
Mid-Lub	-10.070 -2.394	-14.881 -8.662	-4.724 1.924	-5.286 1.362	-7.610 -0.962

As expected, the one-way ANOVA test showed significantly different truck tire pressures in different Texas areas. The 95 percent confidence level intervals for estimation of the area means and the Turkey's pairwise comparisons concluded that area means were ranked in an ascending order as Border, Austin/San Antonio, Houston, Dallas, Corpus Christi, and Midland/Lubbock. Turkey's multiple comparisons exhibited the grouping pattern shown in Figure 10. Note that the "Border" mean was the lowest and was distinctly different from the rest of Texas. Figure 11 shows the area effect in the one-way ANOVA analysis.

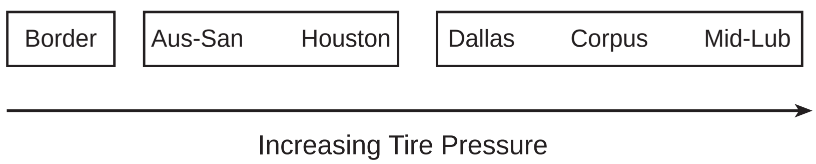


Figure 10 Tire Pressures Grouped by Geographical Areas

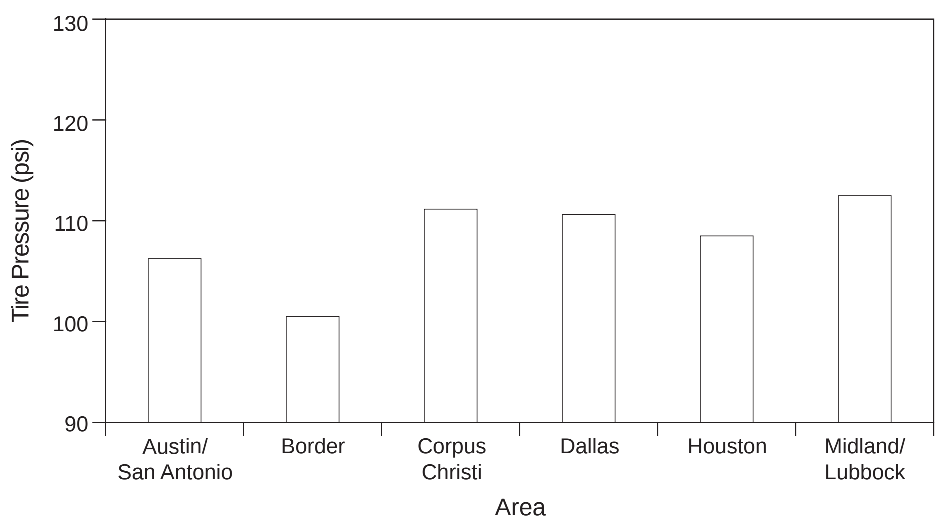


Figure 11 Tire Pressures versus Geographical Areas (including border areas)

BORDER VERSUS NON-BORDER COMPARISON

In Section 6.4 the “Border” area was tested along with other Texas areas and was found to be significantly different from the other areas. This time the data were rearranged so that “Border” areas and “Non-border” areas could be compared in a one-way ANOVA of two levels, as shown in Table 32. Truck tire pressure data (obtained by averaging all the tires of each truck) corrected for tire temperature were entered into MINITAB, and the ANOVA results are shown in Table 33. The F test value of 126.35 and the P value of 0.00 well demonstrated the significant difference between the truck tire pressure configurations of the border areas and those in the non-Texas areas. The 95 percent confidence intervals for the two means are also shown in the printout.

Table 32 Data Arrangement for the Border versus Non-border Comparison

	Area					
	Non-Border					Border
Location	Mt. Pleasant I-30 WB	Katy I-10 EB	Three Rivers I-37 SB	San Marcos I-35 SB	Odessa I-20 WB	El Paso Loop375 WB
	Mt. Vernon I-30 EB	Victoria US 59 SB	Riviera US 77 NB	San Marcos I-35 NB	Odessa I-20 EB	El Paso Loop375 EB
	Denison US 75 SB	Centerville I-45 SB	Falfurrias US 281 SB		Childress US 287 SB	Laredo
						Brownsville
# of Locations	14					4
# of Trucks	483					140

Table 33 One-way ANOVA of Tire Pressure for

Factor of Border and Non-border Areas

Descriptive Statistics: NBorder, Border

Variable	N	Mean	Median	TrMean	StDev	SE Mean
NBorder	483	110.30	110.00	110.41	7.61	0.35
Border	140	101.00	101.00	101.25	11.43	0.97

Variable	Minimum	Maximum	Q1	Q3
NBorder	72.00	133.00	106.00	115.00
Border	61.00	127.00	94.25	109.00

One-way ANOVA: Press versus Area

```
Analysis of Variance for Press
Source     DF        SS        MS       F       P
Area        1   9,379.6   9,379.6  126.35   0.000
Error     621  46,098.7      74.2
Total     622  55,478.3
                                   Individual 95 percent CIs For Mean
                                   Based on Pooled StDev
Level       N     Mean     StDev   ------+---------+---------+---------+
Border    140   101.00     11.43   (----*---)
NBorder   483   110.30      7.61                               (-*-)
                                   ------+---------+---------+---------+
Pooled StDev =    8.62               101.5     105.0     108.5     112.0

Turkey's pairwise comparisons
    Family error rate = 0.0500
Individual error rate = 0.0500
Critical value = 2.78
Intervals for (column level mean) - (row level mean)
           Border
 NBorder     -10.920
              -7.672
```

Furthermore, the difference among the three border areas was tested using a one-way ANOVA. Truck tire pressures were corrected for gauge errors and tire temperatures and then entered into MINITAB. Table 34 shows the outputs of the descriptive statistics, the one-way ANOVA test, the 95 percent confidence intervals for the estimated means, and the Turkey's multiple comparisons.

Table 34 One-way ANOVA of Tire Pressure for Factor of Different Non-border Areas

Descriptive Statistics: El Paso, Laredo, Brown

Variable	N	Mean	Median	TrMean	StDev	SE Mean
ElPaso	70	103.76	104.18	104.03	11.49	1.37
Laredo	35	97.42	97.88	97.34	8.97	1.52
Brown	35	99.16	99.48	100.10	12.43	2.10

Variable	Minimum	Maximum	Q1	Q3
ElPaso	74.22	126.70	95.29	112.45
Laredo	81.39	118.31	89.82	103.65
Brown	60.58	118.47	93.90	107.99

One-way ANOVA: press versus area

Analysis of Variance for press

Source	DF	SS	MS	F	P
area	2	1,098	549	4.40	0.014
Error	137	17,094	125		
Total	139	18,192			

```
                                   Individual 95 percent CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
Brown      35     99.16     12.43        (---------*----------)
ElPaso     70    103.76     11.49                        (------*-------)
Laredo     35     97.42      8.97   (---------*----------)
                                   ---+---------+---------+---------+---
Pooled StDev =    11.17            94.5      98.0     101.5     105.0
```

Turkey's pairwise comparisons
Family error rate = 0.0500
Individual error rate = 0.0192
Critical value = 3.35
Intervals for (column level mean) - (row level mean)

	Brown	El Paso
El Paso	-10.07 0.88	
Laredo	-4.59 8.06	0.86 11.81

The F test obtained a 4.4 with a P- value of 0.014, which implied a moderate difference among the three border areas. The 95 percent confidence intervals for the estimated means and the Turkey's multiple comparisons showed that the average truck tire pressures in Laredo and Brownsville were more similar to each other than to those of El Paso. Trucks in El Paso tended to have a higher tire pressure than those in Laredo and Brownsville.

AXLE COMPARISON FOR 3-S2 TRUCKS

Tire pressure comparisons were conducted among the five axles of the 500 3-S2 trucks in the sample. All tires in the same axle were pooled and averaged to represent the axle tire pressure condition. Data were corrected for both gauge errors and tire temperature and entered into MINITAB. The MINITAB printouts are shown in Table 35.

Table 35 One-way ANOVA of Tire Pressure for Factor of Different Truck Axles

Descriptive Statistics: Axle1, Axle2, Axle3, Axle4, Axle5

Variable	N	N*	Mean	Median	TrMean	StDev
Axle1	499	1	114.04	114.99	114.21	10.40
Axle2	500	0	109.04	109.44	109.44	10.67
Axle3	498	2	108.91	110.06	109.22	10.51
Axle4	491	9	109.28	110.08	109.88	11.46
Axle5	491	9	107.93	109.23	108.62	12.11

Variable	SE Mean	Minimum	Maximum	Q1	Q3
Axle1	0.47	74.96	142.58	107.58	121.00
Axle2	0.48	59.00	135.53	103.08	116.28
Axle3	0.47	64.43	138.79	103.40	115.99
Axle4	0.52	59.05	139.96	103.56	116.68
Axle5	0.55	42.50	139.01	102.51	115.36

One-way ANOVA: Press versus Axle

Analysis of Variance for Press

Source	DF	SS	MS	F	P
Axle	4	11,488	2872	23.54	0.000
Error	2,474	301,813	122		
Total	2,478	313,301			

```
                                   Individual 95 percent CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
Axle1     499    114.04     10.40                         (---*---)
Axle2     500    109.04     10.67       (---*---)
Axle3     498    108.91     10.51       (---*---)
Axle4     491    109.28     11.46        (---*---)
Axle5     491    107.93     12.11   (---*---)
                                   ---+---------+---------+---------+---
Pooled StDev =   11.05            107.5     110.0     112.5     115.0
```

The one-way ANOVA results showed a significant difference among the five axles of the 3-S2s. Comparisons were shown in the 95 percent confidence intervals and Turkey's multiple comparisons. Most prominently, the first axle (steering axle) possessed a much higher axle tire pressure mean than the other four axles did. Axles 2 and 3 (drive axles) were almost the same both in mean values and in confidence intervals. By contrast, axles 4 and 5 (trailer axles) were very different from each other, although they were part of the same tandem axle. Actually, during the survey many trailers had ownership different from that of the truck and frequently had poorer maintenance than the truck, partially explaining the greater deviation of tire pressure means of trailer axles compared to drive axles. The five axles were arranged in ascending order (from left to right) in tire pressure mean and grouped by boxes as shown in Figure 12.

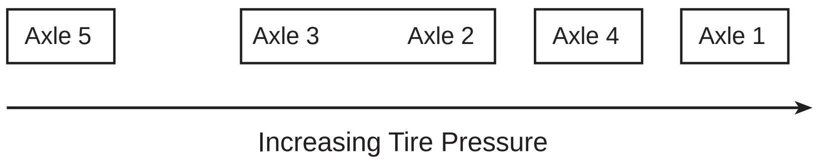


Figure 12 Tire Pressures Grouped by Truck Axles

COMPARISON OF TRIP TYPES

Tire pressure means of different trip O/D types were compared using a one-way ANOVA. A total of 583 truck tire pressures projected for the summer critical condition and corrected for tire gauge errors, and organized under the four trip O/D types were entered into MINITAB. The printouts are shown in Table 36.

Table 36 One-way ANOVA of Tire Pressure for Factor of Trip Types

One-way ANOVA: Pressure versus Trip type

```
Analysis of Variance for pressure
Source     DF        SS        MS        F        P
Trip typ    3   12,948.7    4,316.2    63.12    0.000
Error     579   39,593.9      68.4
Total     582   52,542.6
                                   Individual 95 percent CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+---------+---------+---------
1         235    109.13      7.83                   (-*-)
2         188    111.86      6.56                       (-*-)
3          35    114.22      7.59                         (---*----)
4         125     99.73     11.08   (-*--)
                                   -------+---------+---------+---------
Pooled StDev =     8.27                102.0     108.0     114.0
```

In the above ANOVA printout, trip O/D types were defined as Type1, origin and destination both in Texas; Type2, origin in Texas and destination in other U.S. states, or origin in other U.S. states and destination in Texas; Type3, origin in other U.S. states and destination in other U.S. states; and Type4, origin or destination in Mexico. Generally speaking, Type3 trips had the longest trip distances; Type2 trips were second-longest; Type1 trips were shortest; and trip distances of Type4 could not be judged from the available information.

The ANOVA test results yielded very significant differences among tire pressure means of the four trip types. Ninety-five percent confidence intervals of tire pressure means showed that trips originating from or bound for Mexico had the lowest tire pressure; the longer the trip distances, the higher the tire pressure means were. Figure 13 shows the ascending order in tire pressure means of the four trip types.

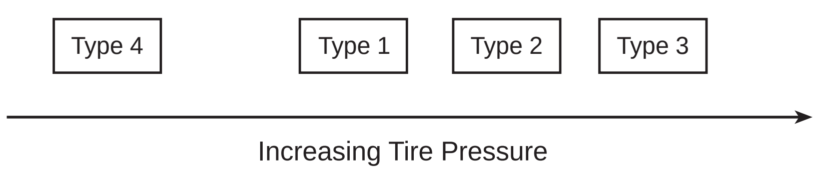


Figure 13 Tire Pressures Grouped by Trip Types

COMPARISON OF COMMODITY CATEGORIES

Tire pressure means of different commodity categories under the names defined by the STCCC were compared using a one-way ANOVA. A total of 596 effective truck tire pressures projected for the summer critical condition, corrected for tire gauge errors, and under 23 STCC commodity categories were entered into MINITAB, and the printout is shown in Table 37.

Table 37 One-way ANOVA of Tire Pressure for Different Commodity Categories

One-way ANOVA: pressure versus STCC Code

```
Analysis of Variance for pressure
Source     DF        SS        MS        F        P
STCC Cod   22    5,380.3     244.6     2.90    0.000
Error     573   48,272.6      84.2
Total     595   53,652.9
                                   Individual 95 percent CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
 1         27    111.21      5.46          (--*--)
13         21    113.14      5.83           (--*---)
19          4    107.98      4.12  (-------*------)
20         58    110.75      7.99          (-*-)
22          7    113.94      8.85         (-----*-----)
23          9    110.67      9.14       (----*----)
24         10    113.81     10.14          (----*----)
25          6    108.33      2.06    (-----*-----)
26         29    107.90      9.87       (--*--)
27          5    110.41      3.24     (------*------)
28         15    109.41      9.23       (---*---)
29          6    112.15      7.18       (-----*------)
30         26    106.50     11.19      (--*--)
32         53    110.20      8.30          (-*-)
33         14    109.38      6.80       (---*---)
34         35    110.17      8.38         (--*-)
35         21    109.03     11.07        (--*--)
36         16    108.03      5.66      (---*---)
38          1    121.85      0.00       (--------------*--------------)
39         27    110.83      9.75         (--*--)
40         14    108.33     14.26      (---*---)
41         23    107.26     10.01      (--*---)
42        169    104.24     10.02      (*)
                                   --------+---------+---------+--------
Pooled StDev =     9.18                  108       120       132
```

The F test and associated P-values show that significant differences of tire pressure means existed between different commodity categories. The tire pressure mean, standard deviation, and number of trucks counted for each commodity category are listed in Table 38.

Table 38 Truck Tire Pressures for Commodity Categories

Good Category	STCC Code	Average	Stdev	Count
containers/returned empty	42	104.24	10.02196	169
rubber/plastics products	30	106.50	11.18529	26
misc freight	41	107.26	10.01148	23
pulp/paper products	26	107.90	9.869147	29
ordnance	19	107.98	4.124488	4
electrical machinery/equip/supply	36	108.03	5.657554	16
furniture	25	108.33	2.061921	6
waste	40	108.33	14.25971	14
machinery excluding electrical	35	109.03	11.07022	21
primary metal products	33	109.38	6.798612	14
chemicals	28	109.41	9.228789	15
fabricated metal products	34	110.17	8.382992	35
clay/concrete/glass/stone	32	110.20	8.304609	53
printed matter	27	110.41	3.241713	5
finished textile products	23	110.67	9.139875	9
food	20	110.75	7.985285	58
misc products	39	110.83	9.745329	27
farm products	1	111.21	5.463976	27
petro/coal products	29	112.15	7.175768	6
crude oil/gas	13	113.14	5.828185	21
lumber products	24	113.81	10.14353	10
textile mill products	22	113.94	8.848741	7
instruments	38	121.85	*	1

The truck tire pressure means (data projected for summer conditions) shown in the above table demonstrated a reasonable pattern in the distribution of truck tire pressure means over commodity categories. The empty trucks had the lowest tire pressures; rubber/plastics products, paper products, electrical equipment, furniture, and waste were the second lowest in tire pressure means; machinery, metal products, chemicals, and foods had next to the highest tire pressure means; and farm products, petroleum products, and lumbers had the highest tire pressure means. Some commodity categories, such as instruments, textile products, and printed paper products, were difficult to judge because of the small size in each commodity category.

SUMMARY

This chapter has presented in-depth tire pressure data analysis. So far, the collected tire pressure data have been analyzed to identify possible factors that are affecting truck tire pressures significantly. In Chapter 7, the tire pressure analysis will be continued, complementing Chapter 6 with more related studies.

CHAPTER 7 RELEVANT STUDIES

This chapter will complement the tire pressure data analysis in Chapter 6. In this chapter, newly collected tire pressure data are compared with historic tire pressure data to determine whether there are any changes over the years. The assumptions regarding tire pressure data in the experiment design and the data analysis are also checked in this chapter. Current tire pressure data are compared with findings of previous studies, and the assumptions of homogeneous tires within a truck and elevated summertime truck tire pressures are also investigated.

COMPARISONS WITH 1986 TEXAS DATA

The Texas Transportation Institute (TTI) conducted a similar tire pressure survey during the period from 1982 through 1986 (Roberts et al., 1986). The comparable survey results of TTI in 1986 and CTR in 2000 are shown and compared in Tables 39 through 41.

Table 39 lists the tire data computed from the four major truck classes, e.g., 3-S2, SU-3, SU-2, and 2-S2, for both surveys. Comparison of the tire data exhibited a significant decrease in usage of bias-ply tires. Today's trucks are riding almost exclusively on radial-ply tires, which typically have 10 to 20 psi higher pressure than the bias-tires. Although there was only a 3.7 psi increase in the average of collected current tire pressure over the older data, the CTR-projected summer average tire pressure showed a 15.8 psi increase, which was very significant.

Table 39 Comparison of TTI and CTR Tire Data (over major truck classes)

	Percent of bias tires	Avg collected tire pressure (psi)	Projected summer avg (psi)
TTI (1986)	32.22	93.12	*
CTR (2000)	2.23	96.78	108.94

Although the two surveys differed from each other regarding classes of trucks observed and truck sample distribution, 3-S2, SU-3, SU-2, and 2-S2 were the four most common truck classes for both surveys, as shown in Table 40. The percentage of 3-S2s increased from 69.52 percent in 1986 to 80.26 percent in 2000, constituting a significant change in trucking fleet composition. In the same time, usage of 2-S2s showed a moderate drop. Usage of SU-3s and SU-2s remained almost unchanged

Table 40 Comparison of Truck Class Distributions

TTI (1982–1986)			**CTR (2000)**		
Class	# Trucks	Truck percent	Class	# Trucks	Truck percent
3-S2	1,033	69.52	3-S2	500	80.26
2-S2	52	3.50	SU-3	47	7.54
SU-3	90	6.06	SU-2	39	6.26
SU-2	86	5.79	2-S2	9	1.44
3-2	11	0.74	3-S3	7	1.12
2-S1-2	6	0.40	2-S1	5	0.80
2-S1	13	0.87	2-S1-2	5	0.80
Other	195	13.12	3-S1	5	0.80
Sum	1486	100	3-S1-2	4	0.64
			4-S3	1	0.16
			SU-4	1	0.16
			Sum	623	100

Although the CTR data were collected in winter, almost every area tire pressure mean of the CTR data showed an increase over those of TTI. Furthermore, the CTR-projected summer tire pressure means showed more than a 10 psi increase over the TTI data. Also noticeable is the comparison between all 3-S2s in the TTI data and all trucks in the CTR data.

Table 41 Comparison of Area Tire Pressure Means

Area	3-S2s of TTI (1982–1986)	All Trucks of CTR (2000)	
	Data Mean (psi)	Data Mean (psi)	Projected Mean (psi)
Dallas	91.68	100.44	111.34
Houston	92.58	95.65	109.00
Corpus Christi	96.75	98.95	111.60
Austin/San Antonio	94.60	96.77	106.18
Lubbock/Midland	101.34	100.88	112.81

AIR TEMPERATURE AND PAVEMENT TEMPERATURE

This report and the data analysis provide projected tire pressure data for the summer season. This action was actually based on two assumptions. The first assumption was that tires were operated in normal conditions without serious leakage and that no intentional adjustment to the tire pressure owing to hot weather was performed. The second assumption was that tire temperature was affected by ambient air and pavement temperature. The first assumption is not very easy to prove, but the second assumption can be proved easily by measuring tire pressure as tire temperature increases and running linear regression of average truck tire temperature against the measured air and pavement temperatures, which is shown in the MINITAB printout in Table 42.

Table 42 Regression of Tire Temperature versus Air and Pavement Temperatures

Regression Analysis: Truck temperature versus Air Temp, Pavement Temp

The regression equation is
Truck temperature = 35.8 + 0.605 Air Temp + 0.177 Pavement Temp
614 cases used 9 cases contain missing values

Predictor	Coef	SE Coef	T	P
Constant	35.762	2.151	16.62	0.000
Air Temp	0.60509	0.06659	9.09	0.000
Pavement	0.17722	0.05258	3.37	0.001

S = 9.419 R-Sq = 47.1 percent R-Sq(adj) = 46.9 percent

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	48,233	24,117	271.82	0.000
Residual Error	611	54,209	89		
Total	613	102,442			

The equation exhibits a positive relationship between the truck tire average temperature and the ambient air and pavement temperatures, with an R-squared value of 47 percent. Actually, the ambient air and pavement temperatures are not the only variables that affect the average tire temperature, because some other variables such as axle weight, traveled distance, and pavement resistance could probably all contribute to the increase in the tire temperature.

Figures 14 through 16 test the normality, hetero-scedasiticity, and auto-correlation of the regression. The tests demonstrate that the regressed residuals are of normal distribution, constant error variance, and have no autocorrelation. Therefore, the linear regression well reflects the real relationship among truck average tire temperature, air temperature and pavement temperature.

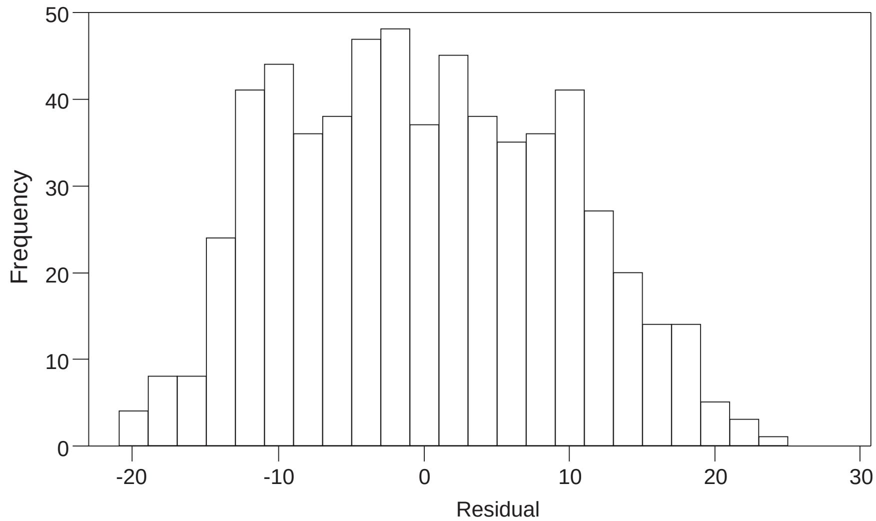


Figure 14 Normality Test of the Regression

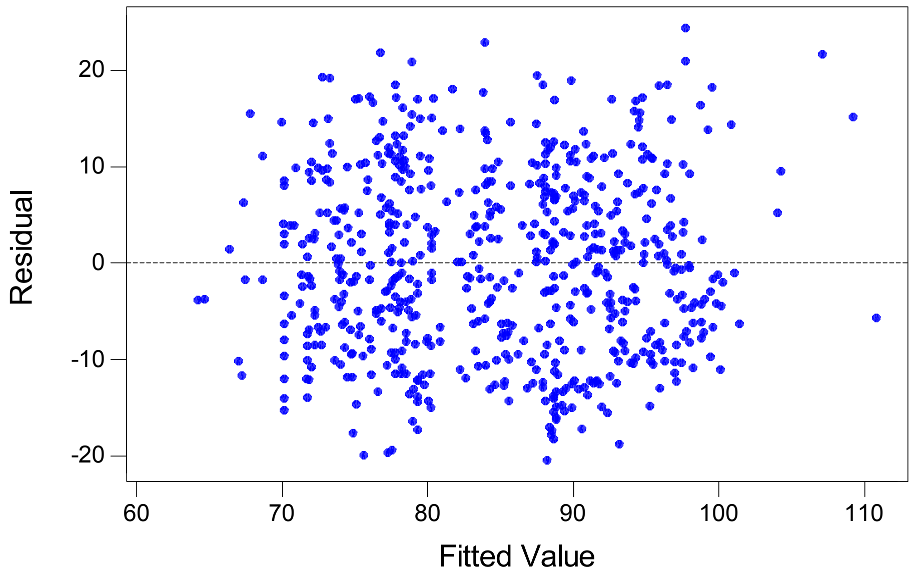


Figure 15 Regression Hetero-scedasiticity Test

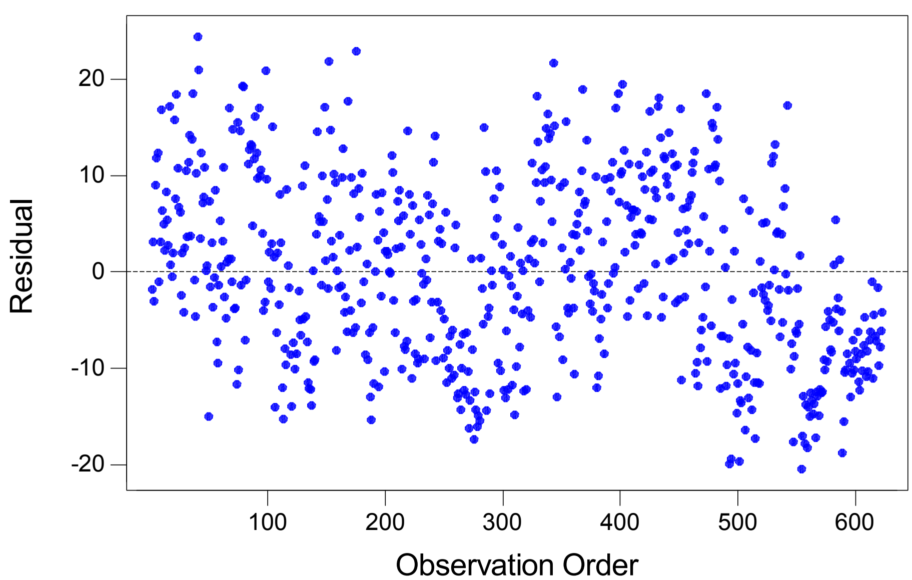


Figure 16 Regression Auto-correlation Test

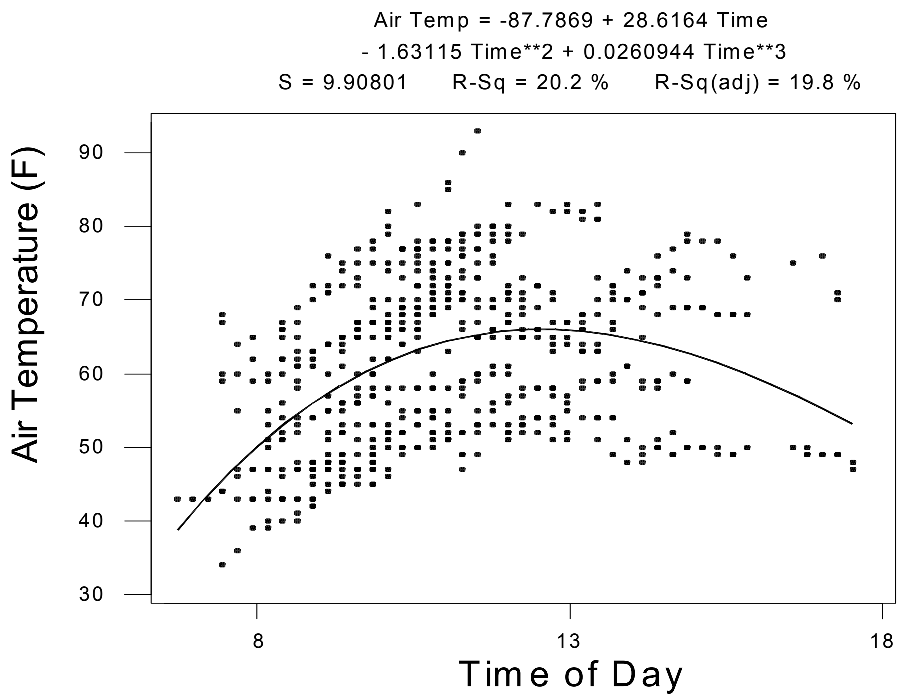


Figure 17 Variation of Air Temperature in Time of Day

Regression of air temperature and pavement temperature against time of day were also conducted to find the variation patterns of ambient air and pavement temperatures with time of day. Actually, because all the data were collected during daytime, no nighttime variation could be plotted. Every individual day has its own temperature curve pattern that is different from that of other days, and, similarly, every season and every place should be different from other seasons and places in the temperature variation curve pattern. The curves shown in Figures 17 and 18 only reflect data collected in the selected collection locations during the Texas wintertime.

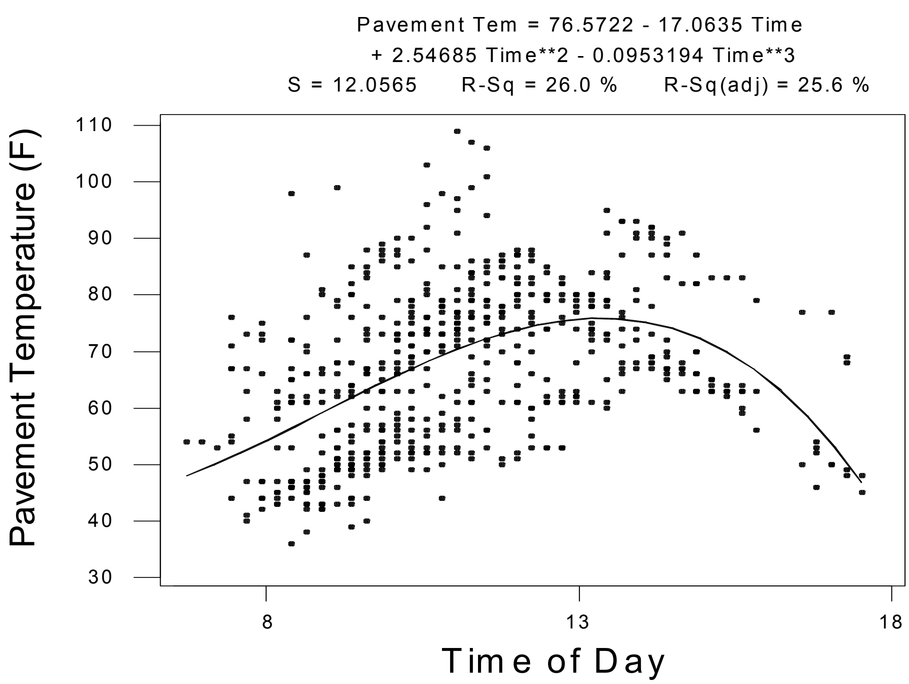


Figure 18 Variation of Pavement Temperature in Time of Day

Therefore, from the above regression analysis, the average tire temperature of a truck is found to be linearly related to air and pavement temperatures. Air temperature and pavement temperature account for about 47 percent of the variability in truck average tire temperatures. Variables such as truck weight, travel distance, road surface resistance, and random errors could constitute the rest of the variability. Air and pavement temperatures varied with time of day. However, the time of day could account for only about 20 percent and 26 percent of the variability in air and pavement temperatures, respectively, with most of the variability explained by unknown variables. Compared with the slow and uniform change in the curve of air temperature, the pavement temperature curve exhibited a slower increase after the sunrise and through the morning time, and a much sharper declination during the afternoon, especially after sunset. However, the ambient air and pavement temperatures in seasons other than winter and in different places could have different curve patterns and could therefore affect the truck tire temperature and the truck tire pressure in a different way.

THE INDEPENDENCE OF TIRE OBSERVATIONS

The survey plan was actually based on the assumption that the tires of a single truck tended to be homogeneous. The logical conclusion derived from this assumption would be that the tire observations of one truck would tend to be more similar to one another than tire observations of different trucks. In other words, variability in the tire observations of one truck would be smaller than the variability of tire observations from different trucks. To test the validity of the assumption, another ANOVA test was conducted for the pilot survey data collected in San Marcos southbound and northbound and in Odessa westbound and eastbound. The one-way ANOVA was used to test the truck-difference factor. Tire pressure observations of each truck, corrected for both gauge errors and tire temperature variations, were input as replicates of the truck effect. The MINITAB printouts for the ANOVA of Odessa westbound and eastbound, and San Marcos southbound and northbound, are shown in Table 43.

Table 43 One-way ANOVA of Tire Pressure for Different Trucks

1) Odessa WB

Factor	Type	Levels	Values
truck	fixed	35	t1 t10 t11 t12 t13 t14 t15 t16 t17 t18 t19 t2 t20 t21 t22 t23 t24 t25 t26 t27 t28 t29 t3 t30 t31 t32 t33 t34 t35 t4 t5 t6 t7 t8 t9

Analysis of Variance for pressure, using Adjusted SS for Tests

Source	DF	SEq. SS	Adj SS	Adj MS	F	P
truck	34	26,406.4	26,406.4	776.7	7.30	0.000
Error	509	54,149.8	54,149.8	106.4		
Total	543	80,556.2				

2) Odessa EB

Factor	Type	Levels	Values
truck	fixed	35	t1 t10 t11 t12 t13 t14 t15 t16 t17 t18 t19 t2 t20 t21 t22 t23 t24 t25 t26 t27 t28 t29 t3 t30 t31 t32 t33 t34 t35 t4 t5 t6 t7 t8 t9

Analysis of Variance for pressure, using Adjusted SS for Tests

Source	DF	SEq. SS	Adj SS	Adj MS	F	P
truck	34	21,098.7	21,098.7	620.5	5.09	0.000
Error	538	65,534.0	65,534.0	121.8		
Total	572	86,632.6				

3) San Marcos SB

Factor	Type	Levels	Values
truck	fixed	30	t1 t10 t11 t12 t13 t14 t15 t16 t17 t18 t19 t2 t20 t21 t22 t23 t24 t25 t26 t27 t28 t29 t3 t30 t4 t5 t6 t7 t8 t9

Analysis of Variance for pressure, using Adjusted SS for Tests

Source	DF	SEq. SS	Adj SS	Adj MS	F	P
truck	29	10,706.7	10,706.7	369.2	2.36	0.000
Error	442	69,005.9	69,005.9	156.1		
Total	471	79,712.6				

4) San Marcos NB

Factor	Type	Levels	Values
truck	fixed	33	t1 t10 t11 t12 t13 t14 t15 t16 t17 t18 t19 t2 t20 t21 t22 t23 t24 t25 t26 t27 t28 t29 t3 t30 t31 t32 t33 t4 t5 t6 t7 t8 t9

Analysis of Variance for pressure, using Adjusted SS for Tests

Source	DF	SEq. SS	Adj SS	Adj MS	F	P
truck	32	37,461.0	37,461.0	1,170.7	6.95	0.000
Error	465	78,300.0	78,300.0	168.4		
Total	497	115,761.1				

For example, the ANOVA analysis of San Marcos northbound shows that the sum of squares for the difference within trucks was 78,300.0; the sum of squares for the difference among trucks was 37,461 and the total sum of squares 115,761.1. Therefore, the Intracluster Correlation Coefficient (ICC), which yields the degree of similarity among tires in the same truck are, is calculated in Equation (54), where SSW is the sum of squares within clusters (trucks), SSTO is the total sum of squares, and M is the average size of a cluster. Then the ICC is calculated from

$$ICC = 1 - \frac{M}{M-1}\frac{SSW}{SSTO} \qquad \text{(Eq. 54)}$$

using the numerical values for *SSW* and *SSTO*, $ICC \approx 1 - \frac{78300.0}{115761.1} = 0.324$. The ICC will be 1.0 for complete within-cluster homogeneity. The ICC of 0.324 shows a moderate homogeneity of tires within trucks. Similar results are attained from other pilot survey data, as shown in Table 44.

Table 44 ICC Computations for Pilot Surveys

Location	SSW	SSTO	ICC
Odessa WB	54,149.8	80,556.2	0.328
Odessa EB	65,534.0	86,632.6	0.244
San Marcos SB	69,005.9	79,712.6	0.134
San Marcos NB	78,300.0	115,761.1	0.324

The fact that tires within the same truck are only moderately similar, but certainly not identical to one another, signified that taking tire observations from all tires of different trucks tended to be much more cost effective and information effective than taking one tire observation from each randomly selected truck.

SUMMARY

This chapter finalizes the tire pressure data analysis by comparing the newly collected data with historic Texas tire pressure data. The assumptions for the survey design and data analysis were reviewed and checked in this chapter. Conclusions, based on the data analysis conducted in the previous chapters, will be presented in Chapter 8.

CHAPTER 8 CONCLUSIONS

The Texas 2000 truck configuration survey investigated the current truck technologies used by trucks traveling in Texas and included the distributions of tire pressures, tire sizes and constructs, tandem/tri-tandem axle spacings, truck classes, suspension usages, trip O/Ds, and commodities carried. The state of Texas was divided into six geographical areas represented by the cities of Dallas, Houston, Corpus Christi, Austin/San Antonio, Midland/Lubbock, and border areas. Data collection locations were selected from every area to make a complete sample representing the whole state. A total of 623 trucks were sampled at eighteen locations. Stratified and cluster sampling techniques and factorial experiment design methods were used in the sample design. Pilot surveys were conducted, the sample plan was adjusted accordingly, and the full-scale survey was carried out according to the designed plan. Various truck configuration statistics were reported for Texas based on the sampled data. Truck configurations of non-border and border areas were compared to check for any differences.

In addition to conducting examinations of the general configuration data, truck tire pressures were analyzed through more detailed studies. As a matter of fact, tire pressure was the major variable that dictated the design of the survey plan. Tire pressure differences in different Texas areas, different highway classes, and in different highway directions were tested. Relationships of tire pressure with tire temperature; air and pavement temperatures with tire temperature; and air and pavement temperatures with time of day were studied. Based on the relationship study, another set of tire pressure data were reported, projecting the tire pressure conditions to summertime values.

The sample of 9,600 tested tires was found to have an overall average tire pressure value of 96.75 psi with a standard deviation of 15.03 psi; the 2,870 axles tested had an overall mean tire pressure of 97.17 psi with a standard deviation of 12.39 psi; and the calculated overall mean tire pressure for the sampled 623 trucks in the survey was 96.0 psi with a standard deviation of 9.99 psi. Comparison between border and non-border trucks showed that trucks in non-border areas tended to have a 10 psi higher average tire pressure than those in border areas.

Based on the relationship of tire pressure with tire temperature, tire pressures projected for a 140 °F summertime situation were calculated. The sample of tires was projected to have an overall average tire pressure value of 108.93 psi with a standard deviation of 14.68 psi. The sample of axles then had an overall mean tire pressure of 109.17 psi with a standard deviation of 11.80 psi, and the projected overall mean tire pressure for the sample of trucks was 108.2 psi with a standard deviation of 9.44 psi.

The 3-S2, SU-3, and SU-2 types were the three most common truck classes in the sample, representing 80.3 percent, 7.5 percent, and 6.3 percent of the 623 trucks in the sample, respectively. However, 3-S1-2 and 2-S1-2, the only two kinds of double-trailer trucks in the sample, had the highest tire pressures among all truck classes. Although 3-S2, SU-3, and SU-2, were the most commonly used truck classes in both border and non-border areas, there were significant differences between border and non-border areas. These classes represented 85.9 percent, 3.1 percent, and 4.8 percent of trucks in non-border areas, and 60.7 percent, 22.9 percent, and 11.4 percent in border areas.

Air springs and leaf springs were the two most commonly used truck suspension systems. Air springs and leaf springs were mutually exclusive to each other in usage. Patterns in suspension usage existed in different combination axles. Leaf springs were predominantly used in steering axles in the 612 sampled axles, 98 percent of which were found to have shock absorbers. In the 618 sampled drive combination axles, 72 percent were air springs 28 percent were leaf springs, and 71 percent of the drive axles had shock absorbers. In contrast, only 34 percent of the 528 trailer combination axles had air springs; 66 percent of them had leaf springs; and only 34 percent of the trailer axles had shock absorbers. Comparisons between non-border and border areas showed that the border and non-border areas had similar suspension usages for the steering axles, but significantly different suspension usages in the drive and trailer axles. Approximately 99.6 percent and 100 percent of the steering axles in non-border and border areas had leaf springs. For drive and trailer axles, 82.5 percent of the drive axles and 36.9 percent of the trailer axles in non-border areas used air springs, but only 35.5 percent of the drive axles and 18.0 percent of the trailer axles in border areas used air springs. On the other hand, 17.5 percent of the drive axles and 63.1 percent of the trailer axles in non-border areas had leaf springs, and 64.5 percent of the drive axles and 82.0 percent of the trailer axles in border areas used leaf springs.

The tire manufacturer distribution showed that Bridgestone, Michelin, and Goodyear were the three most popular tire providers for the sampled trucks, representing 27.3 percent, 22.6 percent, and 17.6 percent of the sampled tires. Comparisons between the border and non-border areas showed moderate differences. While Bridgestone, Michelin, and Goodyear ranked as the top three in non-border areas representing 29.2 percent, 24.0 percent, and 16.4 percent of the tires, Goodyear, Bridgestone, and Michelin were the top three tires in border areas, representing 22.2 percent, 19.4 percent, and 17.2 percent of the tires tested.

Tire size distribution showed that 295-75R22.5, 11R24.5, 11R22.5, and 285-75R24.5 were the four most popular tire sizes found in the sampled trucks, representing 25.7 percent, 21.8 percent, 17.3 percent, and 15.4 percent of the sampled tires. Comparisons between the border and non-border areas showed only minor differences. 295-75R22.5, 11R24.5, 11R22.5, and 285-75R24.5 were the four most common tire sizes in both non-border and border areas, with only small differences in percentages between the areas. Tire size usages in front and non-front axles were also compared, which showed that 11R24.5 was the most popular size, accounting for 24.1 percent of front tires, whereas 295-75R22.5 represented 26.2 percent of non-front tires. Very few tires were found to be "super singles" with wide bases.

Studies in tandem/tri-tandem axle usages showed that of the 2,892 axles sampled, 71.5 percent were in tandem or tri-tandem axle combinations, with 0.9 percent and 70.5 percent in tri-tandem and tandem combinations, respectively. Comparisons between border and non-border areas showed very similar distributions with a slightly higher tandem axle percentage in non-border areas. It is noticeable that only 27 axles of the 2,892 sampled axles were found to be in tri-tandem combinations, suggesting that tri-tandems have not yet come into wide use. The distribution of tandem/tri-tandem spacings yielded a mean value of 4.23 ft, with 0.22 ft in standard deviation.

The study of trip O/Ds of the sampled trucks showed very different O/D distribution patterns in border and non-border areas. In non-border areas, 63.5 percent of the trips sampled originated from places in Texas; 36.5 percent of the trips came from places in the U.S. other than Texas; and none of the trips were found from Mexico. For destinations, 79.1 percent of the surveyed trips were bound for places in Texas, 20.7

percent were bound for places in U.S. but out of Texas, and 0.2 percent were headed for Mexico. In border areas, 38.6 percent of truck trips were from places in Texas; 6.4 percent were from places in the U.S. but other than Texas; and 55 percent originated in Mexico. For destinations, 65 percent of the sampled trips were going to places in Texas, 0.7 percent to places in the U.S. but out of Texas, and 34.3 percent to Mexico.

The distributions of commodity categories for the sample showed that the top two commodity classes in the sample for both border and non-border areas were empty trucks or trucks with empty containers, and metal and electronics products, representing 28.0 percent and 18.9 percent, respectively, of all the trucks in the sample.

Pilot survey data and *t*-tests did not find significant differences in tire pressure means between trucks traveling in opposite highway directions. It would be reasonable to declare that for 95 percent confidence, tire pressures of opposite highway directions are identical to each other at every location. Examination of the variance analysis results showed significant differences in tire pressure among different geographical areas and among different highway classes. The six Texas areas could be arranged in the ascending order of mean tire pressure as follows: Border, Austin/San Antonio, Houston, Dallas, Corpus Christi, Midland/Lubbock, with some similarities between Austin/San Antonio and Houston, and among Dallas, Corpus Christi, and Midland/Lubbock. Mean tire pressure on interstate highways was determined to be higher than that of non-interstate highways. Mean tire pressure in border areas was significantly different from that non-border areas, and the former was found to be about 10 psi lower than the latter. Differences in tire pressure means were also found among the border areas. El Paso was found to have a higher average tire pressure than did Brownsville and Laredo. Significant differences in tire pressure means among the five axles of all the 3-S2s were found. The front axle tended to have the highest mean tire pressure, and the other four axles were listed in descending order as axle 4, axle 2, axle 3, and axle 5. Axles 2 and 3 had mean tire pressures very similar to each other, while axles 4 and 5 did not, suggesting two conclusions: 1) trailers frequently were different from trucks in truck configurations; and 2) trailers were frequently not given as good maintenance as the trucks. The ANOVA test results yielded very significant differences between tire pressure means of different trip types. Comparisons of the tire pressure means showed that the trips originating from or bound for Mexico had the lowest tire pressure values; the trips with both origins and destinations in U.S. places other than Texas had the highest tire pressure mean; the trips with either origins or destinations in Texas, but heading for or originating from U.S. places out of Texas, had the second highest tire pressure mean; and trips with both origins and destinations in Texas tended to have a lower tire pressure mean, which was higher than that of the Mexico-based trips. The trip pattern of longer trip distances yielding higher tire pressure means signified the potential effects of the assumed NAFTA trucking corridors on Texas pavements. Significant differences of tire pressure means existed between different commodity categories. The truck tire pressure means demonstrated a reasonable pattern in the distribution of truck tire pressure means over commodity categories. The empty trucks had the lowest tire pressures; rubber/plastics products, paper products, electrical equipment and supplies, furniture, and wastes were the second lowest in tire pressure means; machinery, metal products, chemicals, and foods had high tire pressure means; and farm products, petroleum products, and lumbers had the highest tire pressure means. However, some commodity categories, such as instruments, textile products, and printed paper, were difficult to judge because of the small sample size in each commodity category.

The comparison of the CTR 2000 data with the TTI 1986 data showed a significant decrease in bias-ply tire usage, from 32.2 percent in 1986 to 2.2 percent in 2000. Accordingly, the tire data collected by CTR exhibited a 4 psi increase in mean tire pressure over that of TTI; however, the CTR projected the critical mean tire pressure at 140 °F in summertime to be 108.94 psi, constituting a 16 psi increase over the TTI survey.

Lab experiments and linear regressions were employed to study the relationship between tire pressure and tire temperature. The relationship coefficient of 0.22 PSI/0F was found, and the formula of $P_2 = P_1 + 0.22 (T_2 - T_1)$ was used for the tire temperature variability correction and for the summer data projection where P_1 and P_2 are tire pressures measured at tire temperatures T_1 and T_2, respectively.

Air and pavement temperatures were found to be lineally related to tire temperature, and both air and pavement temperatures were found to be non-lineally related to time of day. The fact that much variability in the air and pavement temperature data was left unexplained implied the difficulty in the attempt to relate air and pavement temperatures solely to time of day.

APPENDIX A DATA COLLECTION SHEET

TEXAS TRUCK CONFIGURATION SURVEY DATA SHEET

Serial No. __________ Start Time:____________ Finish Time:___________

I. GENERAL INFORMATION

Date: ______/______/______ Weigh Station: ______________
Highway MP & Direction: ____________________________
Plate No. ___________________ State/Country: ____________

II. TRIP INFORMATION

Origin: _________________________
Destination: _____________________
Commodity: _____________________

III. WEATHER INFORMATION (Check One)

☐ Sunny ☐ Cloudy ☐ Shower ☐ Persistent Rain

IV. TEMPERATURE

Air: ______ (°F) Pavement: ______ (°F)

V. TRUCK CLASSIFICATION (Check One)

Single Units	Trucks &Trailers		Trucks &Trailers	Tractor, Semi-Trailers & Trailers		
☐ SU-2	☐ 2-2	☐ 2-2-2	☐ 2-S1	☐ 2-S1-2	☐ 3-S2-3	☐ 2-S2-3-2
☐ SU-3	☐ 2-3	☐ 2-2-3	☐ 3-S1	☐ 3-S1-2	☐ 3-S2-4	☐ 3-S1-2-3
☐ SU-4	☐ 3-2	☐ 3-2-2	☐ 2-S2	☐ 2-S1-3	☐ 2-S1-2-2	
			☐ 3-S2	☐ 3-S2-2	☐ 3-S1-2-2	

VI. TIRE DATA

Left (Outer / Inner)

Axle	Tire Mfg.	Tire Size	Pressure (psi) Measured	Pressure (psi) Tire Temp.	Axle Dist. Ft. - In.
1	/	/	/	/	XXXX
2	/	/	/	/	-
3	/	/	/	/	-
4	/	/	/	/	-
5	/	/	/	/	-
6	/	/	/	/	-
7	/	/	/	/	-
8	/	/	/	/	-
9	/	/	/	/	-

Right (Outer / Inner)

Axle	Tire Mfg.	Tire Size	Pressure (psi) Measured	Pressure (psi) Tire Temp.	Axle Dist. Ft. - In.
1	/	/	/	/	XXXX
2	/	/	/	/	-
3	/	/	/	/	-
4	/	/	/	/	-
5	/	/	/	/	-
6	/	/	/	/	-
7	/	/	/	/	-
8	/	/	/	/	-
9	/	/	/	/	-

VIII. AXLE WEIGHT (lb)

Steer	
Drive:	
Trailer:	
2 nd Trailer:	

IX. COMMENTS

X. INSPECTORS:

Notes: ___________________
Pressure: ________________
Temperature: ____________

VII. SUSPENSION

Steering Suspension	Drive Suspension	Trailer Suspension
☐ Airbag	☐ Airbag	☐ Airbag
☐ Semi-elliptic	☐ Semi-elliptic	☐ Semi-elliptic
☐ Quarter-elliptic	☐ Quarter-elliptic	☐ Quarter-elliptic
☐ Monoleaf	☐ Monoleaf	☐ Monoleaf
☐ Shocks	☐ Shocks	☐ Shocks
☐ Leading arm	☐ Leading arm	☐ Leading arm
☐ Spring eye	☐ Spring eye	☐ Spring eye
☐ Laterally coupled	☐ Laterally coupled	☐ Laterally coupled
☐ Dual airbag	☐ Dual airbag	☐ Dual airbag

APPENDIX B TRUCK SUSPENSION TYPES

As part of the field survey, the suspension system characteristics of each vehicle were recorded. The suspension system must permit vertical motion of the axle so that unevenness in the road surface does not cause undue disturbance of the vehicle cargo and driver. Ideally, the suspension system has provisions to control excessive oscillations of the spring-axle system. It must also control lateral and axial motions so the axles stay properly positioned.

Springs

Vertical movements of axles relative to the vehicle's body are accommodated by connecting axles to the frame by an elastic member or spring. A spring is a device that creates a reactive force that is proportional to its displacement, when measured from an unloaded condition. It was found that there were two types of springs in use: leaf springs and air or Air-ride springs.

Leaf springs are usually made of steel and are configured to act as a beam that is loaded in bending. They are further designated as semi-elliptic, Fig. B-1 (b), or quarter-elliptic, Fig. B-1 (a). Semi-elliptic springs approximate the shape of half of an ellipse. Quarter-elliptic springs have the shape of one-fourth of an ellipse.

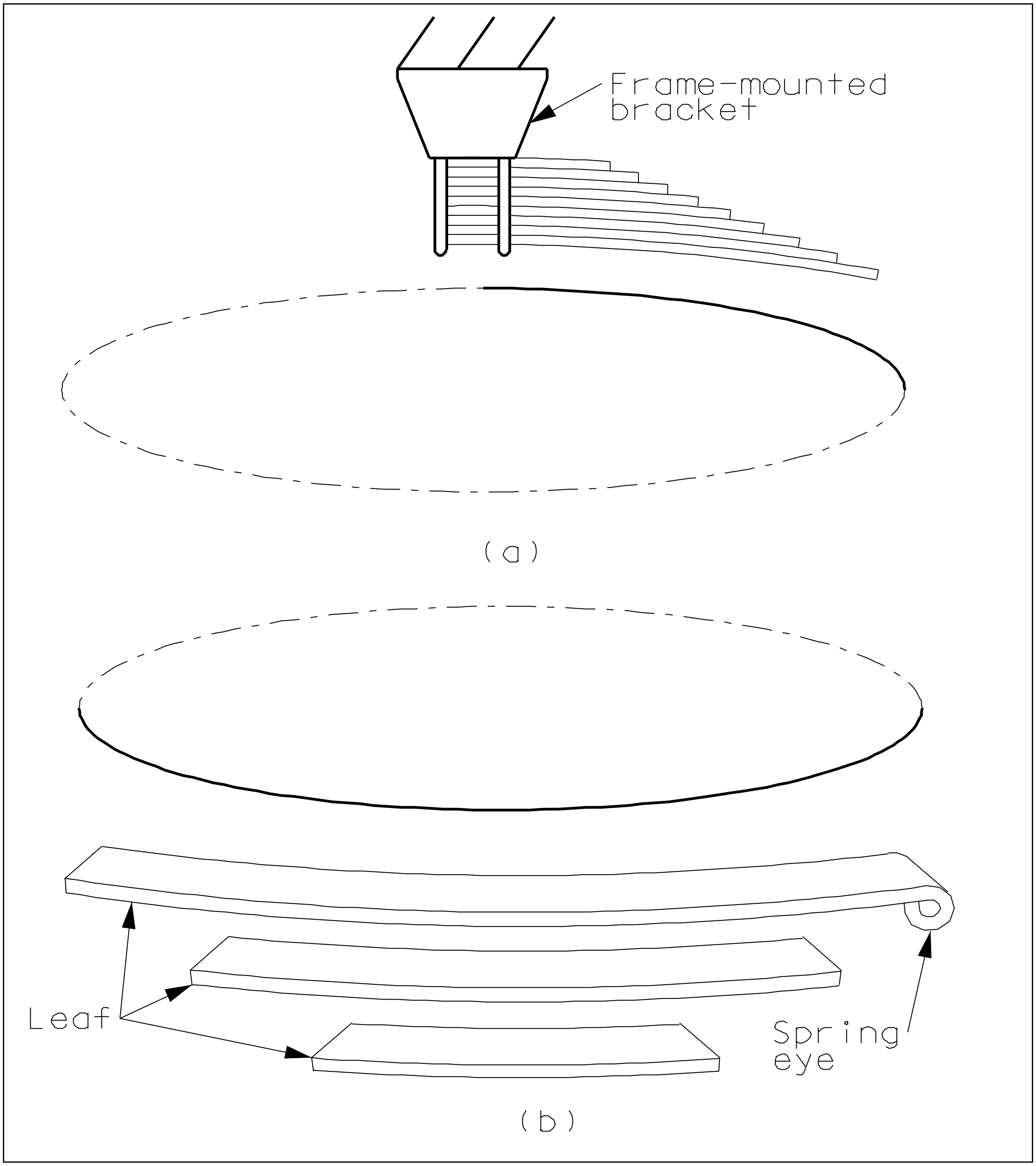


Figure B-1 Leaf Spring Nomenclature

As used in current vehicles, quarter-elliptic springs are actually semi-elliptic in form but are mounted with the midpoint rigidly attached to the vehicle frame, as shown in Fig. B-2. In this arrangement the spring acts as two independent quarter-elliptic springs. All leaf springs are highly resistant to side forces and so provide a constraint to lateral motion of the axle relative to the vehicle frame.

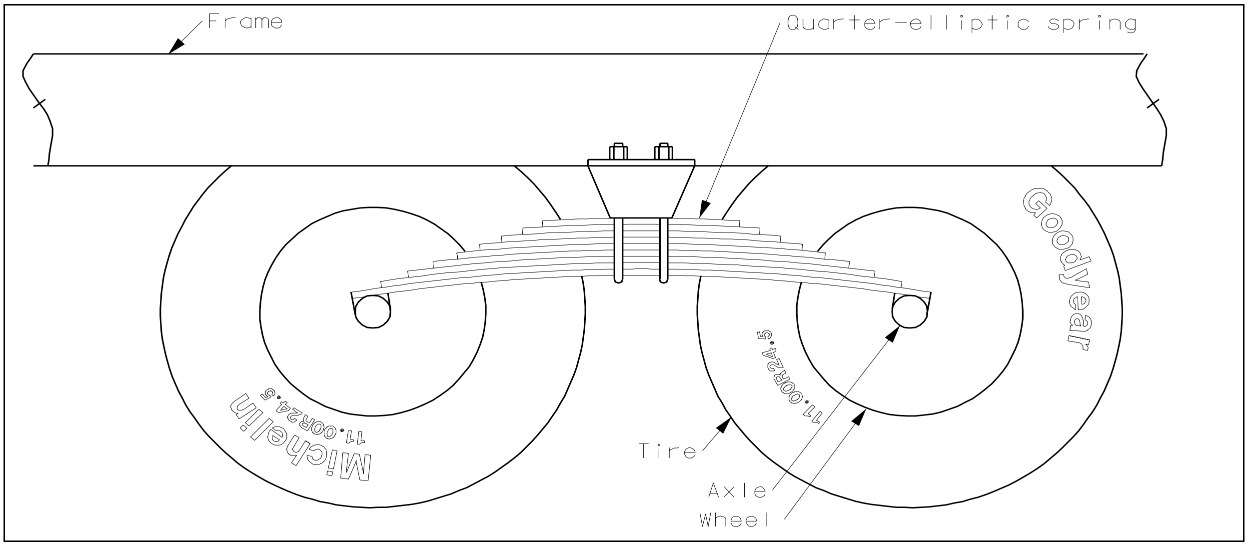


Figure B-2 Quarter-elliptic Leaf Spring

Most leaf springs are formed from a stack of leafs, each shorter than the adjacent leaf, as indicated in Fig. B-3. This configuration places more material in the portion of the spring that has the higher bending moment, so stresses within the leaf are more uniform. Some leaf springs, called monoleaves,

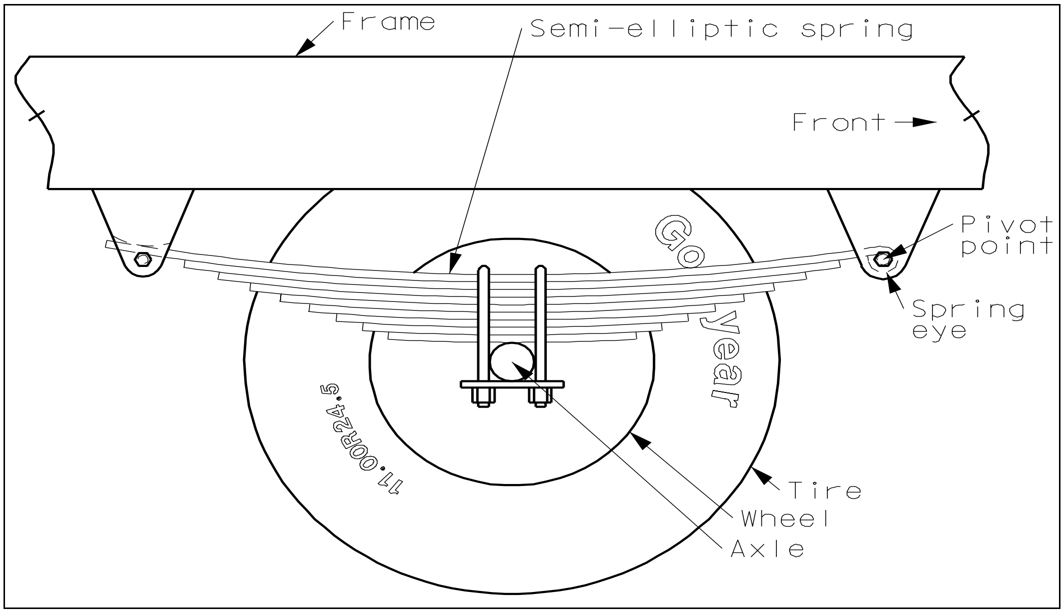


Figure B-3 Semi-elliptic Leaf Spring, as Installed

Fig. B-4, are formed of a single leaf with a non-uniform cross section. This non-uniform cross section helps equalize stresses by utilizing a larger cross section in the areas with higher bending moments.

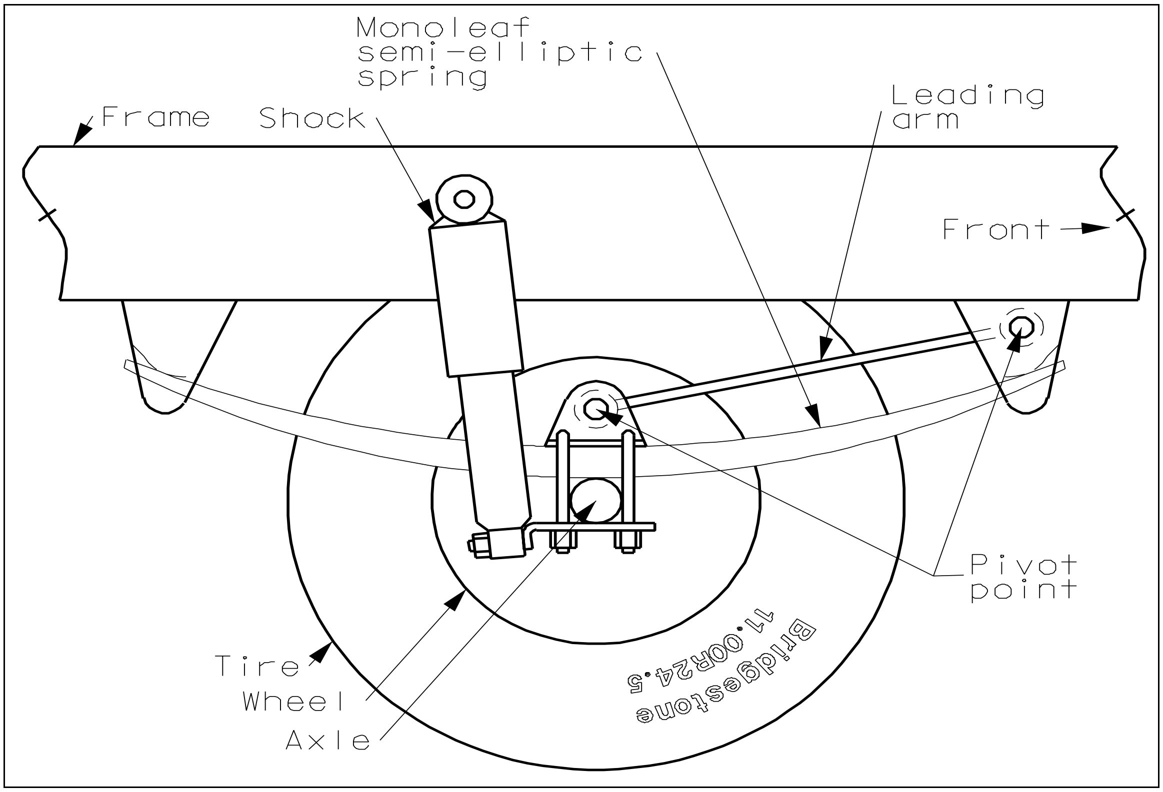


Figure B-4 Monoleaf Semi-elliptic Spring, as Installed

When the load on a leaf spring is changed, the shape of the spring changes in response. An increase in load increases bending stresses that increase the radius of curvature of the leaf. Fig. B-5 (a) shows a leaf for a given load condition. This spring has a chord or length of D. Fig. B-5 (b) shows the same spring after an increase in load. The spring can be seen to have "flattened out." The chord has increased to D1. The spring mounting hardware must accommodate this change in spring "length" as the load changes.

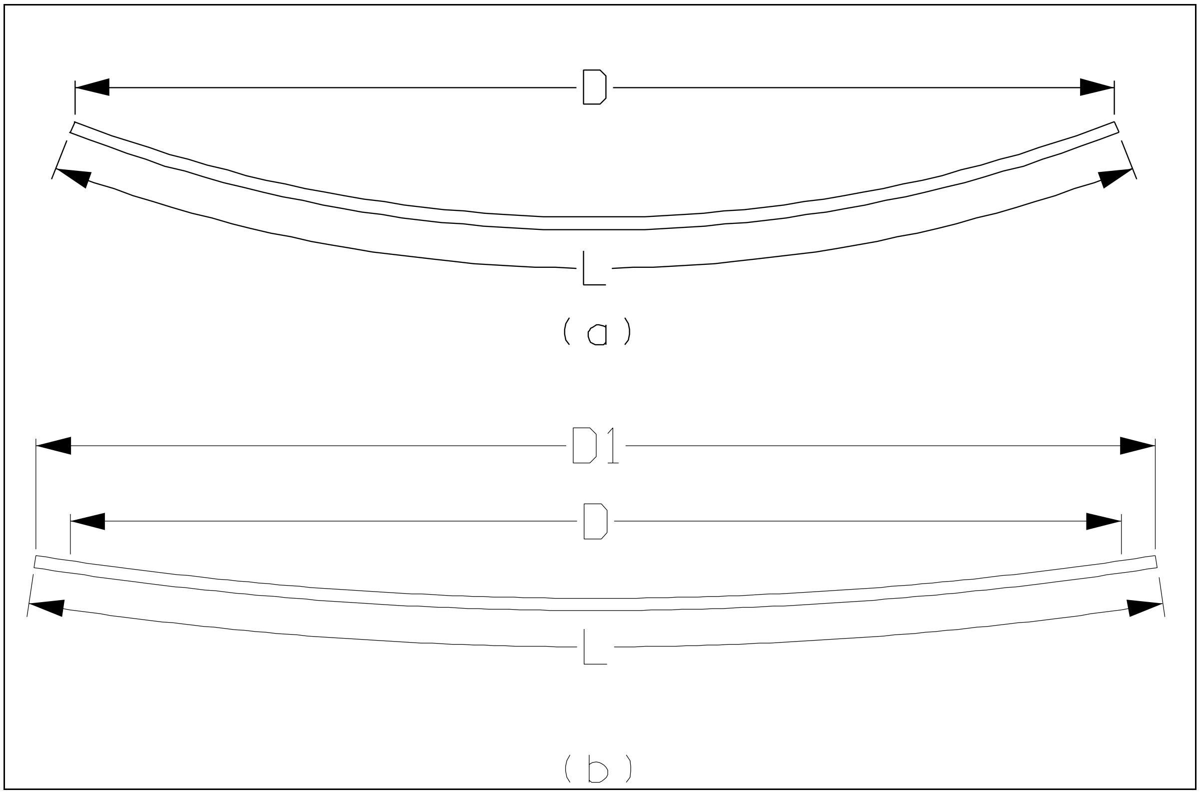


Figure B-5 Leaf under Different Loads

Some leaf springs have a loop or spring eye, Fig. B-1 (b) formed on the forward end. A bolt or pin is placed through this spring eye and also through a frame-mounted bracket. This arrangement permits the spring to pivot about the pin and also constrains axial motion of the spring/axle assembly. With the forward end constrained, the rear end moves as the spring length changes with changing loads.

The aft spring mount accommodates this with a sliding contact point, Fig. B-6 (a), or a shackle, Fig. B-6 (b), that pivots about a fixed point to permit needed spring-end motion. Each mount bracket has constraints to prevent lateral motion of the spring.

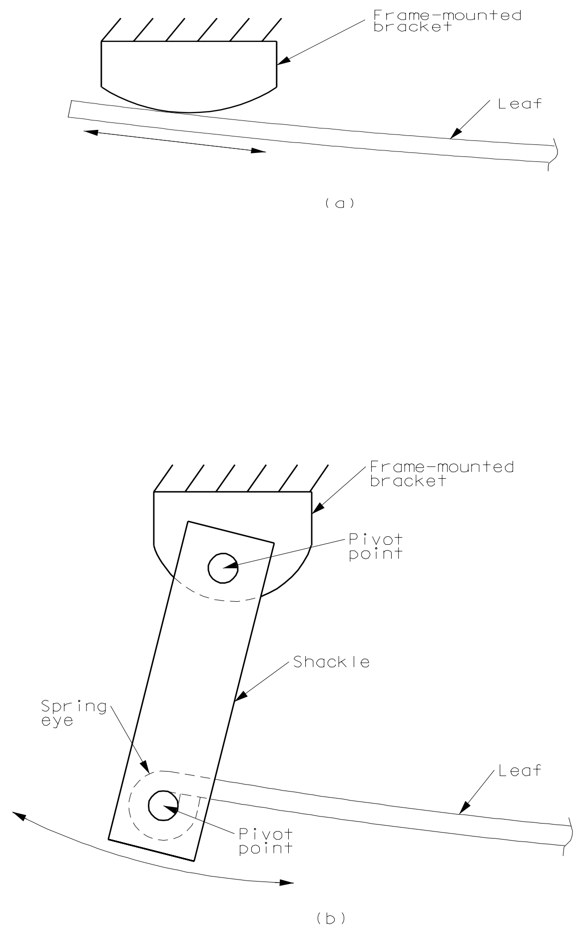


Figure B-6 Leaf Spring Mounts

Other leaf springs are provided with a sliding contact-type bracket at each end. The sliding contact bracket does not constrain axial movement. Axial motion must be controlled by other means. One such device, called a trailing arm, Fig. B-7, is a rigid member with its forward end pivoted from the frame and its aft end pivoted from the axle. A trailing arm permits free vertical movement with only a small amount of axial movement. Trailing arms also help to prevent axle rotation resulting from torque from driving and braking forces.

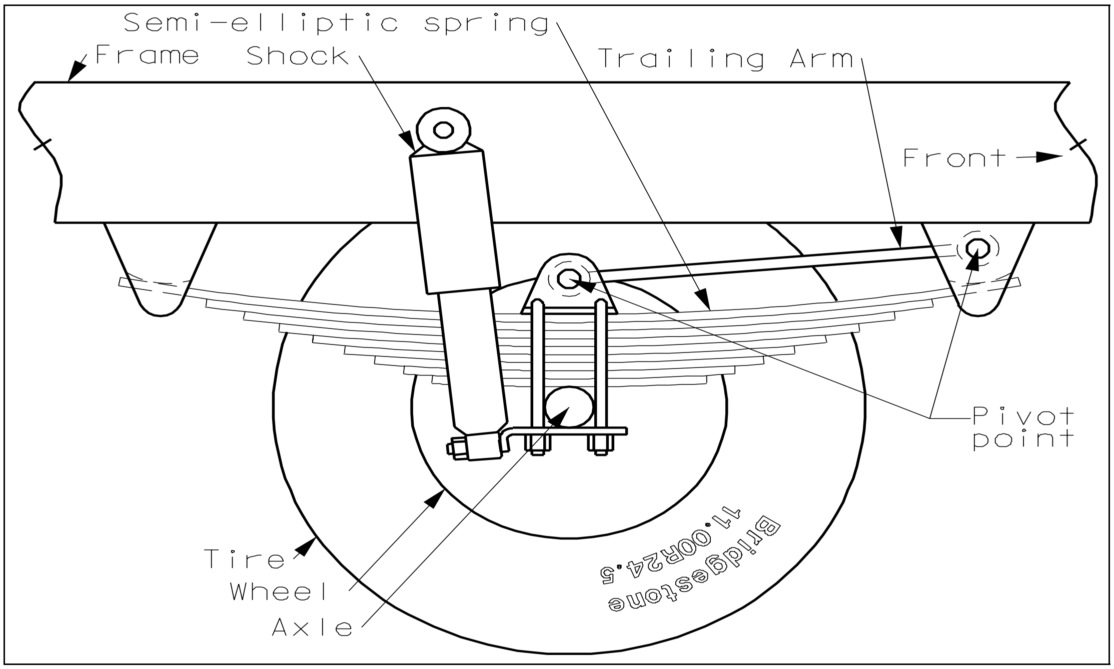


Figure B-7 Trailing Arm

Currently, many over-the-road vehicles have air springs. Air springs use pressurized air as the elastic medium. Air is contained within a reinforced rubber bladder with a piston at each end, as shown in Fig. B-8. One piston is attached to the axle and the other to the vehicle frame, as seen in Fig. B-9. When the spring load increases, the pistons move closer, the volume of air within the bladder is decreased, and the air pressure within increases. This air pressure, acting on the cross-sectional area of the air spring, creates the spring's reactive force.

Air springs offer little resistance to lateral or axial forces, so the vehicle must be provided with hardware to permit only the desired vertical axle motion.

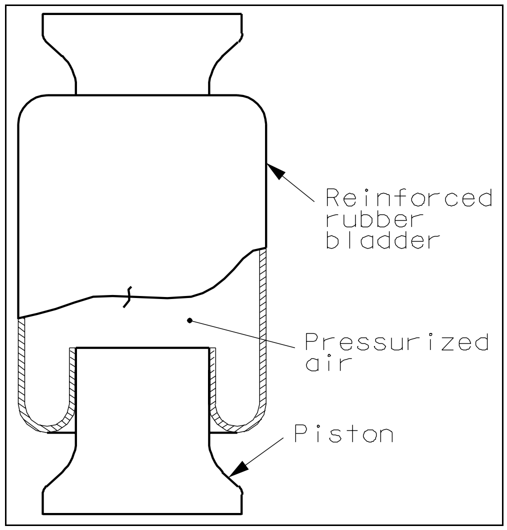


Figure B-8 Air (Air-ride) Spring

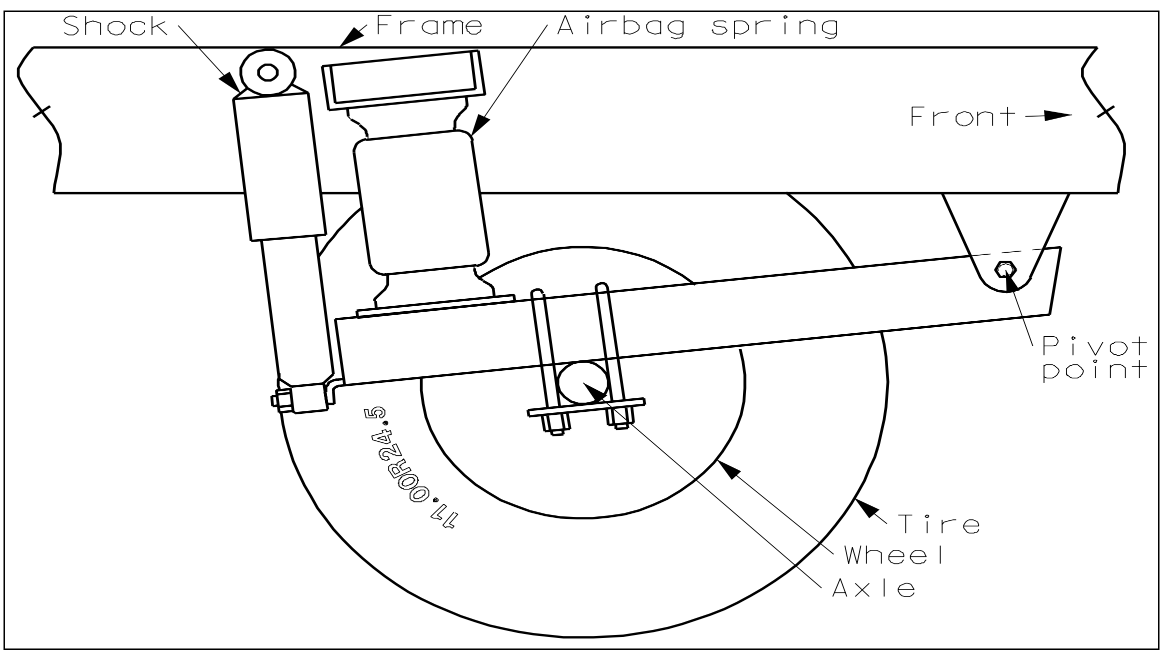


Figure B-9 Air Spring, Typical Installation

A newer system, using two smaller air springs per wheel, is shown in Fig. B-10. This configuration also requires mechanisms to permit only vertical axle movement. Drivers report that this system provides the best ride.

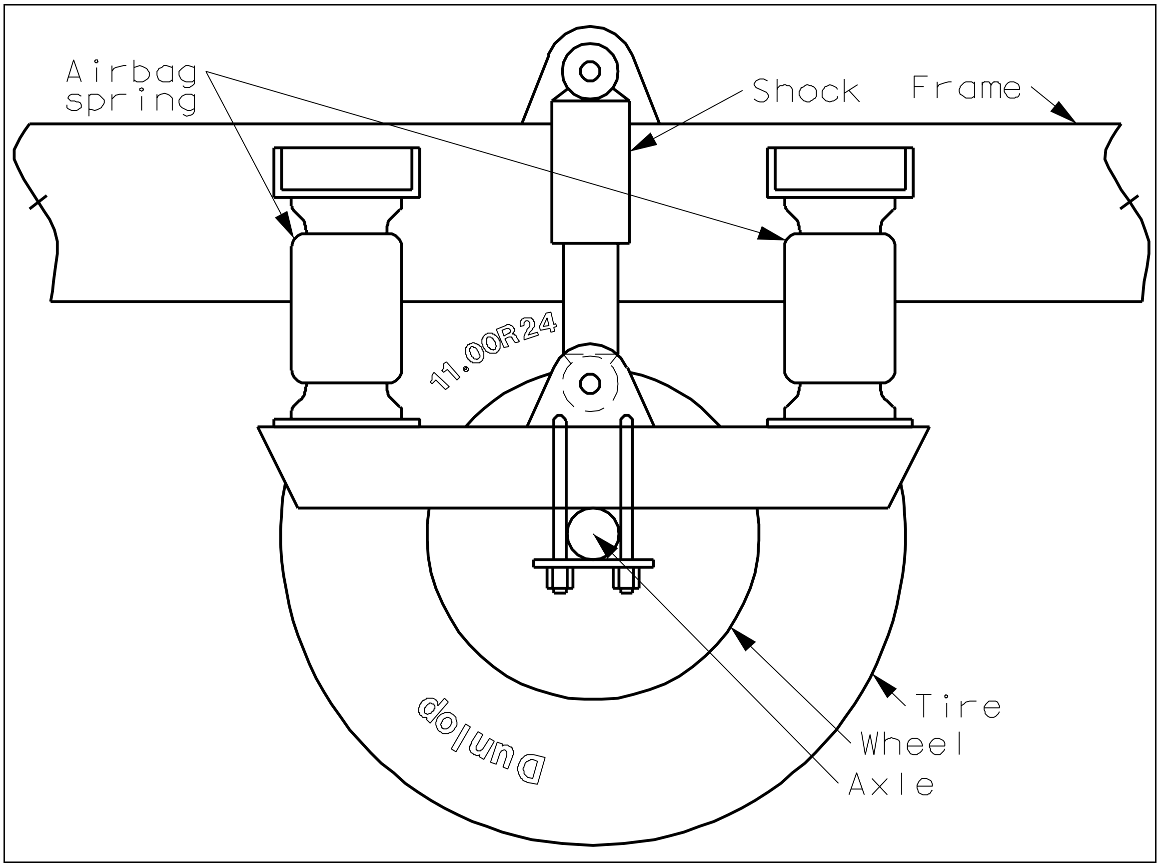


Figure B-10 Dual Air Springs (two for each wheel)

Damping

When external energy is applied to a spring-mass system, the system will enter into harmonic motion and oscillate until the kinetic energy resulting from this motion is removed from the system. Dissipating this kinetic energy is called damping. Friction between moving parts is an effective damper. Friction changes energy from motion into heat energy. This heat is then transferred from the parts, usually to the surrounding air.

Road roughness will induce motion in a vehicle's suspension system. Because continued oscillation of a vehicle's suspension system is undesirable, all vehicle suspension systems are damped. The ever-present friction provides some damping. For additional damping, devices designed specifically for this purpose are used. These are called shock absorbers, or just "shocks."

Sliding friction occurs when two bodies in contact are acted on by forces that tend to induce sliding motion between them. This friction creates a force that resists the sliding motion and has a magnitude that is directly proportional to the force between the parts.

During deformation of a multi-leaf spring, there is sliding motion between adjacent leafs. Maximum motion occurs at the leaf tip and there is no movement where the spring is clamped at the mid-leaf position. The resulting interleaf friction damps suspension system motion. This damping force, known as Coulomb damping, acts between each pair of adjacent leafs. It can be substantial for a spring with multiple leafs and may be the only damping or the predominant damping present.

Vehicle designers wanting more damping provided by friction within the suspension system use shock absorbers, Fig. B-11, to provide additional damping. A rod attaches one end of the shock to a piston that slides in an oil-filled cylinder. This cylinder is attached to the other end of the shock. Any relative motion between the frame and axle causes the piston to act against the oil in the cylinder. This action forces oil to flow through small openings or a spring-loaded valve in the piston. The oil's viscosity resists this flow, creating a force opposing the suspension system motion. This force, known as viscous damping, is proportional to the velocity between the vehicle frame and axle.

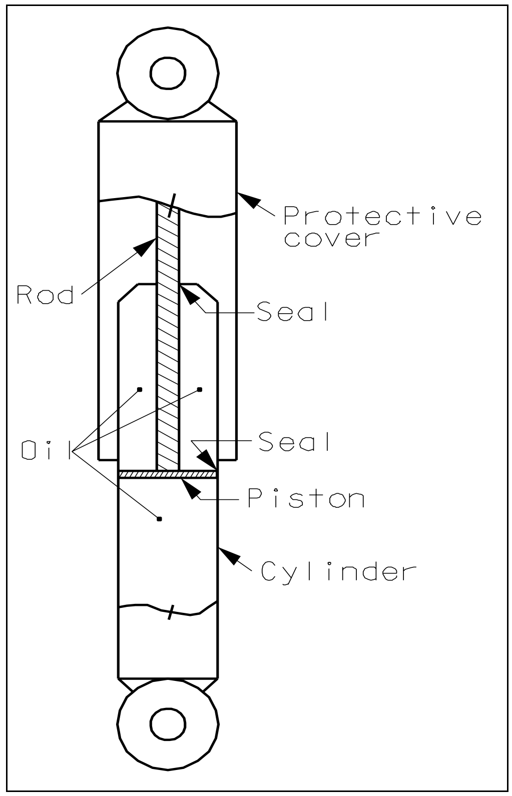
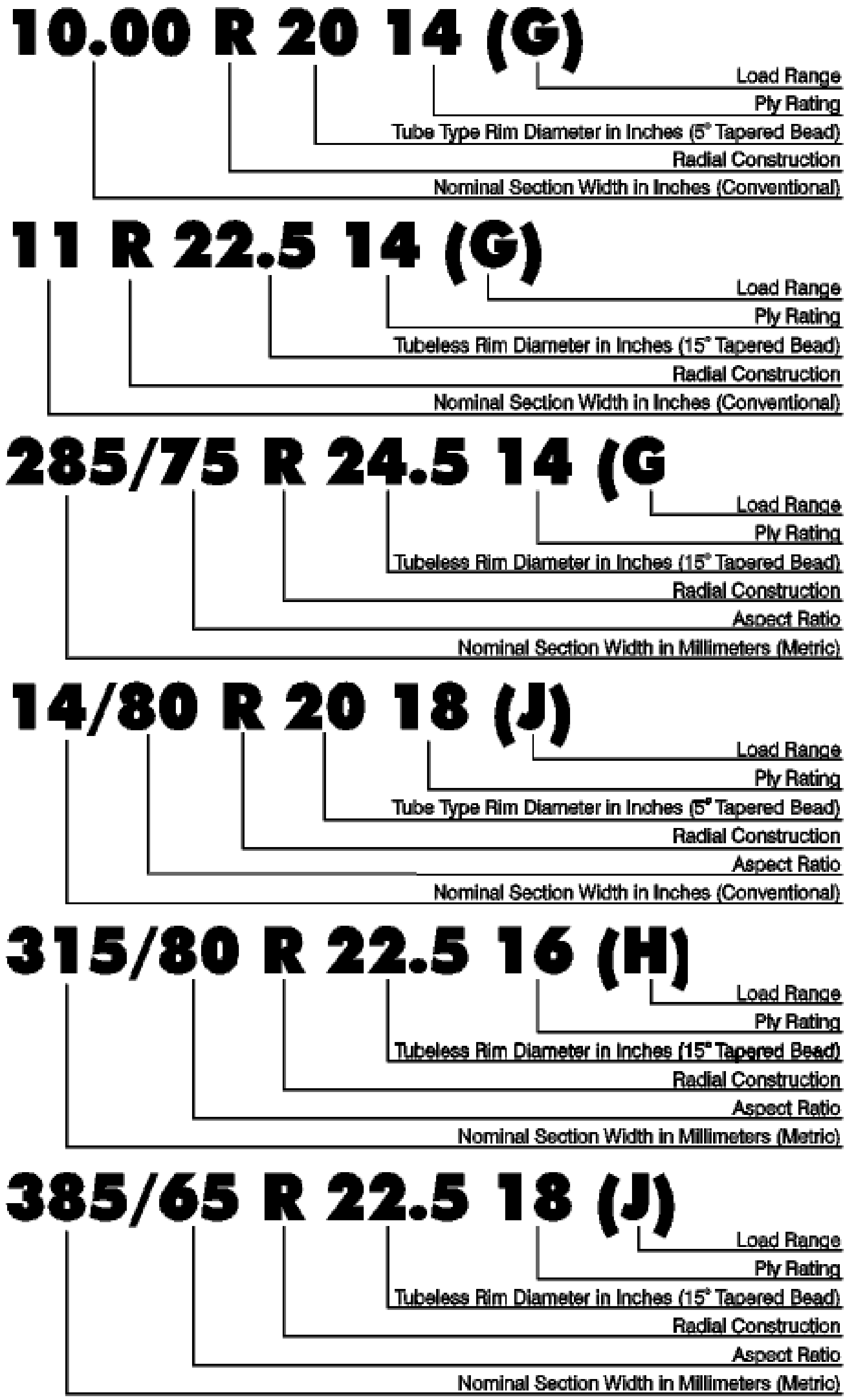


Figure B-11 Shock Absorber

APPENDIX C TRUCK TIRE SIZE SPECIFICATIONS

1. Truck Size Specifications



2. Dimensions of Truck Tires

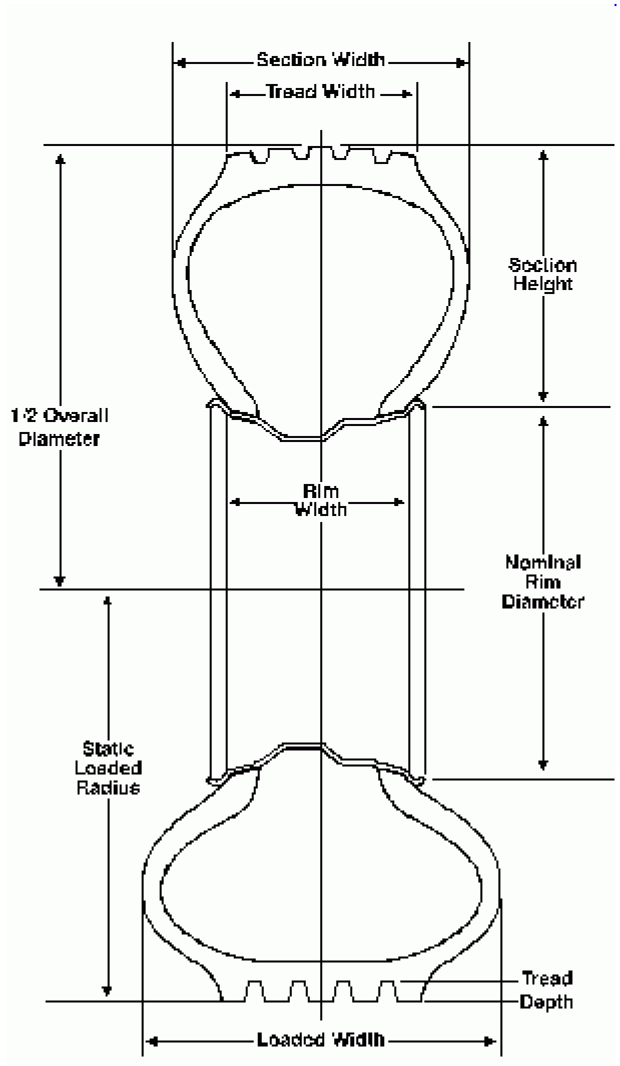


Figure C-1 Dimensions of a Truck Tire

ASPECT RATIO

AR =
<u>Section height</u>

Section width

OVERALL DIAMETER

The measurement of the distance of an unladen tire from tread surface to tread surface on opposite sides of the tire.

OVERALL WIDTH

Measurement of the cross section of an unladen tire including ribs and protrusions. Usually the same as section width on radial tires.

SECTION WIDTH

Measurement of the cross section of an unladen tire across the casing only—not including ribs or protrusions.

TREAD WIDTH

Distance across the tread face of an unladen tire.

TREAD DEPTH

Distance from tread surface to major groove base at designated measuring point.

SECTION HEIGHT

Distance from the bead seat to the tread surface of an unladen tire.

RIM WIDTH

Distance between the rim flanges.

NOMINAL RIM DIAMETER

Diameter of the rim from bead seat to bead seat in inches.

STATIC LOADED RADIUS

Distance from the center of the axle to the ground of a loaded tire under maximum dual load and inflation as stamped on the sidewall of the tire.

LOADED WIDTH

The maximum section width of a loaded tire under maximum dual load and inflation as stamped on the sidewall of the tire.

MINIMUM DUAL SPACING

The minimum allowable distance between the wheel center lines in a dual arrangement.

APPENDIX D STANDARD TRANSPORTATION COMMODITY CLASSIFICATION INFORMATION

The commodities shown below are classified in accordance with the Standard Transportation Commodity Classification (STCC) system, published by the Association of American Railroads. For shipments of more than one commodity, the STCC code for the major commodity, defined as the commodity of the greatest total weight in the shipment, should be used. For easy use, the five-digit STCC codes are aggregated to the two-digit level and adopted in the data collection.

Table D-1 Two-digit STCC Codes

Code	Commodity Description	Code	Commodity Description
01	Farm products	30	Rubber or miscellaneous plastics products
08	Forest products	31	Leather or leather products
09	Fresh fish	32	Clay, concrete, glass, or stone products
		33	Primary metal products
10	Metallic ores	34	Fabricated metal products
11	Coal	35	Machinery, excluding electrical
13	Crude petroleum, natural gas, or gasoline	36	Electrical machinery, equipment, or supplies
14	Non-metallic ores, minerals, excluding fuels	37	
19	Ordnance or accessories	38	Instruments, photographic goods, optical goods, watches, or clocks
20	Food and kindred products	39	Miscellaneous products of manufacturing
21	Tobacco products, excluding insecticides		

22	Textile mill products	40	Waste or scrap materials not identified by producing industry
23	Apparel or other finished textile products or knit apparel		
24	Lumber or wood products, excluding furniture	41	Miscellaneous freight shipments
25	Furniture or fixtures	42	Empty containers, carriers, or devices
26	Pulp, paper, or allied products		
27	Printed matter	48	Waste hazardous materials or waste hazardous substances
28	Chemicals or allied products		
29	Petroleum or coal products		
		--	Commodity unknown

Table D-2 Detailed Commodity Data Collected in the Survey

Site and Direction	Vehicle Serial No.	Axles	Class	Cargo	STCC Code
Mount Vernon EB	8	5	3-S2	broccoli	1
Mount Vernon EB	22	5	3-S2	produce	1
Victoria SB	28	5	3-S2	soy seed	1
Centerville SB	34	5	3-S2	oats	1
Three Rivers SB	15	5	3-S2	produce	1
Three Rivers SB	30	5	3-S2	milo	1
Riviera NB	3	5	3-S2	produce	1
Riviera NB	6	5	3-S2	cabbage	1
Riviera NB	14	5	3-S2	cottonseed hulls	1
Riviera NB	15	5	3-S2	cottonseed hulls	1
Falfurrias SB	5	5	3-S2	grain	1
Falfurrias SB	25	5	3-S2	grain	1
Falfurrias SB	27	5	3-S2	milo (grain)	1
Falfurrias SB	35	5	3-S2	seed	1
San Marcos SB	4	2	SU-2	mushrooms	1
San Marcos SB	14	5	3-S2	cotton bales	1
San Marcos NB	1	5	3-S2	grass	1
San Marcos NB	4	5	3-S2	pallets	1
Odessa EB	1	5	3-S2	cotton	1
Odessa EB	9	5	3-S2	eggplant	1
Odessa EB	12	5	3-S2	lettuce	1
Odessa EB	16	5	3-S2	lettuce	1
Odessa EB	33	5	3-S2	fruit, vegetables	1
Odessa EB	35	5	3-S2	produce	1
Childress SB	3	5	3-S2	cattle	1
El Paso WB	29	5	3-S2	pecans	1
Brownsville NB	28	5	3-S2	cotton	1
Mount Vernon EB	5	5	3-S2	fuel	13
Katy EB	6	5	3-S2	used oil	13
Katy EB	7	5	3-S2	crude oil	13
Katy EB	32	5	3-S2	crude oil	13
Riviera NB	19	5	3-S2	diesel	13
Falfurrias SB	7	3	SU-3	oil	13
Falfurrias SB	23	5	3-S2	gas	13
Falfurrias SB	34	5	3-S2	gas	13
San Marcos SB	16	2	SU-2	diesel	13
San Marcos SB	21	5	3-S2	oil	13
San Marcos NB	3	5	3-S2	gasoline	13
San Marcos NB	7	5	3-S2	fuel	13
San Marcos NB	9	5	3-S2	gas/water	13
Odessa EB	13	5	3-S2	oil	13
El Paso WB	1	5	3-S2	propane	13
El Paso WB	5	5	3-S2	propane	13
El Paso WB	12	5	3-S2	diesel	13
El Paso WB	14	5	3-S2	propane	13

El Paso WB	27	5	3-S2	propane	13
El Paso EB	12	3	SU-3	oil	13
Brownsville NB	32	5	3-S2 spread	diesel	13
Mount Vernon EB	7	5	3-S2 spread	big containers for military	19
Victoria SB	3	5	3-S2	military household goods	19
Three Rivers SB	23	5	3-S2	military equipment	19
Odessa WB	3	5	3-S2	military freight	19
Mount Pleasant WB	5	5	3-S2	mayonnaise	20
Mount Pleasant WB	7	3	2-S1	food	20
Mount Pleasant WB	13	5	3-S2	chicken	20
Mount Pleasant WB	20	5	3-S2	peanut butter	20
Mount Pleasant WB	25	5	3-S2	black pulp meal	20
Mount Pleasant WB	26	5	3-S2	frozen food	20
Mount Pleasant WB	27	5	3-S2	chicken	20
Denison SB	24	5	3-S2	baby formula	20
Katy EB	3	5	3-S2	beer	20
Katy EB	4	2	SU-2	chili	20
Katy EB	12	5	3-S2	milk	20
Katy EB	16	5	3-S2	food	20
Katy EB	24	5	3-S2	milk	20
Victoria SB	5	5	3-S2	frozen orange juice	20
Victoria SB	9	5	3-S2	candy	20
Centerville SB	1	5	3-S2	meat	20
Centerville SB	2	5	3-S2	candy	20
Centerville SB	5	5	3-S2	cheese	20
Centerville SB	14	5	3-S2	food	20
Centerville SB	17	5	3-S2	milk	20
Centerville SB	22	5	3-S2	food	20
Centerville SB	27	5	3-S2	Wesson Oil	20
Centerville SB	30	5	3-S2	feed	20
Three Rivers SB	2	5	3-S2	canned tomatoes	20
Three Rivers SB	3	5	3-S2	beer	20
Three Rivers SB	11	5	3-S2	baking products	20
Three Rivers SB	16	5	3-S2	milk	20
Three Rivers SB	24	5	3-S2	Coke	20
Three Rivers SB	26	5	3-S2	water	20
Riviera NB	1	5	3-S2	frozen food	20
Riviera NB	22	3	SU-3	water	20
Riviera NB	29	5	3-S2	food	20
Falfurrias SB	10	5	3-S2	coffee	20
Falfurrias SB	13	5	2-S1-2	food	20
San Marcos SB	8	5	3-S2	bakery	20
San Marcos SB	30	5	3-S2	frozen corn dogs	20
San Marcos NB	8	2	SU-2	meat	20
San Marcos NB	24	5	3-S2	frozen food	20
San Marcos NB	28	4	2-S2	pet supplies	20
Odessa WB	9	5	3-S2	chickens	20
Odessa WB	11	5	3-S2	food	20
Odessa WB	12	5	3-S2	chewing gum	20
Odessa WB	22	5	3-S2	frozen chickens	20

Odessa WB	35	5	3-S2	sugar, food	20
Odessa EB	19	5	3-S2	Corona beer	20
Odessa EB	28	5	3-S2	cheese	20
Odessa EB	29	5	3-S2	milk	20
Childress SB	5	5	3-S2	meat	20
Childress SB	13	5	3-S2	beef	20
Childress SB	27	5	3-S2	ketchup	20
Childress SB	30	5	3-S2	meat	20
Childress SB	32	5	3-S2	perishable food	20
Childress SB	35	5	3-S2	beef	20
El Paso EB	3	5	3-S2	milk	20
El Paso EB	13	5	3-S2	food	20
El Paso EB	15	5	3-S2	milk	20
El Paso EB	24	5	3-S2	beef	20
Brownsville NB	24	5	3-S2	bread	20
Mount Pleasant WB	29	5	3-S2	burlap	22
Odessa WB	6	5	3-S2	fabric	22
Odessa WB	24	5	3-S2	yarn	22
Odessa WB	25	5	3-S2	yarn	22
Odessa WB	33	5	3-S2	fabric	22
Odessa EB	21	5	3-S2	fabric	22
El Paso WB	10	5	3-S2	bandage materials	22
Mount Vernon EB	2	5	3-S2	car seats	23
Falfurrias SB	21	4	2-S2	laundry	23
Odessa WB	10	5	3-S2	carpet	23
Odessa WB	31	5	3-S2	carpet	23
Odessa EB	5	5	3-S2	shoes	23
El Paso WB [(1)]	4	2	SU-2	tea	23
El Paso EB	35	2	SU-2	towels	23
Brownsville NB	27	5	3-S2	pads	23
Brownsville NB	29	5	3-S2	pads	23
Mount Pleasant WB	6	5	3-S2	lumber	24
Mount Pleasant WB	12	5	3-S2	paneling	24
Mount Vernon EB	12	5	3-S2 spread	storage buildings	24
Centerville SB	31	5	3-S2	floor	24
Three Rivers SB	1	5	3-S2	drywall	24
Three Rivers SB	21	5	3-S2	drywall studs	24
Falfurrias SB	1	5	3-S2	lumber	24
Falfurrias SB	11	5	3-S2	boards	24
San Marcos SB	1	5	3-S2	overhead doors	24
Odessa WB	17	5	3-S2	wood	24
Victoria SB	34	5	3-S2	furniture	25
Odessa EB	32	5	3-S2	light fixtures, mattresses	25
Childress SB	7	5	3-S2	furniture	25
Childress SB	24	5	3-S2	cabinets	25
Childress SB	28	5	3-S2	wood cabinets	25
Childress SB	31	5	3-S2	cat litter	25
Mount Pleasant WB	23	5	3-S2	air filters	26
Mount Vernon EB	16	4	2-S2	paper goods	26
Mount Vernon EB	25	5	3-S2	cardboard boxes	26

Denison SB	2	5	3-S2	toilet paper	26
Denison SB	7	5	3-S2	insulation	26
Katy EB	2	5	3-S2	toilet paper	26
Katy EB	9	5	3-S2 spread	building sections	26
Centerville SB	21	5	3-S2	paper	26
Centerville SB	33	5	3-S2	paper	26
Three Rivers SB	31	5	3-S2	cardboard boxes	26
Riviera NB	21	5	3-S2	paper bags	26
Falfurrias SB	26	5	3-S2	paper	26
San Marcos SB	23	5	3-S2	paper	26
San Marcos SB	26	5	3-S2	paper	26
San Marcos SB	27	5	3-S2	cardboard boxes	26
San Marcos SB	29	5	3-S2	paper	26
Odessa WB	4	5	3-S2	toilet paper	26
Odessa WB	16	5	3-S2	paper	26
Odessa WB	32	5	3-S2	paper	26
Odessa EB	10	5	3-S2	cardboard/foam	26
Childress SB	33	5	3-S2	paper napkins	26
El Paso WB	2	2	SU-2	carton boxes	26
El Paso WB	17	2	SU-2	carton	26
El Paso WB	22	5	3-S2	paper	26
El Paso WB	26	5	3-S2	carton	26
El Paso WB	28	5	3-S2	carton	26
El Paso WB	30	5	3-S2	laminate	26
El Paso EB	11	5	3-S2	carton	26
El Paso EB	19	5	3-S2	carton	26
Mount Pleasant WB	1	3	2-S1	mail (UPS)	27
Centerville SB	35	2	SU-2	books	27
Three Rivers SB	22	5	3-S2	U.S. mail	27
Odessa EB	24	5	3-S2	phone books	27
Childress SB	20	5	3-S2	mail	27
Mount Pleasant WB	34	5	3-S2	paint	28
Victoria SB	11	5	3-S2	chemicals	28
Victoria SB	17	5	3-S2	paint	28
Victoria SB	21	5	3-S2	carbon dioxide	28
Victoria SB	27	5	3-S2	chemicals	28
Victoria SB	31	4	2-S2	chemicals	28
Three Rivers SB	5	5	3-S2	cologne	28
Falfurrias SB	15	5	3-S2	fertilizer	28
Falfurrias SB	17	2	SU-2	medical supplies	28
San Marcos SB	18	5	3-S2	chemicals	28
Odessa WB	5	5	3-S2	paint cans	28
Odessa WB	28	5	3-S2	acid	28
Odessa WB	34	5	3-S2	vitamins	28
Odessa EB	23	5	3-S2	hydrochloric acid	28
Childress SB	14	5	3-S2	soda ash	28
Mount Pleasant WB	9	5	3-S2	ethylene	29
Mount Vernon EB	35	5	3-S2	shingles	29
Denison SB	5	5	3-S2	roofing	29
Centerville SB	3	5	3-S2	shingles	29

San Marcos SB	28	2	SU-2	motor oil	29
San Marcos NB	27	5	3-S2	cases of oil	29
Mount Pleasant WB	21	2	SU-2	tires	30
Mount Pleasant WB	33	5	3-S2	plastic packing material	30
Mount Pleasant WB	35	5	3-S2	plastic	30
Mount Vernon EB	27	5	3-S2	trampolines	30
Denison SB	17	5	3-S2	plastics	30
Katy EB	8	5	3-S2	baskets	30
Victoria SB	1	5	3-S2	plastic bread trays	30
Victoria SB	10	5	3-S2	plastic parts	30
Centerville SB	11	5	3-S2	tires	30
Centerville SB	25	3	2-S1	camper tops	30
Centerville SB	26	5	3-S2	plastic	30
Falfurrias SB	2	5	3-S2	plastic bags	30
Falfurrias SB	24	5	3-S2	plastic auto parts	30
San Marcos SB	5	5	3-S2	polymer beads	30
San Marcos NB	32	2	SU-2	tires	30
Odessa EB	2	5	3-S2	plastic	30
Odessa EB	11	5	3-S2	a/c vents	30
Childress SB	10	5	3-S2	Formica	30
Childress SB	11	5	3-S2	tires	30
Childress SB	12	5	3-S2	fiberglass	30
El Paso WB	13	5	3-S2	plastic bases	30
El Paso WB	20	5	3-S2	plastic trays	30
El Paso EB	5	5	3-S2	plastic boxes	30
Brownsville NB	19	5	3-S2	plastic covers	30
Brownsville NB	25	5	3-S2	plastic bags	30
Brownsville NB	31	5	3-S2	rubber	30
Mount Pleasant WB	8	2	SU-2	sheet rock	32
Mount Vernon EB	10	5	3-S2 spread	construction materials	32
Mount Vernon EB	15	5	3-S2	clay	32
Mount Vernon EB	19	5	3-S2	building materials	32
Denison SB	4	5	3-S2	rocks	32
Denison SB	6	5	3-S2	rocks	32
Denison SB	8	5	3-S2	rocks	32
Denison SB	9	5	3-S2	rocks	32
Denison SB	13	5	3-S2	rock	32
Denison SB	14	5	3-S2	rock	32
Denison SB	15	5	2-S1-2	concrete	32
Denison SB	16	5	3-S2	rock	32
Denison SB	18	5	3-S2	rock	32
Denison SB	19	5	3-S2	rock	32
Denison SB	20	5	3-S2	rock	32
Denison SB	22	5	3-S2	rock	32
Denison SB	28	5	3-S2	rock	32
Denison SB	34	5	3-S2	rock	32
Katy EB	11	5	3-S2	cement	32
Katy EB	13	5	3-S2	gravel	32
Katy EB	17	5	3-S2	bricks	32
Katy EB	21	5	3-S2	gravel	32

Katy EB	22	5	3-S2	gravel	32
Katy EB	23	5	3-S2	gravel	32
Katy EB	26	5	3-S2	sheet rock	32
Victoria SB	6	3	SU-3	hot mix	32
Victoria SB	24	5	3-S2	soil	32
Centerville SB	7	5	3-S2	glass	32
Centerville SB	15	5	3-S2	bricks	32
Three Rivers SB	10	5	3-S2	concrete	32
Three Rivers SB	13	5	3-S2	fly ash	32
Three Rivers SB	19	5	3-S2	cement	32
Three Rivers SB	25	5	3-S2	concrete slabs	32
Three Rivers SB	27	5	3-S2	brick	32
Three Rivers SB	32	4	SU-4	glass	32
Riviera NB	5	5	3-S2 spread	concrete mix	32
Riviera NB	12	5	3-S2	asphalt products	32
Falfurrias SB	14	5	3-S2	concrete	32
San Marcos SB	6	5	3-S2	cement	32
San Marcos SB	15	5	3-S2	sheet rock	32
San Marcos SB	17	5	3-S2	asphalt mix	32
San Marcos SB	24	5	3-S2	concrete blocks	32
San Marcos NB	2	5	3-S2	concrete	32
San Marcos NB	17	5	3-S2	cement	32
San Marcos NB	18	5	3-S2	liquid asphalt	32
San Marcos NB	19	5	3-S2	crushed stone	32
San Marcos NB	26	5	3-S2	glass	32
San Marcos NB	29	5	3-S2	crushed stone	32
Odessa WB	1	5	3-S2	sheetrock	32
Odessa WB	19	5	3-S2 spread	building materials	32
Odessa WB	27	5	3-S2 spread	building materials	32
Odessa EB	6	5	3-S2 spread	stone	32
Odessa EB	31	5	3-S2	rock	32
Mount Pleasant WB	3	5	3-S2 spread	steel sheets	33
Mount Pleasant WB	30	5	3-S2 spread	steel beams	33
Mount Vernon EB	11	5	3-S2	forklift counterweights	33
Mount Vernon EB	32	5	3-S2	copper	33
Denison SB	25	5	3-S2 spread	metal	33
Victoria SB	13	5	3-S2	steel	33
Victoria SB	16	5	3-S2 spread	steel	33
Three Rivers SB	14	5	3-S2	steel beams	33
Three Rivers SB	29	5	3-S2	steel beams	33
San Marcos SB	20	5	3-S2	metals	33
San Marcos SB	25	5	3-S2	aluminum pipes	33
Odessa EB	3	5	3-S2 spread	metal	33
Odessa EB	20	5	3-S2 spread	copper	33
Odessa EB	25	5	3-S2 spread	copper	33
Mount Pleasant WB	2	5	3-S2	plumbing	34
Mount Pleasant WB	4	5	3-S2	engine parts	34
Mount Pleasant WB	15	5	3-S2	auto parts	34
Mount Pleasant WB	16	5	3-S2	auto parts	34
Mount Vernon EB	9	5	3-S2	auto parts	34

Mount Vernon EB	13	5	3-S2	truck parts	34
Mount Vernon EB	20	5	3-S2	auto parts	34
Mount Vernon EB	24	5	3-S2	dinnerware, kitchenware	34
Mount Vernon EB	31	5	3-S2	auto parts	34
Denison SB	11	5	3-S2	auto parts	34
Katy EB	19	5	3-S2	auto parts	34
Victoria SB	12	5	3-S2	pipe	34
Victoria SB	33	3	SU-3	crank shaft	34
Centerville SB	9	5	3-S2 spread	steel coil	34
Centerville SB	23	5	3-S2	railroad axles	34
Centerville SB	32	5	3-S2	pipe fitting	34
Three Rivers SB	28	5	3-S2	conveyor shaft	34
Three Rivers SB	35	2	SU-2	auto parts	34
Riviera NB	20	5	3-S2	auto parts	34
Falfurrias SB	6	5	3-S2 spread	machinery parts	34
Falfurrias SB	20	5	3-S2	auto supplies	34
Falfurrias SB	29	5	3-S2 spread	pipes	34
Falfurrias SB	32	5	3-S2	auto parts	34
San Marcos SB	11	5	3-S2	Caterpillar parts	34
San Marcos NB	15	5	3-S2	wheels	34
San Marcos NB	22	2	SU-2	truck parts	34
Odessa WB	15	5	3-S2 spread	truck axles	34
Odessa EB	14	5	3-S2	auto parts	34
Odessa EB	15	5	3-S2	piping	34
El Paso EB	4	3	2-S1	skid	34
El Paso EB	14	5	3-S2	vacuum parts	34
Brownsville NB	5	4	2-S2	hoods	34
Brownsville NB	16	5	3-S2	doors, windows	34
Brownsville NB	21	5	3-S2	clamps	34
Brownsville NB	35	5	3-S2	machinery parts	34
Mount Pleasant WB	28	5	3-S2 spread	plane porter and starter	35
Mount Pleasant WB	31	5	3-S2 spread	helicopter	35
Denison SB	30	5	3-S2 spread	forklifts	35
Victoria SB	2	5	3-S2	cars	35
Victoria SB	7	5	3-S2	forklifts	35
Centerville SB	10	5	3-S2	household mover	35
Three Rivers SB	9	5	3-S2	trucks	35
Falfurrias SB	4	5	3-S2	cars	35
Falfurrias SB	12	2	SU-2	machinery	35
Falfurrias SB	18	6	3-S3	machinery	35
Falfurrias SB	28	5	3-S2	mixing pump	35
Falfurrias SB	33	2	SU-2	truck	35
San Marcos SB	10	3	SU-3	crane	35
Odessa EB	4	5	3-S2	farm equipment	35
Childress SB	1	5	3-S2 spread	crushed cars	35
Childress SB	9	5	3-S2	crushed cars	35
Childress SB	15	5	3-S2	mill	35
El Paso WB	16	5	3-S2	forklift	35
El Paso WB	19	5	3-S2	Pathfinder	35
El Paso WB	25	5	3-S2	crushed cars	35

El Paso EB	18	5	3-S2	heater	35
Mount Vernon EB	3	5	3-S2	copper wire	36
Mount Vernon EB	6	5	3-S2	wire	36
Denison SB	23	5	3-S2	wire	36
Denison SB	27	5	3-S2	communication equipment	36
Denison SB	31	5	3-S2	blowers, fans	36
Denison SB	33	5	3-S2	fuses	36
Falfurrias SB	19	2	SU-2	cable	36
San Marcos SB	13	5	3-S2	batteries	36
San Marcos SB	19	2	SU-2	electronics	36
Odessa WB	8	5	3-S2	refrigerator	36
Odessa WB	20	5	3-S2	wire	36
Odessa WB	29	5	3-S2	cables	36
El Paso WB	11	5	3-S2	vacuums	36
El Paso EB	1	5	3-S2	wire	36
El Paso EB	7	5	3-S2	computers	36
El Paso EB	22	5	3-S2	telephone products	36
Centerville SB	4	5	3-S2	meters	38
Mount Pleasant WB	11	5	3-S2	appliances	39
Mount Pleasant WB	32	5	3-S2	general merchandise	39
Mount Vernon EB	4	5	3-S2	groceries	39
Mount Vernon EB	17	6	3-S1-2	dry goods	39
Mount Vernon EB	26	5	3-S2	household products	39
Denison SB	32	6	3-S1-2	hardware	39
Katy EB	27	4	2-S2	household goods	39
Victoria SB	4	5	3-S2	personal household items	39
Centerville SB	20	5	3-S2	groceries	39
Three Rivers SB	34	5	3-S2	household goods	39
Falfurrias SB	8	5	3-S2	merchandise	39
Falfurrias SB	22	4	3-S1	appliances	39
San Marcos SB	7	5	3-S2	Home Depot	39
San Marcos SB	9	5	3-S2	groceries	39
Odessa WB	13	5	3-S2	misc LTL	39
Odessa WB	14	5	3-S2	miscellaneous blenders	39
Odessa WB	21	5	3-S2	misc	39
Odessa WB	26	5	3-S2	misc	39
Odessa EB	17	5	3-S2	Sears	39
Odessa EB	26	5	3-S2	consolidated parts	39
Odessa EB	27	4	2-S2	hardware	39
Odessa EB	30	5	2-S1-2	consolidated freight	39
Childress SB	2	5	3-S2	household goods	39
Childress SB	6	6	3-S1-2	freight (UPS)	39
El Paso WB	3	5	3-S2	maquila	39
El Paso WB	32	5	3-S2	maquila	39
El Paso EB	33	2	SU-2	office equipment	39
Mount Vernon EB	1	5	3-S2	scrap metal	40
Denison SB	21	5	3-S2	scrap paper	40
Denison SB	29	2	SU-2	trash	40
Victoria SB	8	5	3-S2	waste	40
Victoria SB	35	2	SU-2	waste	40

Centerville SB	18	5	3-S2 spread	waste	40
Riviera NB	28	3	SU-3	waste	40
San Marcos NB	5	5	3-S2	garbage	40
San Marcos NB	10	5	3-S2	scrap	40
San Marcos NB	12	5	3-S2	scrap wood	40
San Marcos NB	13	6	3-S3	scrap wood	40
Childress SB	34	5	3-S2	waste paper	40
El Paso WB	6	3	SU-3	trash	40
El Paso WB	8	5	3-S2	sewage sludge	40
Mount Pleasant WB	22	4	2-S2	freight	41
Katy EB	14	4	3-S1	air freight	41
Centerville SB	16	5	2-S1-2	freight	41
Three Rivers SB	7	5	3-S2	various freight	41
San Marcos NB	23	2	SU-2	UPS	41
Odessa WB	23	6	3-S1-2	small parcels	41
Childress SB	19	5	3-S2	air freight	41
Childress SB	22	5	2-S1-2	mixed cargo	41
Childress SB	23	5	3-S2	air cargo	41
El Paso WB	33	2	SU-2	raw material	41
El Paso WB	34	2	SU-2	raw material	41
El Paso WB	35	5	3-S2	raw material	41
El Paso EB	6	2	SU-2	raw material	41
El Paso EB	16	5	3-S2	raw material	41
El Paso EB	20	5	3-S2	raw material	41
El Paso EB	21	5	3-S2	raw material	41
El Paso EB	23	5	3-S2	raw material	41
El Paso EB	25	2	SU-2	raw material	41
El Paso EB	26	2	SU-2	raw material	41
El Paso EB	28	5	3-S2	raw material	41
El Paso EB	32	3	2-S1	freight	41
Brownsville NB	12	2	SU-2	raw material	41
Brownsville NB	34	2	SU-2	raw material	41
Mount Pleasant WB	14	5	3-S2	Rubbermaid containers	42
Mount Pleasant WB	17	5	3-S2	empty	42
Mount Pleasant WB	18	4	3-S1	empty	42
Mount Pleasant WB	19	5	3-S2	empty cable reels	42
Mount Vernon EB	14	5	3-S2	empty	42
Mount Vernon EB	18	5	3-S2	empty	42
Mount Vernon EB	21	5	3-S2	empty	42
Mount Vernon EB	23	5	3-S2	empty	42
Mount Vernon EB	28	5	3-S2	empty	42
Mount Vernon EB	29	5	3-S2	empty	42
Mount Vernon EB	30	5	3-S2	empty	42
Mount Vernon EB	33	5	3-S2	empty bottles	42
Mount Vernon EB	34	5	3-S2	empty	42
Denison SB	1	5	3-S2	empty	42
Denison SB	3	5	3-S2	empty	42
Denison SB	10	3	SU-3	empty	42
Denison SB	12	5	3-S2	empty	42
Denison SB	26	5	3-S2	empty	42

Denison SB	35	5	3-S2	empty plastic tubs	42
Katy EB	1	5	3-S2	empty	42
Katy EB	10	3	SU-3	empty	42
Katy EB	15	5	3-S2	empty	42
Katy EB	18	5	3-S2	empty	42
Katy EB	20	5	3-S2	empty	42
Katy EB	25	5	3-S2	empty	42
Katy EB	28	5	3-S2	empty	42
Katy EB	29	5	3-S2	empty	42
Katy EB	30	5	3-S2	empty	42
Katy EB	31	5	3-S2	empty	42
Katy EB	34	5	3-S2 spread	empty	42
Katy EB	35	5	3-S2	empty	42
Victoria SB	14	5	3-S2	empty	42
Victoria SB	15	5	3-S2	empty	42
Victoria SB	18	5	3-S2	empty	42
Victoria SB	19	5	3-S2	empty	42
Victoria SB	20	5	3-S2	empty	42
Victoria SB	22	5	3-S2	empty	42
Victoria SB	23	2	SU-2	empty drums	42
Victoria SB	25	5	3-S2	empty	42
Victoria SB	29	4	2-S2	empty	42
Victoria SB	32	5	3-S2	empty	42
Centerville SB	6	5	3-S2	bottles	42
Centerville SB	8	5	3-S2	empty	42
Centerville SB	12	6	3-S3	containers	42
Centerville SB	19	6	3-S3	empty	42
Centerville SB	24	5	3-S2	empty	42
Centerville SB	29	2	SU-2	empty	42
Three Rivers SB	4	5	3-S2	empty	42
Three Rivers SB	6	5	3-S2	empty	42
Three Rivers SB	8	5	3-S2	empty baskets	42
Three Rivers SB	12	5	3-S2	empty	42
Three Rivers SB	17	5	3-S2	empty	42
Three Rivers SB	18	5	3-S2	empty	42
Three Rivers SB	20	5	3-S2	empty gas tanks	42
Three Rivers SB	33	5	3-S2	empty	42
Riviera NB	2	5	3-S2	empty crates	42
Riviera NB	4	5	3-S2	empty	42
Riviera NB	7	5	3-S2	empty	42
Riviera NB	8	5	3-S2 spread	empty	42
Riviera NB	9	5	3-S2	empty	42
Riviera NB	10	5	3-S2	empty	42
Riviera NB	11	5	3-S2	empty	42
Riviera NB	13	3	SU-3	nothing (tractor only)	42
Riviera NB	16	5	3-S2	empty	42
Riviera NB	17	5	3-S2 spread	empty	42
Riviera NB	18	5	3-S2	tractor parts	42
Riviera NB	23	5	3-S2	empty	42
Riviera NB	24	5	3-S2 spread	truck tractor	42

Riviera NB	26	5	3-S2	empty	42
Riviera NB	27	5	3-S2	empty	42
Riviera NB	30	5	3-S2	empty	42
Riviera NB	31	5	3-S2 spread	empty	42
Riviera NB	32	5	3-S2	empty	42
Riviera NB	34	4	3-S1	boxes	42
Riviera NB	35	5	3-S2	empty	42
Falfurrias SB	3	5	3-S2	empty	42
Falfurrias SB	9	3	SU-3	nothing (tractor only)	42
Falfurrias SB	16	5	3-S2	empty	42
Falfurrias SB	30	5	3-S2	empty	42
San Marcos SB	12	5	3-S2	aluminum cans	42
San Marcos NB	6	7	4-S3	empty	42
San Marcos NB	11	5	3-S2	empty	42
San Marcos NB	20	5	3-S2	empty	42
San Marcos NB	25	5	3-S2	empty	42
San Marcos NB	30	5	3-S2	empty	42
San Marcos NB	31	5	3-S2	empty	42
San Marcos NB	33	5	3-S2	empty	42
Odessa WB	2	5	3-S2	empty	42
Odessa WB	7	2	SU-2	empty	42
Odessa WB	30	5	3-S2	empty	42
Odessa EB	7	5	3-S2	empty	42
Odessa EB	8	5	3-S2	empty	42
Odessa EB	22	5	3-S2	empty	42
Odessa EB	34	5	3-S2	empty	42
Childress SB	4	3	SU-3	empty	42
Childress SB	16	5	3-S2	empty	42
Childress SB	17	5	3-S2	empty	42
Childress SB	18	5	3-S2	empty	42
Childress SB	21	5	3-S2	empty	42
Childress SB	25	5	3-S2	tractor	42
Childress SB	26	5	3-S2	cable reels	42
Childress SB	29	5	3-S2 spread	empty	42
El Paso WB	7	5	3-S2	empty	42
El Paso WB	9	5	3-S2	empty	42
El Paso WB	15	5	3-S2	plastic containers	42
El Paso WB	18	5	3-S2	empty	42
El Paso WB	21	5	3-S2	empty	42
El Paso WB	23	5	3-S2	empty	42
El Paso WB	24	5	3-S2	empty	42
El Paso WB	31	3	SU-3	empty	42
El Paso EB	2	5	3-S2	empty	42
El Paso EB	8	3	SU-3	nothing (tractor only)	42
El Paso EB	9	5	3-S2	empty	42
El Paso EB	10	2	SU-2	empty	42
El Paso EB	17	3	SU-3	nothing (tractor only)	42
El Paso EB	27	5	3-S2	empty	42
El Paso EB	29	3	SU-3	nothing (tractor only)	42
El Paso EB	30	3	SU-3	nothing (tractor only)	42

El Paso EB	31	3	SU-3	empty	42
El Paso EB	34	5	3-S2	empty	42
Laredo Columbia Bridge	1	5	3-S2	empty	42
Laredo Columbia Bridge	2	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	3	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	4	5	3-S2	empty	42
Laredo Columbia Bridge	5	5	3-S2	empty	42
Laredo Columbia Bridge	6	5	3-S2	empty	42
Laredo Columbia Bridge	7	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	8	5	3-S2	empty	42
Laredo Columbia Bridge	9	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	10	5	3-S2	empty	42
Laredo Columbia Bridge	11	5	3-S2	empty	42
Laredo Columbia Bridge	12	3	SU-3	empty	42
Laredo Columbia Bridge	13	4	3-S1	empty	42
Laredo Columbia Bridge	14	2	SU-2	empty	42
Laredo Columbia Bridge	15	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	16	5	3-S2	empty	42
Laredo Columbia Bridge	17	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	18	5	3-S2	empty	42
Laredo Columbia Bridge	19	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	20	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	21	3	SU-3	empty	42
Laredo Columbia Bridge	22	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	23	5	3-S2	empty	42
Laredo Columbia Bridge	24	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	25	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	26	5	3-S2	empty	42
Laredo Columbia Bridge	27	5	3-S2	empty	42
Laredo Columbia Bridge	28	5	3-S2 spread	empty	42
Laredo Columbia Bridge	29	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	30	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	31	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	32	3	SU-3	empty	42
Laredo Columbia Bridge	33	5	3-S2	empty	42
Laredo Columbia Bridge	34	3	SU-3	nothing (tractor only)	42
Laredo Columbia Bridge	35	5	3-S2	empty	42
Brownsville NB	1	6	3-S3	empty	42
Brownsville NB	2	6	3-S3	empty	42
Brownsville NB	4	6	3-S3	empty	42
Brownsville NB	7	5	3-S2	empty	42
Brownsville NB	9	5	3-S2	empty	42
Brownsville NB	10	2	SU-2	empty	42
Brownsville NB	11	3	SU-3	empty	42
Brownsville NB	15	5	3-S2	empty	42
Brownsville NB	17	2	SU-2	empty	42
Brownsville NB	18	5	3-S2	empty	42
Brownsville NB	23	5	3-S2	cans	42
Brownsville NB	26	5	3-S2	empty	42
Brownsville NB	30	5	3-S2	empty	42

Brownsville NB	33	5	3-S2	empty	42
Mount Pleasant WB	10	5	3-S2	unknown	*
Mount Pleasant WB	24	5	3-S2	unknown	*
Katy EB	33	5	3-S2	Cutter Citronella	*
Centerville SB	13	5	3-S2	unknown	*
San Marcos SB	22	5	3-S2	unknown	*
Odessa WB	18	5	3-S2	unknown	*
Odessa EB	18	5	3-S2	unknown	*
Childress SB	8	5	3-S2	outer globe items	*
Katy EB[2]	5	5	3-S2		
Victoria SB	26	3	SU-3		
Victoria SB	30	3	SU-3		
Centerville SB	28	5	3-S2		
Riviera NB	25	3	SU-3		
Riviera NB	33	5	3-S2		
Falfurrias SB	31	3	SU-3		
San Marcos SB	2	5	3-S2		
San Marcos SB	3	5	3-S2		
San Marcos NB	14	5	3-S2		
San Marcos NB	16	2	SU-2		
San Marcos NB	21	5	3-S2		
Brownsville NB	3	5	3-S2		
Brownsville NB	6	3	SU-3		
Brownsville NB	8	3	SU-3		
Brownsville NB	13	3	SU-3		
Brownsville NB	14	3	SU-3		
Brownsville NB	20	3	SU-3		
Brownsville NB	22	5	3-S2		

(1) Darkened cells indicate commodities on board but not identified.

(2) Blank cells means commodity information was not collected.

APPENDIX E TIRE PRESSURE AND TIRE TEMPERATURE EXPERIMENTS

1) Tire Pressure Gauges

Four truck tire pressure gauges (P1, P2, P3, and P4 in Fig. E-1) were initially purchased for evaluation (Table E-1). Early in the data collection process, gauges P5 and P6 were purchased. The initial gauges were tested for ease of use and measurement accuracy. It was found that a gauge with a straight chuck—like the Milton 986—was compatible with more tire valves than an angled chuck gauge was. In addition, it was found that bending the pipe between the chuck and the gauge's measuring mechanism by about 10° (Fig. E-2) made the gauge compatible with virtually all tire valves. This modification had no effect on gauge accuracy. Gauges P1, P5, and P6 were modified in this manner.

Table E-1 Tire Pressure Gauge Information

Identifier	Manufacturer	Model
P1	Milton	986
P2	Milton	967
P3	Camel	40-050
P4	Camel	40-410
P5	Milton	986
P6	Milton	986

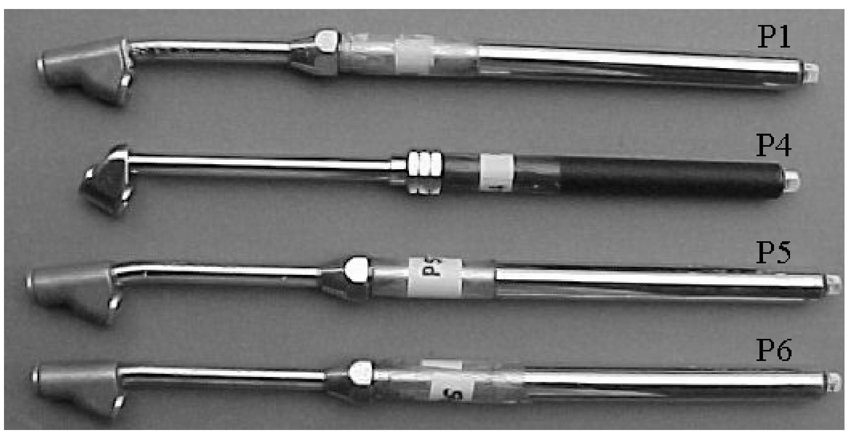


Figure E-1 Four Tire Pressure Gauges Used for Field Data Collection

Figure E-2 Gauge P5 as Modified

Gauges were checked for accuracy by comparing them to a Trautwein electronic pressure sensor. The Trautwein sensor had recently been calibrated against a dead-weight pressure gauge in the Civil Engineering Department soils lab. The test setup had the electronic sensor, a tire valve stem, and an air pressure reservoir connected through a tee fitting. The tire valve stem was used for adding or removing air to adjust pressure in the reservoir to a test point pressure. This pressure was then measured by the gauge being tested. Results of this initial test are shown in Fig. E-3. Gauges P5 and P6 were later tested in a similar manner. Gauges P1 and P4 were also tested again later (Fig. E-4).

Results of these tests were used to compensate for gauge error in tire pressures measured during field data collection.

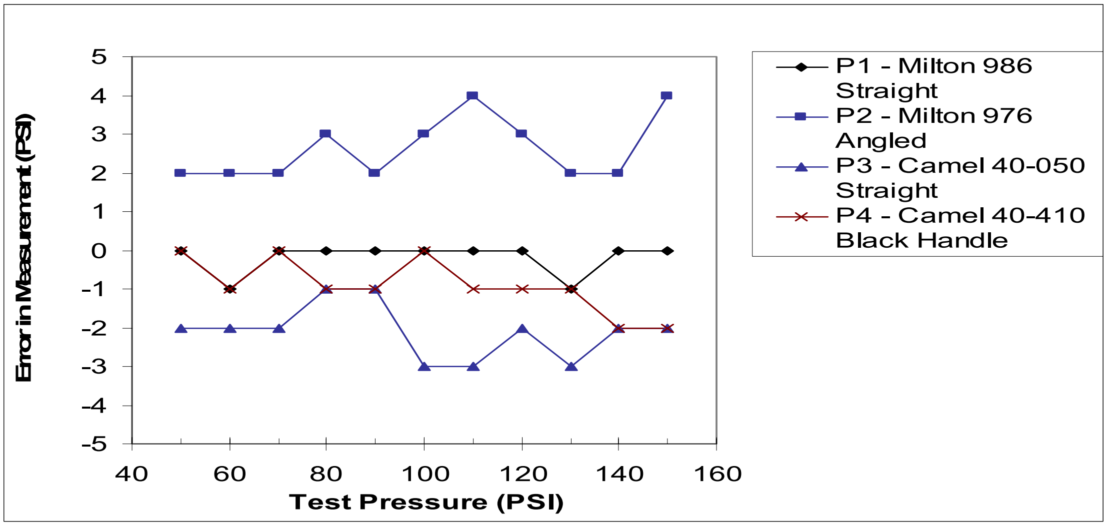
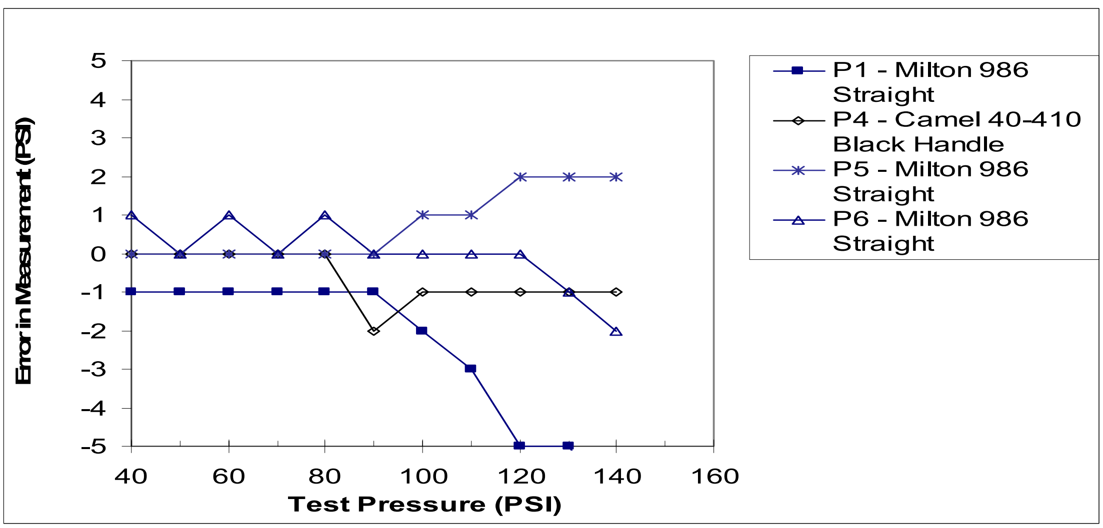


Figure E-3 Initial Tire Pressure Gauge Evaluation



2) Temperature Measurements

A Fluke Model 51 type K thermo-couple instrument was chosen to be the reference for temperature measurements. This instrument was compared to laboratory grade mercury bulb thermometers and found to have an error of less than 1 ^{o}F, which was considered satisfactory. The instrument was also used in the field to measure air temperature.

Table E-2 Infrared Thermometer Data

Identifier	Manufacturer	Model	*Serial #*
T1	Wahl	DHS-14X	B-4653
T2	Raytek	Raynger ST	3759680401 0068
T3	Raytek	Raynger ST	3759680401 0012

It was decided that infrared (IR) non-contacting thermometers would be used to measure tire and pavement temperatures. A Wahl Model DHS-14X infrared thermometer was used for the initial field data collection. Later, two Raytek Raynger ST infrared thermometers were purchased and used as the primary instruments for the remainder of the field data collection.

Figure E-5 Tire Sidewall Pieces with Imbedded Thermo-couple Sensor in Oven

The three IR thermometers were checked as follows. A used tire was obtained from The University of Texas auto shop and two pieces approximately 3 in. by 5 in. were cut from its sidewall. A probe of the Fluke thermo-couple was embedded into one of the pieces. The two pieces were placed in a laboratory oven (Fig. E-5), and the oven door was closed with the probe lead passed to the outside of the oven so the temperature of the tire sidewall pieces could be read from the instrument outside the oven.

Figure E-6 Measuring the Temperature of the Tire Sidewall Piece inside Oven with Infrared Thermometer

Table E-3 Measured Temperature Data (^oF)

Set Point	T1	T2
81.6	81	82
90.0	89	90
100.0	98	99
109.4	205	106
119.6	114	116
129	124	126
140	135	137
80	79	79
90	89	90
100	97	97
110	206	108
120	117	118
130	127	129
140	136	138

For each test point shown in Table E-3, the oven was adjusted to hold the temperature and the Fluke instrument was observed until the tire sidewall piece temperature was stable. The oven door was then opened and the temperature of each piece was measured. (Fig. E-6). The test points and measured temperatures for each instrument are shown in Table E-3.

3) Relationship Between Truck Tire Pressure and Tire Temperature

Ideally, all tire pressures would be measured when the vehicle had not been driven for several hours and the tires were "cold." As this was not possible, it was decided to measure both temperature and pressure of each tire observed during the field data collection process. The pressures could then be corrected to the "cold" value.

To adjust pressure readings to compensate for tire heating, one must determine a relationship between temperature and pressure within a tire. The Ideal Gas Law states that for a gas confined within a fixed volume, with a known temperature (T_1) and pressure (P_1), the pressure (P_2) at another temperature (T_2) can be found by the equation

$$P_2 = P_1 \times {}^{T_2}\!/_{T_1}$$

In the above equation, temperatures are absolute temperatures (^{O}F + 460). Pressures are absolute pressures and are found by adding the atmospheric pressure ($\approx$ 14.7 PSI) to gauged or measured pressure.

In practice, the volume of air in the wheel-tire assembly may not be constant. The elasticity of the wheel-tire may allow the volume to change with pressure changes. Thermal expansion/contraction may occur with changes in temperature. Moisture present in the air may change between liquid and gaseous states. The volume of a fixed weight of gaseous moisture is many times that of the same weight of liquid moisture. A change of any amount of moisture from liquid to gas would effectively add more gas to the enclosed volume, with the reverse effect for a change from gas to liquid.

An experiment was designed to determine the relationship between temperature and internal pressure for a typical truck tire. The experiment was conducted in an environmental chamber located on the campus of The University of Texas at Austin in the Earnest Cockrell, Jr. Hall, Room B.204, Fig. E-7. This room has facilities to maintain a constant temperature in the range of -40 ^{O}F to 150 ^{O}F. It was decided to conduct the test over a temperature range of 40 ^{O}F to 140 ^{O}F, as this would include the range of tire temperatures that were seen in the field.

Temperatures were read from the sensors that were a part of the chamber control system. Pressures were measured by a Trautwein electronic sensor that had recently been calibrated against the lab's dead-weight pressure tester.

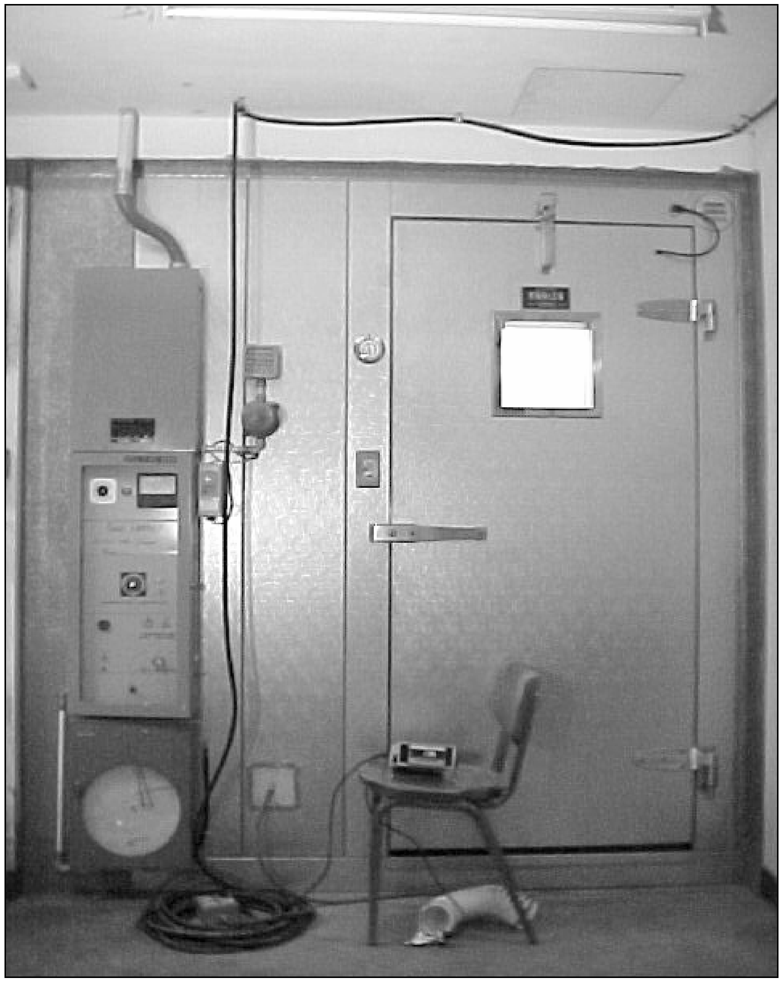


Figure E-7 Environmental Chamber (exterior view)

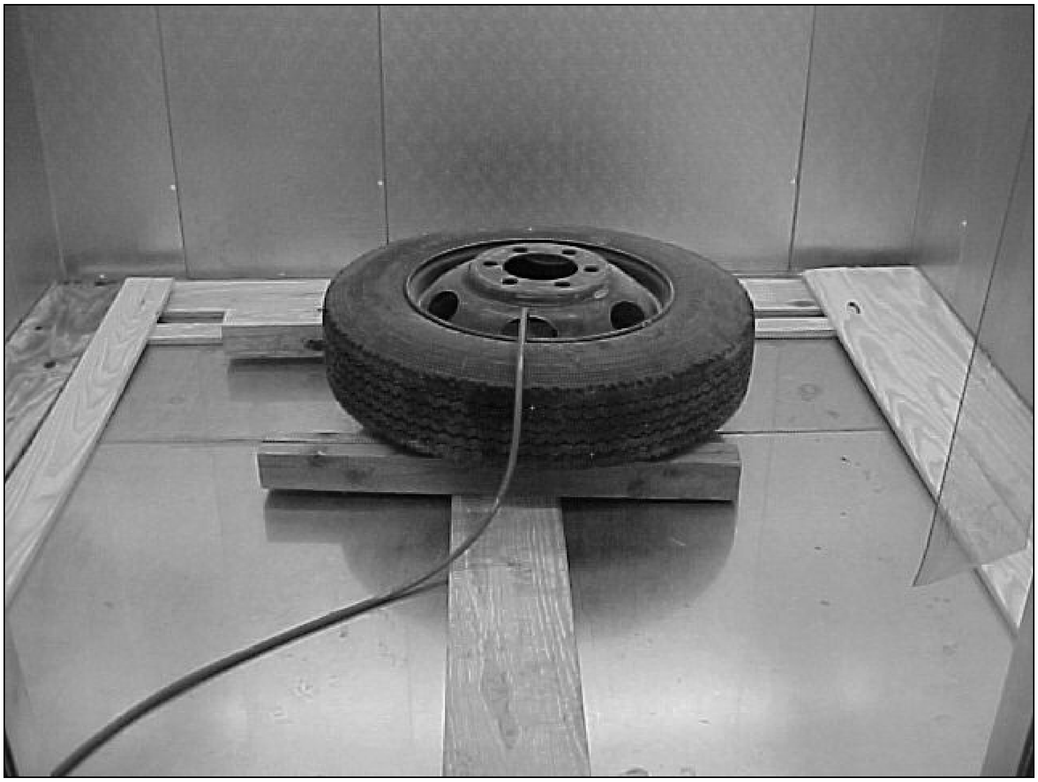


Figure E-8 Test Tire in Environmental Chamber

Figure E-9 Air Hose Connection to Tire Valve Stem

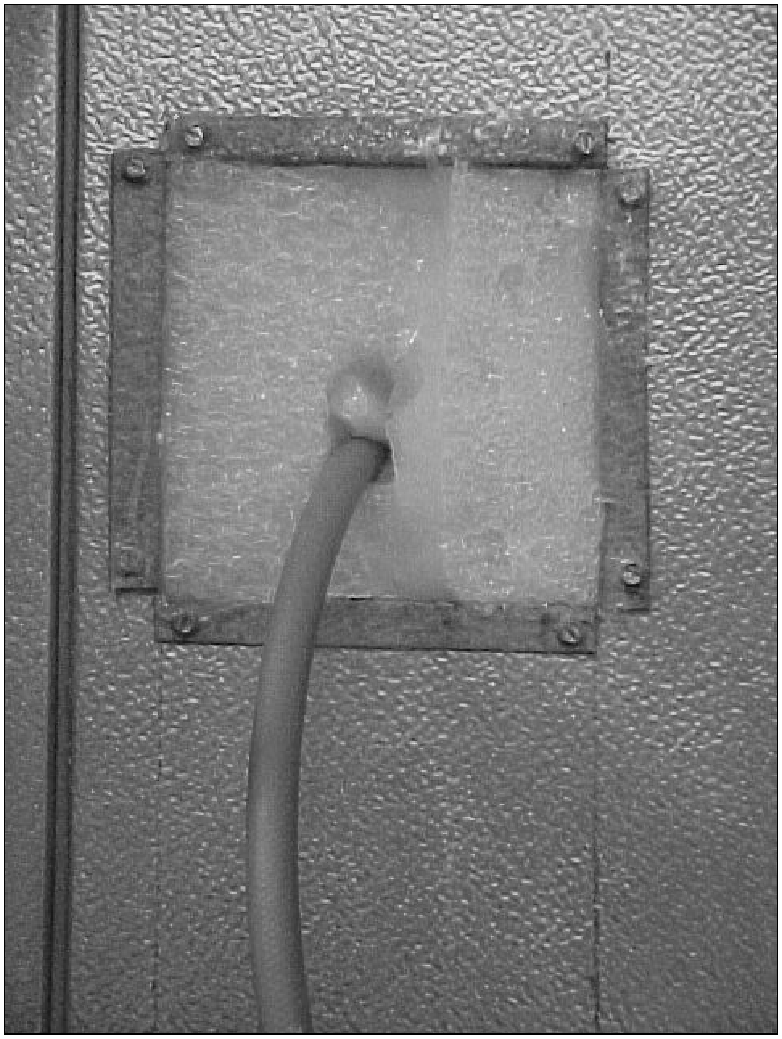


Figure E-10 Air Hose Exiting Environmental Chamber

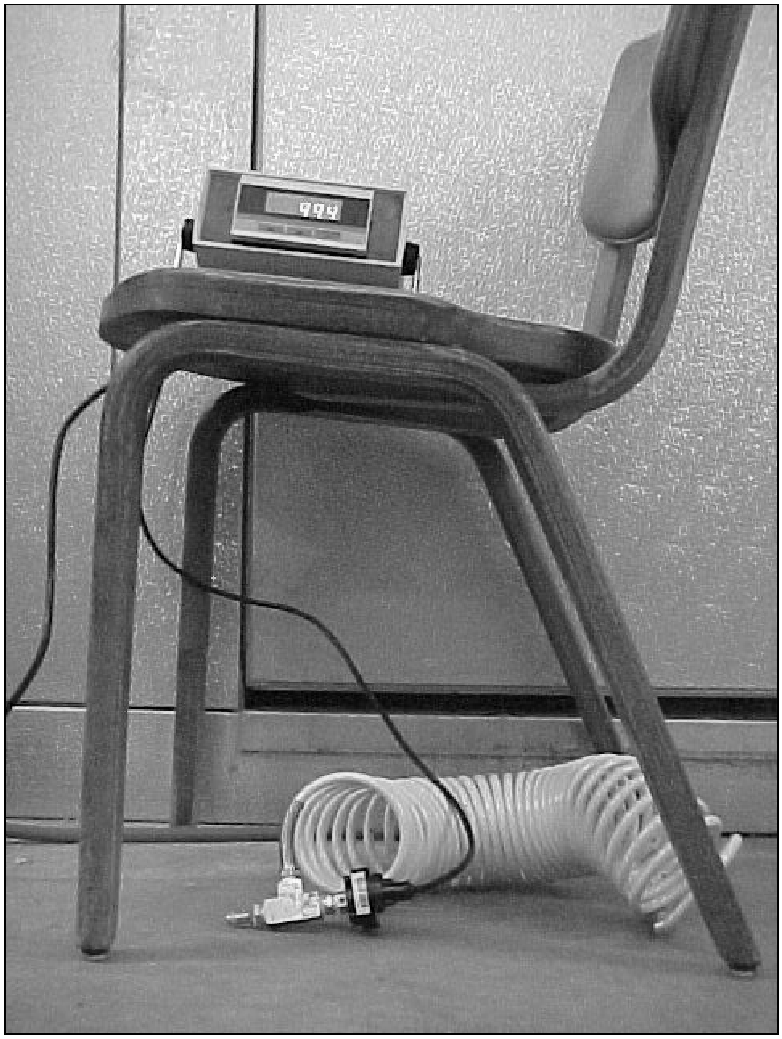


Figure E-11 Pressure Sensing Equipment and Connections Outside Chamber

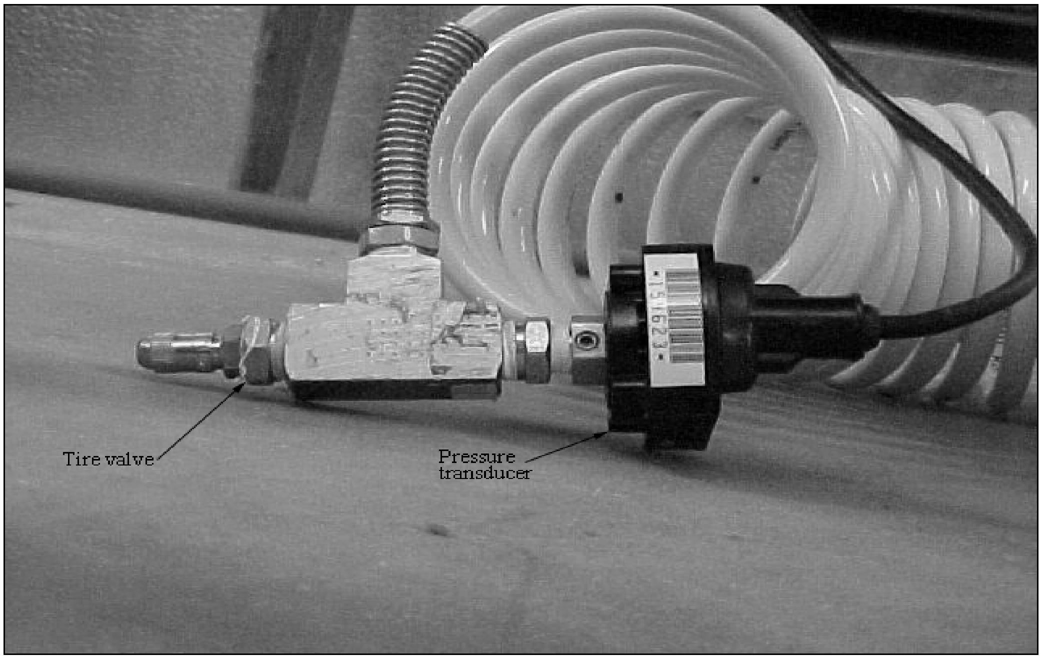


Figure E-12 Connections at Tee Fitting

Figure E-13 Pressure Sensor Readout

The tire to be tested was a Goodyear Unisteel 9R22.5 mounted on a one-piece steel wheel as shown in Fig. E-8. The tire was positioned in the chamber in a horizontal position, supported about 4 in. above the chamber floor by two boards. The valve chore was removed from the tire's valve stem. A new one-fourth inch (inside diameter) rubber air hose about 15 ft. long was pushed about a three-eight inch over the valve stem and clamped with a worm drive clamp, Fig. E-9. The hose exited through the chamber wall as shown in Fig. E-10. About 8 ft. of hose remained inside the chamber. Outside the chamber, Fig. E-11, an additional 25 ft. of quarter-inch coiled plastic hose connected the 15ft. rubber hose to the pressure transducer through a Tee fitting that also had a tire valve fitting attached, Fig. E-12. The pressure sensor readout as depicted in Fig. E-13, was placed at a convenient height.

Testing proceeded as follows. The chamber temperature was adjusted to 60 ^{O}F, and the tire pressure was set to 100 psi and left overnight to stabilize. When the pressure reading was stable, the pressure was again set to 100 psi. The pressure was monitored and stayed stable at 100 psi for several hours. The temperature was decreased by 10 ^{O}F to 50 ^{O}F. The pressure was monitored until stable and was recorded. The time for pressure stabilization was found to be no more than 4 hours.

The temperature was decreased to 40 ^{O}F, and the pressure was recorded when stable. As 40 ^{O}F was the lowest temperature point in the experiment, temperature was then raised in 10 ^{O}F increments. This process of increasing the temperature by 10 ^{O}F, waiting for pressure stabilization, and recording the pressure was repeated until a stable pressure for a temperature of 140 ^{O}F was reached. The temperature was then lowered in 10 ^{O}F increments, with pressures recorded for each set point until the 60 ^{O}F point was completed. The data are shown in Table E-4 and Fig. E-14.

Table E-4 Data Collected

Measurement			Pressure PSI		Time Between Readings	Time From Start
Date	Time	Temp. ^{o}F	Measured	Adjusted		
04/18/00	10:00 AM	60	100.0	100.0	00 00:00	00 00:00
04/18/00	01:38 PM	50	98.6	98.6	00 03:38	00 03:38
04/19/00	06:55 AM	40	95.5	95.6	00 17:17	00 20:55
04/19/00	02:10 PM	50	97.7	97.8	00 07:15	01 04:10
04/20/00	02:50 PM	60	99.5	99.7	01 00:40	02 04:50
04/24/00	06:45 AM	70	101.6	102.0	03 15:55	05 20:45
04/24/00	03:30 PM	80	103.8	104.2	00 08:45	06 05:30
04/25/00	06:55 AM	90	105.9	106.4	00 15:25	06 20:55
04/25/00	03:45 PM	100	108.3	108.8	00 08:50	07 05:45
04/26/00	07:15 AM	110	110.4	110.9	00 15:30	07 21:15
04/26/00	02:45 PM	120	112.6	113.2	00 07:30	08 04:45
04/27/00	07:25 AM	130	114.9	115.5	00 16:40	08 21:25
04/27/00	03:00 PM	140	117.0	117.6	00 07:35	09 05:00
04/28/00	08:20 AM	130	114.7	115.4	00 17:20	09 22:20
04/28/00	03:25 PM	120	112.5	113.2	00 07:05	10 05:25
05/01/00	03:20 PM	110	109.9	110.8	02 23:55	13 05:20
05/02/00	07:15 AM	100	107.6	108.6	00 15:55	13 21:15
05/02/00	03:20 PM	90	105.4	106.4	00 08:05	14 05:20
05/03/00	08:55 AM	80	103.2	104.2	00 17:35	14 22:55
05/03/00	03:10 PM	70	101.6	102.7	00 06:15	15 05:10
05/04/00	06:45 AM	60	98.9	100.0	00 15:35	15 20:45
			Leakage:	1.1		

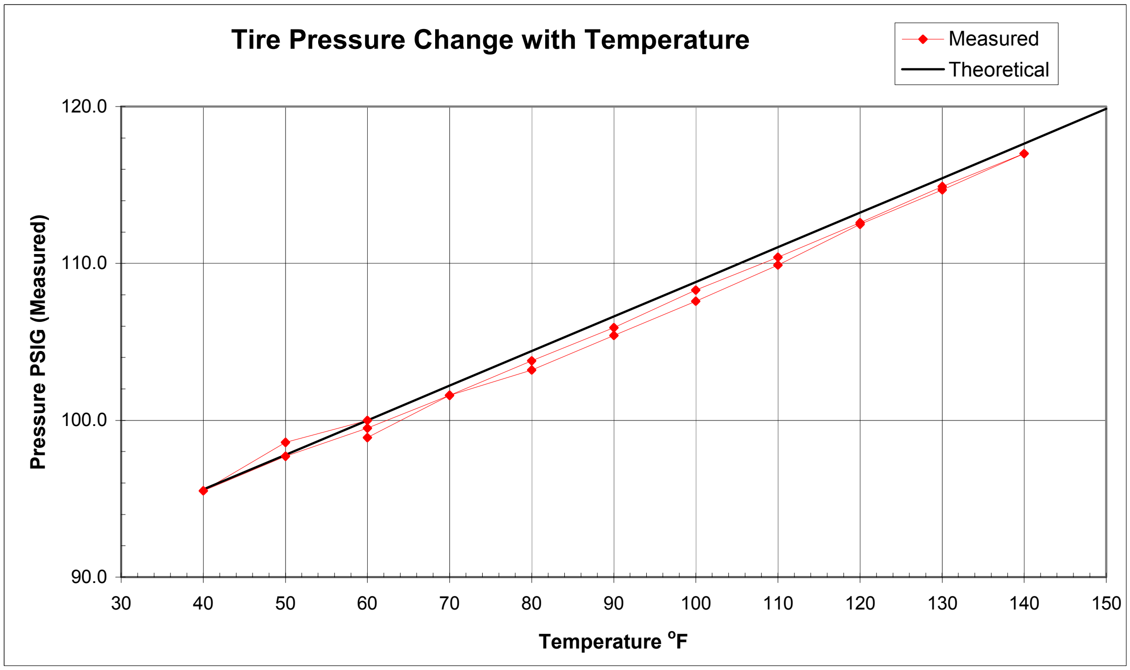


Figure E-14 Pressures as Measured

The experiment was conducted over a period of 15 days. The pressure measured for the 60 ^{o}F point at the end of the test was 1.1 psi lower than that for the beginning

60 ^{o}F pressure. This implies a small leak in the pressurized system. It was assumed that this leak was constant over the duration of testing. To compensate, each measured pressure was adjusted by an amount proportional to the time from the start of the experiment, using this equation:

$$P_A = P_M + P_L \times {}^{T_M}\!/_{T_E}$$

P_A − Pressure adjusted to compensate for leak

P_M − Measured pressure

P_L − Pressure leakage during experiment

T_M − Time from start of experiment to measurement

T_E − Elapsed time for experiment

The data with adjusted pressures are shown in Fig. E-15. The rate of change of pressure with temperature ($\Delta P/\Delta T$) for the adjusted data was found through linear regression to be 0.219 PSI/^{o}F.

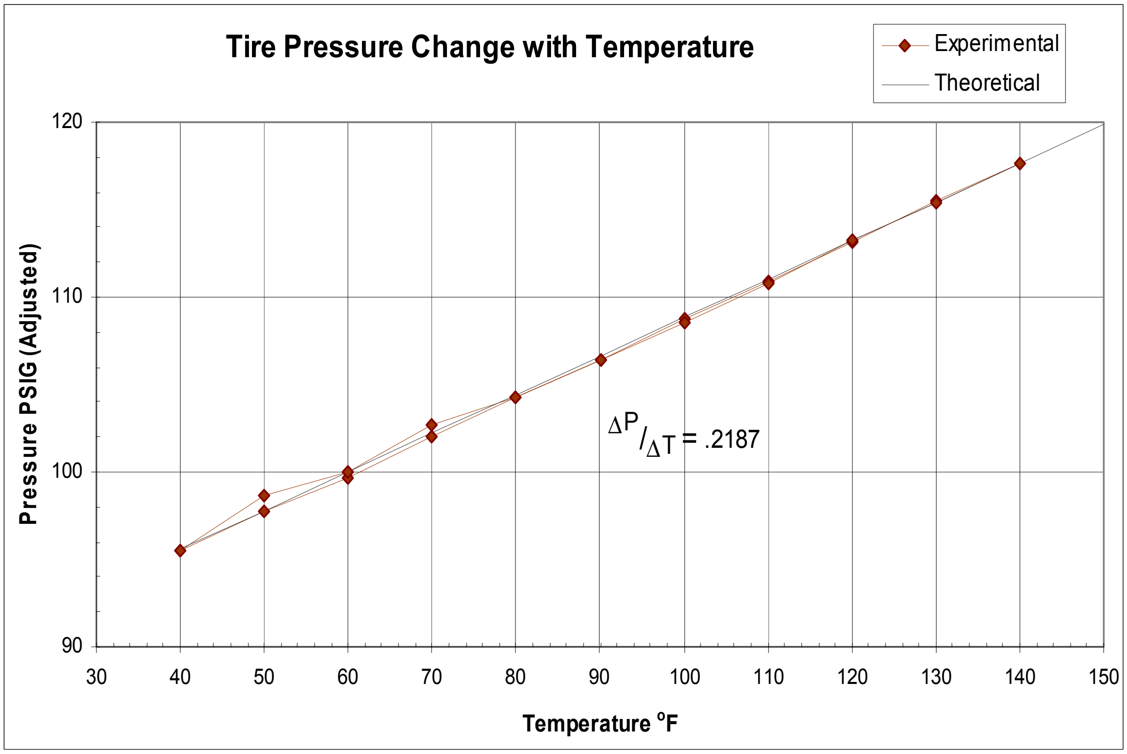


Figure E-15 Tire Pressure Change with Temperature

APPENDIX F ILLUSTRATION OF TRUCK CLASSES

The following illustration was redrawn by the author according to the definitions for Truck and Size (TW&S) classifications set by the Federal Highway Administration (TRB, 2002). This illustration focuses on the truck classes that were sampled in the survey.

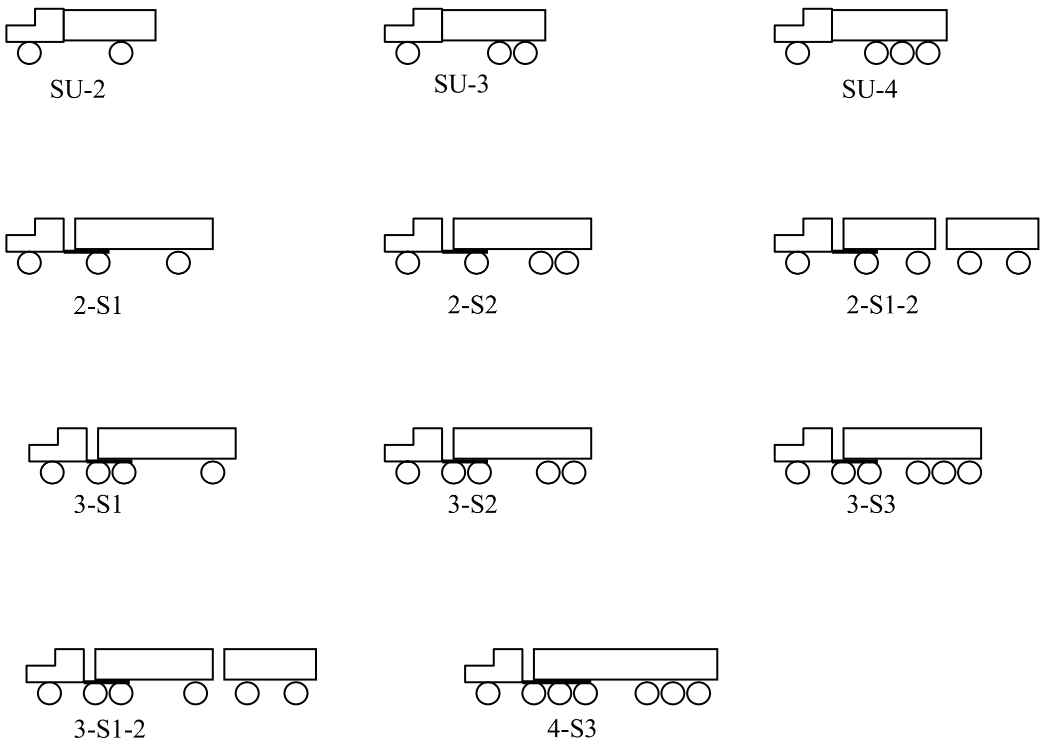


Figure F-1   Truck size and Weight Classifications

APPENDIX G TRUCK AXLE SPACING DATA

No.	Site and Direction	No. in Site	Veh. Class	Axles	Axle Spacing (ft)					
					Axles 1-2	Axles 2-3	Axles 3-4	Axles 4-5	Axles 5-6	Axles 6-7
1	Mount Pleasant WB	1	2-S1	3	13.1	21.1				
2	Mount Pleasant WB	7	2-S1	3	12.5	21.8				
3	Centerville SB	25	2-S1	3	16.0	35.0				
4	El Paso EB	4	2-S1	3	15.3	21.3				
5	El Paso EB	32	2-S1	3	12.5	21.7				
6	Denison SB	15	2-S1-2	5	12.3	15.7	9.5	15.7		
7	Centerville SB	16	2-S1-2	5	21.3	12.5	8.4	22.9		
8	Falfurrias SB	13	2-S1-2	5	12.3	20.9	9.8	21.4		
9	Odessa EB	30	2-S1-2	5	16.9	21.2	9.3	21.9		
10	Childress SB	22	2-S1-2	5	16.5	21.7	8.8	22.3		
11	Mount Pleasant WB	22	2-S2	4	13.4	33.6	4.2			
12	Mount Vernon EB	16	2-S2	4	13.5	33.4	4.1			
13	Katy EB	27	2-S2	4	11.9	30.8	5.8			
14	Victoria SB	29	2-S2	4	11.5	24.8	4.1			
15	Victoria SB	31	2-S2	4	12.9	17.4	4.3			
16	Falfurrias SB	21	2-S2	4	12.3	28.3	4.1			
17	San Marcos NB	28	2-S2	4	12.3	19.1	4.2			
18	Odessa EB	27	2-S2	4	17.0	36.4	4.3			
19	Brownsville NB	5	2-S2	4	9.6	40.8	4.1			
20	Mount Pleasant WB	18	3-S1	4	15.8	4.2	19.6			
21	Katy EB	14	3-S1	4	15.9	4.3	19.3			
22	Riviera NB	34	3-S1	4	13.3	5.2	20.0			
23	Falfurrias SB	22	3-S1	4	11.3	4.3	20.5			
24	Laredo Columbia Bridge	13	3-S1	4	8.6	4.3	19.3			
25	Mount Vernon EB	17	3-S1-2	6	17.5	4.4	21.6	8.7	22.3	
26	Denison SB	32	3-S1-2	6	18.6	3.9	17.8	10.3	21.4	
27	Odessa WB	23	3-S1-2	6	15.8	4.4	20.7	8.8	22.7	
28	Childress SB	6	3-S1-2	6	19.8	4.3	20.7	9.4	22.2	
29	Mount Pleasant WB	2	3-S2	5	16.1	4.3	31.6	4.1		
30	Mount Pleasant WB	4	3-S2	5	15.3	4.3	31.6	4.2		
31	Mount Pleasant WB	5	3-S2	5	16.9	4.3	33.5	4.3		
32	Mount Pleasant WB	6	3-S2	5	18.3	4.4	32.6	4.2		
33	Mount Pleasant WB	9	3-S2	5	19.3	4.3	22.8	7.1		
34	Mount Pleasant WB	10	3-S2	5	17.8	4.5	36.6	4.0		
35	Mount Pleasant WB	11	3-S2	5	18.2	4.3	35.4	3.8		
36	Mount Pleasant WB	12	3-S2	5	19.7	4.5	33.8	4.0		
37	Mount Pleasant WB	13	3-S2	5	15.0	4.4	36.3	4.1		
38	Mount Pleasant WB	14	3-S2	5	17.7	4.4	34.8	4.1		
39	Mount Pleasant WB	15	3-S2	5	16.0	4.6	32.7	4.1		
40	Mount Pleasant WB	16	3-S2	5	16.3	4.3	29.2	3.9		
41	Mount Pleasant WB	17	3-S2	5	16.0	4.4	34.1	4.3		

42	Mount Pleasant WB	19	3-S2	5	16.5	4.3	31.8	4.0		
43	Mount Pleasant WB	20	3-S2	5	9.8	4.5	32.8	4.1		
44	Mount Pleasant WB	23	3-S2	5	16.5	4.3	34.7	4.0		
45	Mount Pleasant WB	24	3-S2	5	17.4	4.3	33.0	4.0		
46	Mount Pleasant WB	25	3-S2	5	15.6	4.1	24.1	4.3		
47	Mount Pleasant WB	26	3-S2	5	17.1	4.3	31.6	4.0		
48	Mount Pleasant WB	27	3-S2	5	15.7	4.2	34.0	4.0		
49	Mount Pleasant WB	29	3-S2	5	15.0	4.4	30.0	4.2		
50	Mount Pleasant WB	32	3-S2	5	11.3	10.3	34.8	4.2		
51	Mount Pleasant WB	33	3-S2	5	18.2	4.3	33.6	4.0		
52	Mount Pleasant WB	34	3-S2	5	20.8	4.3	33.7	4.1		
53	Mount Pleasant WB	35	3-S2	5	17.4	4.3	34.5	4.1		
54	Mount Vernon EB	1	3-S2	5	15.5	4.5	31.8	4.1		
55	Mount Vernon EB	2	3-S2	5	15.0	4.4	34.1	4.3		
56	Mount Vernon EB	3	3-S2	5	15.8	4.2	30.1	4.2		
57	Mount Vernon EB	4	3-S2	5	17.4	4.2	31.7	4.0		
58	Mount Vernon EB	5	3-S2	5	18.8	4.4	26.5	4.1		
59	Mount Vernon EB	6	3-S2	5	17.3	4.2	32.7	4.2		
60	Mount Vernon EB	8	3-S2	5	17.3	4.3	30.8	4.1		
61	Mount Vernon EB	9	3-S2	5	19.8	4.4	33.8	4.2		
62	Mount Vernon EB	11	3-S2	5	18.5	4.3	32.2	4.3		
63	Mount Vernon EB	13	3-S2	5	16.5	4.3	32.5	4.1		
64	Mount Vernon EB	14	3-S2	5	13.5	4.3	32.8	4.2		
65	Mount Vernon EB	15	3-S2	5	16.2	4.3	32.4	4.3		
66	Mount Vernon EB	18	3-S2	5	15.4	4.4	34.1	4.0		
67	Mount Vernon EB	19	3-S2	5	17.8	4.5	31.9	4.0		
68	Mount Vernon EB	20	3-S2	5	19.6	4.5	33.7	4.1		
69	Mount Vernon EB	21	3-S2	5	14.8	4.3	28.9	3.9		
70	Mount Vernon EB	22	3-S2	5	17.7	4.2	32.3	4.1		
71	Mount Vernon EB	23	3-S2	5	18.2	4.2	36.4	4.1		
72	Mount Vernon EB	24	3-S2	5	17.8	4.3	31.3	4.2		
73	Mount Vernon EB	25	3-S2	5	19.8	4.3	32.7	4.0		
74	Mount Vernon EB	26	3-S2	5	16.4	4.3	33.3	4.0		
75	Mount Vernon EB	27	3-S2	5	20.0	4.0	33.3	4.1		
76	Mount Vernon EB	28	3-S2	5	15.7	4.3	32.3	4.1		
77	Mount Vernon EB	29	3-S2	5	18.1	4.3	34.3	4.0		
78	Mount Vernon EB	30	3-S2	5	9.4	4.3	35.5	4.1		
79	Mount Vernon EB	31	3-S2	5	19.5	4.4	30.3	4.1		
80	Mount Vernon EB	32	3-S2	5	17.1	4.4	35.4	4.1		
81	Mount Vernon EB	33	3-S2	5	15.8	4.3	34.3	3.9		
82	Mount Vernon EB	34	3-S2	5	17.9	4.1	39.2	4.0		
83	Mount Vernon EB	35	3-S2	5	17.2	4.3	33.8	4.2		
84	Denison SB	1	3-S2	5	16.3	4.4	30.4	4.1		
85	Denison SB	2	3-S2	5	16.7	4.1	34.5	3.9		
86	Denison SB	3	3-S2	5	14.6	4.2	30.3	4.1		
87	Denison SB	4	3-S2	5	15.0	4.3	29.5	4.2		
88	Denison SB	5	3-S2	5	17.8	4.2	33.0	4.0		
89	Denison SB	6	3-S2	5	17.2	4.3	26.6	4.3		
90	Denison SB	7	3-S2	5	18.5	4.4	33.1	4.0		

91	Denison SB	8	3-S2	5	16.0	4.4	28.3	4.0		
92	Denison SB	9	3-S2	5	18.0	4.4	27.8	4.0		
93	Denison SB	11	3-S2	5	16.7	4.5	31.5	4.2		
94	Denison SB	12	3-S2	5	18.8	4.1	29.0	4.2		
95	Denison SB	13	3-S2	5	17.5	4.5	26.8	4.2		
96	Denison SB	14	3-S2	5	19.5	4.3	25.3	4.3		
97	Denison SB	16	3-S2	5	19.4	4.4	28.3	4.4		
98	Denison SB	17	3-S2	5	17.3	4.3	33.5	4.1		
99	Denison SB	18	3-S2	5	19.3	4.4	27.8	4.1		
100	Denison SB	19	3-S2	5	14.3	4.3	19.6	4.3		
101	Denison SB	20	3-S2	5	15.3	4.3	26.7	4.0		
102	Denison SB	21	3-S2	5	19.5	4.5	34.7	4.2		
103	Denison SB	22	3-S2	5	14.8	4.4	27.3	4.3		
104	Denison SB	23	3-S2	5	18.0	4.2	32.3	4.1		
105	Denison SB	24	3-S2	5	17.1	4.3	32.9	4.3		
106	Denison SB	26	3-S2	5	17.0	4.4	34.8	4.0		
107	Denison SB	27	3-S2	5	16.9	4.5	34.1	3.8		
108	Denison SB	28	3-S2	5	16.8	4.4	28.3	4.2		
109	Denison SB	31	3-S2	5	17.3	4.3	29.2	3.8		
110	Denison SB	33	3-S2	5	13.5	4.3	32.8	4.0		
111	Denison SB	34	3-S2	5	16.0	4.3	26.7	4.0		
112	Denison SB	35	3-S2	5	18.4	4.3	28.5	4.1		
113	Katy EB	1	3-S2	5	9.8	4.3	33.8	4.0		
114	Katy EB	2	3-S2	5	10.3	4.3	33.3	4.1		
115	Katy EB	3	3-S2	5	16.7	4.3	33.1	4.0		
116	Katy EB	5	3-S2	5	14.1	4.3	28.0	4.1		
117	Katy EB	6	3-S2	5	14.3	4.3	28.0	3.1		
118	Katy EB	7	3-S2	5	14.4	4.3	28.5	4.1		
119	Katy EB	8	3-S2	5	11.3	4.3	28.3	3.8		
120	Katy EB	11	3-S2	5	16.6	4.4	28.6	4.1		
121	Katy EB	12	3-S2	5	15.4	4.3	31.8	4.1		
122	Katy EB	13	3-S2	5	13.0	4.3	28.0	4.1		
123	Katy EB	15	3-S2	5	18.4	4.3				
124	Katy EB	16	3-S2	5	16.7	4.2	29.8	4.1		
125	Katy EB	17	3-S2	5	12.8	4.4	27.1	4.2		
126	Katy EB	18	3-S2	5	16.9	4.3	36.2	4.1		
127	Katy EB	19	3-S2	5	11.2	4.3	32.3	4.3		
128	Katy EB	20	3-S2	5	12.1	4.3	28.3	4.2		
129	Katy EB	21	3-S2	5	14.8	4.3	25.3	4.3		
130	Katy EB	22	3-S2	5	14.8	4.3	25.3	4.5		
131	Katy EB	23	3-S2	5	15.0	4.3	25.1	4.3		
132	Katy EB	24	3-S2	5	13.3	4.3	30.4	4.0		
133	Katy EB	25	3-S2	5	9.4	4.3	29.1	3.8		
134	Katy EB	26	3-S2	5	17.0	4.5	33.3	4.1		
135	Katy EB	28	3-S2	5	15.3	4.4	26.3	4.2		
136	Katy EB	29	3-S2	5	16.9	4.1	32.5	3.9		
137	Katy EB	30	3-S2	5	17.1	4.3	33.5	4.2		
138	Katy EB	31	3-S2	5	17.3	4.3	35.1	4.1		
139	Katy EB	32	3-S2	5	15.1	4.0	28.1	4.1		

140	Katy EB	33	3-S2	5	15.3	4.2	33.0	4.2		
141	Katy EB	35	3-S2	5	19.1	4.4	31.9	4.3		
142	Victoria SB	1	3-S2	5	12.2	4.3	35.8	3.9		
143	Victoria SB	2	3-S2	5	14.2	4.3	30.4	8.4		
144	Victoria SB	3	3-S2	5	15.4	4.5	33.8	3.8		
145	Victoria SB	4	3-S2	5	15.0	4.3	29.1	4.1		
146	Victoria SB	5	3-S2	5	9.8	4.3	22.2	4.2		
147	Victoria SB	7	3-S2	5	14.8	4.3	33.0	4.1		
148	Victoria SB	8	3-S2	5	15.1	4.3	27.9	4.3		
149	Victoria SB	9	3-S2	5	19.5	4.3	27.9	4.0		
150	Victoria SB	10	3-S2	5	16.7	4.4	35.1	4.0		
151	Victoria SB	11	3-S2	5	13.8	4.4	29.8	4.1		
152	Victoria SB	12	3-S2	5	8.7	4.3	33.4	3.8		
153	Victoria SB	13	3-S2	5	18.3	4.5	35.2	4.0		
154	Victoria SB	14	3-S2	5	17.8	4.4	26.9	4.2		
155	Victoria SB	15	3-S2	5	16.1	4.4	25.4	3.8		
156	Victoria SB	17	3-S2	5	13.8	4.3	30.8	4.1		
157	Victoria SB	18	3-S2	5	21.2	4.3	29.4	4.2		
158	Victoria SB	19	3-S2	5	11.3	4.3	28.8	4.1		
159	Victoria SB	20	3-S2	5	14.8	4.1	32.0	3.9		
160	Victoria SB	21	3-S2	5	13.0	4.4	29.9	4.3		
161	Victoria SB	22	3-S2	5	18.7	4.3	28.3	3.9		
162	Victoria SB	24	3-S2	5	19.1	4.3	30.8	4.0		
163	Victoria SB	25	3-S2	5	16.7	4.3	30.1	4.3		
164	Victoria SB	27	3-S2	5	13.4	4.3	29.3	4.1		
165	Victoria SB	28	3-S2	5	16.8	4.3	31.6	4.3		
166	Victoria SB	32	3-S2	5	16.1	4.4	26.7	4.3		
167	Victoria SB	34	3-S2	5	17.7	4.3	30.8	4.1		
168	Centerville SB	1	3-S2	5	17.4	4.4	32.6	4.1		
169	Centerville SB	2	3-S2	5	16.8	4.3	35.3	3.9		
170	Centerville SB	3	3-S2	5	16.6	4.1	31.3	10.0		
171	Centerville SB	4	3-S2	5	17.3	4.3	34.8	3.9		
172	Centerville SB	5	3-S2	5	17.3	4.2	33.5	4.1		
173	Centerville SB	6	3-S2	5	14.1	4.2	36.9	3.9		
174	Centerville SB	7	3-S2	5	10.0	4.3	39.3	4.1		
175	Centerville SB	8	3-S2	5	11.8	3.3	29.9	4.3		
176	Centerville SB	10	3-S2	5	12.0	4.3	28.7	1.1		
177	Centerville SB	11	3-S2	5	19.1	5.2	33.8	4.1		
178	Centerville SB	13	3-S2	5	13.5	4.5	34.3	4.0		
179	Centerville SB	14	3-S2	5	17.1	4.3	33.3	4.0		
180	Centerville SB	15	3-S2	5	12.4	4.3	30.1	4.1		
181	Centerville SB	17	3-S2	5	16.3	5.1	31.2	4.0		
182	Centerville SB	20	3-S2	5	11.9	4.7	35.4	4.1		
183	Centerville SB	21	3-S2	5	14.8	4.3	33.1	4.1		
184	Centerville SB	22	3-S2	5	17.2	4.4	34.1	4.1		
185	Centerville SB	23	3-S2	5	18.1	4.7	31.7	3.9		
186	Centerville SB	24	3-S2	5	16.0	4.5	31.8	4.2		
187	Centerville SB	26	3-S2	5	17.3	4.3	35.4	4.2		
188	Centerville SB	27	3-S2	5	12.0	4.4	38.7	4.2		

189	Centerville SB	28	3-S2	5	11.2	4.4	29.7	3.9		
190	Centerville SB	30	3-S2	5	10.7	4.3	32.8	4.2		
191	Centerville SB	31	3-S2	5	15.0	4.3	34.2	4.0		
192	Centerville SB	32	3-S2	5	17.9	4.3	31.3	4.3		
193	Centerville SB	33	3-S2	5	20.1	4.3	33.2	3.8		
194	Centerville SB	34	3-S2	5	12.3	4.3	34.3	4.1		
195	Three Rivers SB	1	3-S2	5	16.8	4.3	31.4	4.2		
196	Three Rivers SB	2	3-S2	5	19.3	4.3	29.6	4.0		
197	Three Rivers SB	3	3-S2	5	12.1	4.3	34.6	4.1		
198	Three Rivers SB	4	3-S2	5	17.6	4.3	32.7	4.0		
199	Three Rivers SB	5	3-S2	5	17.1	4.2	32.9	4.0		
200	Three Rivers SB	6	3-S2	5	13.5	4.3	28.8	4.0		
201	Three Rivers SB	7	3-S2	5	10.8	4.5	29.8	4.1		
202	Three Rivers SB	8	3-S2	5	17.3	4.3	31.9	4.3		
203	Three Rivers SB	9	3-S2	5	18.8	4.2	34.7	4.3		
204	Three Rivers SB	10	3-S2	5	17.9	4.3	30.6	4.1		
205	Three Rivers SB	11	3-S2	5	17.3	4.2	29.6	4.2		
206	Three Rivers SB	12	3-S2	5	14.7	4.3	30.3	4.1		
207	Three Rivers SB	13	3-S2	5	15.8	4.4	29.8	4.0		
208	Three Rivers SB	14	3-S2	5	12.4	4.2	31.1	4.1		
209	Three Rivers SB	15	3-S2	5	17.8	4.3	30.8	4.1		
210	Three Rivers SB	16	3-S2	5	12.2	4.4	38.1	4.3		
211	Three Rivers SB	17	3-S2	5	16.5	4.3	29.2	4.2		
212	Three Rivers SB	18	3-S2	5	10.8	4.4	32.5	4.2		
213	Three Rivers SB	19	3-S2	5	14.8	4.4	30.5	4.0		
214	Three Rivers SB	20	3-S2	5	15.3	4.3	27.4	4.2		
215	Three Rivers SB	21	3-S2	5	19.5	4.3	36.3	4.1		
216	Three Rivers SB	22	3-S2	5	12.3	4.4	32.6	4.2		
217	Three Rivers SB	23	3-S2	5	13.7	4.3	13.4	4.2		
218	Three Rivers SB	24	3-S2	5	11.4	4.6	31.4	4.1		
219	Three Rivers SB	25	3-S2	5	16.2	4.3	30.9	4.0		
220	Three Rivers SB	26	3-S2	5	17.1	4.2	28.4	3.9		
221	Three Rivers SB	27	3-S2	5	14.7	4.3	27.3	4.1		
222	Three Rivers SB	28	3-S2	5	17.3	4.4	29.1	4.2		
223	Three Rivers SB	29	3-S2	5	11.0	4.3	35.2	4.1		
224	Three Rivers SB	30	3-S2	5	16.5	4.4	35.3	4.2		
225	Three Rivers SB	31	3-S2	5	15.1	4.3	36.2	4.2		
226	Three Rivers SB	33	3-S2	5	18.3	4.3	33.6	4.3		
227	Three Rivers SB	34	3-S2	5	16.9	4.4	28.3	4.0		
228	Riviera NB	1	3-S2	5	16.9	4.3	32.9	4.2		
229	Riviera NB	2	3-S2	5	12.0	4.5	32.9	4.2		
230	Riviera NB	3	3-S2	5	12.2	4.5	33.6	4.2		
231	Riviera NB	4	3-S2	5	16.2	4.2	29.7	4.0		
232	Riviera NB	6	3-S2	5	16.3	4.5	32.6	4.1		
233	Riviera NB	7	3-S2	5	11.2	4.0	30.8	4.1		
234	Riviera NB	9	3-S2	5						
235	Riviera NB	10	3-S2	5	14.8	4.3	34.8	4.2		
236	Riviera NB	11	3-S2	5	16.8	4.3	32.2	4.1		
237	Riviera NB	12	3-S2	5	20.0	4.3	31.4	3.8		

238	Riviera NB	14	3-S2	5	16.8	4.2	34.8	4.1		
239	Riviera NB	15	3-S2	5	16.2	4.3	34.9	4.1		
240	Riviera NB	16	3-S2	5	14.8	4.3	29.1	3.4		
241	Riviera NB	18	3-S2	5	18.3	4.3	30.7	10.0		
242	Riviera NB	19	3-S2	5	13.7	4.3	29.1	4.1		
243	Riviera NB	20	3-S2	5	15.8	4.4	37.6	4.0		
244	Riviera NB	21	3-S2	5	13.5	4.2	33.1	4.3		
245	Riviera NB	23	3-S2	5	17.1	4.4	31.2	3.8		
246	Riviera NB	26	3-S2	5	10.8	4.5	27.3	4.2		
247	Riviera NB	27	3-S2	5	21.0	4.4	28.4	3.9		
248	Riviera NB	29	3-S2	5	14.3	4.5	26.4	4.1		
249	Riviera NB	30	3-S2	5	16.7	4.4	33.9	3.9		
250	Riviera NB	32	3-S2	5	10.9	4.2	29.9	4.4		
251	Riviera NB	33	3-S2	5	20.0	4.4	32.0	4.2		
252	Riviera NB	35	3-S2	5	17.5	4.3	28.1	3.9		
253	Falfurrias SB	1	3-S2	5	14.9	4.3	30.3	4.2		
254	Falfurrias SB	2	3-S2	5	17.1	4.3	35.1	4.3		
255	Falfurrias SB	3	3-S2	5	16.5	4.3	34.8	4.1		
256	Falfurrias SB	4	3-S2	5	19.0	4.2	34.6	4.2		
257	Falfurrias SB	5	3-S2	5	18.7	4.6	29.7	3.9		
258	Falfurrias SB	8	3-S2	5	12.3	4.3	29.7	4.0		
259	Falfurrias SB	10	3-S2	5	16.7	4.3	30.3	4.1		
260	Falfurrias SB	11	3-S2	5	18.1	4.3	33.7	4.1		
261	Falfurrias SB	14	3-S2	5	14.8	4.5	30.8	3.9		
262	Falfurrias SB	15	3-S2	5	17.1	4.4	30.1	4.3		
263	Falfurrias SB	16	3-S2	5	14.8	4.3	27.7	4.3		
264	Falfurrias SB	20	3-S2	5	16.8	4.4	29.7	4.3		
265	Falfurrias SB	23	3-S2	5	16.1	4.3	29.3	4.2		
266	Falfurrias SB	24	3-S2	5	19.8	4.3	27.3	3.8		
267	Falfurrias SB	25	3-S2	5	18.8	4.2	32.0	4.0		
268	Falfurrias SB	26	3-S2	5	16.8	4.3	32.6	4.3		
269	Falfurrias SB	27	3-S2	5	10.3	4.4	30.9	4.1		
270	Falfurrias SB	28	3-S2	5	20.4	4.2	31.9	3.8		
271	Falfurrias SB	30	3-S2	5	20.0	4.3	30.8			
272	Falfurrias SB	32	3-S2	5	17.2	4.3	34.5	4.1		
273	Falfurrias SB	34	3-S2	5	15.4	4.3	29.4	4.3		
274	Falfurrias SB	35	3-S2	5	19.3	4.4	30.9	4.3		
275	San Marcos SB	1	3-S2	5	15.2	4.6	36.4	4.3		
276	San Marcos SB	2	3-S2	5	17.1	4.4	31.1			
277	San Marcos SB	3	3-S2	5	18.1	4.2	32.3	4.1		
278	San Marcos SB	5	3-S2	5	17.3	4.3	32.7	3.8		
279	San Marcos SB	6	3-S2	5	12.3	4.2	32.2	4.1		
280	San Marcos SB	7	3-S2	5	19.9	4.1	34.8			
281	San Marcos SB	8	3-S2	5	15.7	4.3	31.5	4.0		
282	San Marcos SB	9	3-S2	5	15.6	4.3	27.1	3.3		
283	San Marcos SB	11	3-S2	5	16.4	4.5	34.0	4.2		
284	San Marcos SB	12	3-S2	5	11.4	4.2	33.8	4.3		
285	San Marcos SB	13	3-S2	5	15.3	5.3	30.5	3.9		
286	San Marcos SB	14	3-S2	5	20.6	4.3	30.8	10.1		

287	San Marcos SB	15	3-S2	5	9.7	4.4	29.9	10.2		
288	San Marcos SB	17	3-S2	5	18.6	4.3	23.6	4.1		
289	San Marcos SB	18	3-S2	5	11.6	4.3	25.1	4.1		
290	San Marcos SB	20	3-S2	5	19.0	4.1	31.3	4.1		
291	San Marcos SB	21	3-S2	5	13.6	4.4	28.0	4.3		
292	San Marcos SB	22	3-S2	5	20.8	4.3	29.3	4.2		
293	San Marcos SB	23	3-S2	5	19.3	4.5	36.0	3.9		
294	San Marcos SB	24	3-S2	5	11.4	4.5	27.0	4.1		
295	San Marcos SB	25	3-S2	5	16.3	4.4	33.3	4.1		
296	San Marcos SB	26	3-S2	5	17.8	4.3	36.2	3.8		
297	San Marcos SB	27	3-S2	5	11.8	4.3	36.9	4.2		
298	San Marcos SB	29	3-S2	5	16.8	4.2	30.3	4.0		
299	San Marcos SB	30	3-S2	5	18.8	4.0	30.8	4.0		
300	San Marcos NB	1	3-S2	5	12.8	4.3	27.2	4.0		
301	San Marcos NB	2	3-S2	5	13.7	4.3	28.6	4.1		
302	San Marcos NB	3	3-S2	5	15.7	4.3	28.8	4.1		
303	San Marcos NB	4	3-S2	5	18.8	4.3	31.7	4.2		
304	San Marcos NB	5	3-S2	5	16.1	4.3	36.8	4.2		
305	San Marcos NB	7	3-S2	5	19.5	4.4	29.0	4.0		
306	San Marcos NB	9	3-S2	5	17.8	4.3	28.6	4.2		
307	San Marcos NB	10	3-S2	5	15.5	4.4	32.1	4.1		
308	San Marcos NB	11	3-S2	5	17.4	4.4	32.4	4.0		
309	San Marcos NB	12	3-S2	5	15.1	4.3	18.5	4.0		
310	San Marcos NB	14	3-S2	5	18.8	4.3	28.9	4.2		
311	San Marcos NB	15	3-S2	5	16.7	4.3	32.1	3.9		
312	San Marcos NB	17	3-S2	5	18.2	4.3	30.2	3.9		
313	San Marcos NB	18	3-S2	5	18.7	4.4	28.3	4.1		
314	San Marcos NB	19	3-S2	5	17.5	4.5	24.1	4.2		
315	San Marcos NB	20	3-S2	5	18.3	4.3	24.5	4.3		
316	San Marcos NB	21	3-S2	5	11.4	4.3	31.1	4.2		
317	San Marcos NB	24	3-S2	5	13.8	4.4	34.3	4.2		
318	San Marcos NB	25	3-S2	5	15.8	4.2	35.3	4.1		
319	San Marcos NB	26	3-S2	5	17.3	4.3	35.5	4.0		
320	San Marcos NB	27	3-S2	5	14.8	4.3	31.3	4.0		
321	San Marcos NB	29	3-S2	5	16.0	4.4	28.8	4.0		
322	San Marcos NB	30	3-S2	5	17.9	4.3	30.8	10.3		
323	San Marcos NB	31	3-S2	5	19.9	4.4	34.5	4.0		
324	San Marcos NB	33	3-S2	5	18.3	4.3	30.9	4.1		
325	Odessa WB	1	3-S2	5	15.6	4.5	31.4	9.1		
326	Odessa WB	2	3-S2	5	16.3	4.3	28.4	4.3		
327	Odessa WB	3	3-S2	5	17.7	4.5	27.3	4.5		
328	Odessa WB	4	3-S2	5	11.0	4.4	32.3	4.0		
329	Odessa WB	5	3-S2	5	17.2	4.4	32.3	4.1		
330	Odessa WB	6	3-S2	5	19.0	4.5	33.6	4.3		
331	Odessa WB	8	3-S2	5	16.5	4.4	31.9	4.1		
332	Odessa WB	9	3-S2	5	19.6	4.4	32.8	4.1		
333	Odessa WB	10	3-S2	5	19.9	3.9	33.1	3.8		
334	Odessa WB	11	3-S2	5	15.8	4.3	31.5	4.2		
335	Odessa WB	12	3-S2	5	19.3	4.5	33.1	4.1		

336	Odessa WB	13	3-S2	5	15.7	4.7	32.8	3.9		
337	Odessa WB	14	3-S2	5	15.3	4.5	33.2	4.0		
338	Odessa WB	16	3-S2	5	17.5	4.3	33.5	4.3		
339	Odessa WB	17	3-S2	5	16.3	4.3	32.1	4.1		
340	Odessa WB	18	3-S2	5	18.3	4.3	33.8	4.1		
341	Odessa WB	20	3-S2	5	16.3	4.5	29.3	4.2		
342	Odessa WB	21	3-S2	5	20.2	4.3	32.1	4.3		
343	Odessa WB	22	3-S2	5	18.1	4.3	34.3	4.0		
344	Odessa WB	24	3-S2	5	16.3	4.3	33.3	4.1		
345	Odessa WB	25	3-S2	5	19.3	4.4	30.3	1.1		
346	Odessa WB	26	3-S2	5	18.3	4.5	33.5	4.0		
347	Odessa WB	28	3-S2	5	12.8	4.1	24.3	4.1		
348	Odessa WB	29	3-S2	5	16.4	4.2	34.0	4.1		
349	Odessa WB	30	3-S2	5	15.3	4.5	30.9	4.1		
350	Odessa WB	31	3-S2	5	19.7	4.5	31.7	3.9		
351	Odessa WB	32	3-S2	5	17.2	4.4	33.7	4.1		
352	Odessa WB	33	3-S2	5	20.1	4.3	33.0	4.2		
353	Odessa WB	34	3-S2	5	17.5	4.3	33.3	4.3		
354	Odessa WB	35	3-S2	5	18.8	4.3	31.4	4.1		
355	Odessa EB	1	3-S2	5	17.6	4.3	37.2	4.3		
356	Odessa EB	2	3-S2	5	17.6	4.3	33.3	4.3		
357	Odessa EB	4	3-S2	5	15.3	4.5	34.6	4.2		
358	Odessa EB	5	3-S2	5	16.9	4.3	34.3	4.1		
359	Odessa EB	7	3-S2	5	18.8	4.5	30.8	4.1		
360	Odessa EB	8	3-S2	5	14.3	4.4	27.6	4.1		
361	Odessa EB	9	3-S2	5	17.5	4.3	32.5	4.0		
362	Odessa EB	10	3-S2	5	17.3	4.3	32.3	4.3		
363	Odessa EB	11	3-S2	5	12.8	4.3	34.6	4.1		
364	Odessa EB	12	3-S2	5	21.3	4.5	33.3	4.2		
365	Odessa EB	13	3-S2	5	17.1	4.5	32.6	4.1		
366	Odessa EB	14	3-S2	5	18.7	4.5	32.4	4.3		
367	Odessa EB	15	3-S2	5	14.6	4.5	29.7	3.9		
368	Odessa EB	16	3-S2	5	16.8	4.3	31.8	4.3		
369	Odessa EB	17	3-S2	5	16.3	4.3	32.5	4.2		
370	Odessa EB	18	3-S2	5	16.7	4.3	36.3	4.1		
371	Odessa EB	19	3-S2	5	16.2	4.3	35.0	4.1		
372	Odessa EB	21	3-S2	5	19.5	4.5	32.3	4.0		
373	Odessa EB	22	3-S2	5	14.6	4.5	27.3	4.3		
374	Odessa EB	23	3-S2	5	13.9	4.3	28.8	4.0		
375	Odessa EB	24	3-S2	5	20.0	4.2	35.2	4.3		
376	Odessa EB	26	3-S2	5	18.3	4.4	33.7	4.2		
377	Odessa EB	28	3-S2	5	18.1	4.3	33.7	4.1		
378	Odessa EB	29	3-S2	5	18.1	4.4	29.8	4.3		
379	Odessa EB	31	3-S2	5	17.3	4.4	27.8	4.3		
380	Odessa EB	32	3-S2	5	15.4	4.3	32.0	3.4		
381	Odessa EB	33	3-S2	5	19.8	3.3	33.3	4.2		
382	Odessa EB	34	3-S2	5	17.3	4.3	30.3	4.1		
383	Odessa EB	35	3-S2	5	15.5	4.4	29.6	4.2		
384	Childress SB	2	3-S2	5	16.8	4.2	34.3	1.1		

385	Childress SB	3	3-S2	5	20.5	4.4	34.9	3.9		
386	Childress SB	5	3-S2	5	18.7	4.5	32.6	3.9		
387	Childress SB	7	3-S2	5	19.3	4.1	30.4	4.2		
388	Childress SB	8	3-S2	5	19.8	4.5	31.8	4.2		
389	Childress SB	9	3-S2	5	18.3	4.1	28.7	4.0		
390	Childress SB	10	3-S2	5	17.3	4.3	33.6	4.1		
391	Childress SB	11	3-S2	5	16.0	4.3	33.3	4.3		
392	Childress SB	12	3-S2	5	12.0	4.0	33.6	3.8		
393	Childress SB	13	3-S2	5	18.5	4.3	32.6	4.2		
394	Childress SB	14	3-S2	5	18.6	4.3	34.4	4.1		
395	Childress SB	15	3-S2	5	14.6	4.3	29.6	4.1		
396	Childress SB	16	3-S2	5	15.6	4.2	33.5	4.0		
397	Childress SB	17	3-S2	5	17.2	4.3	28.5	4.2		
398	Childress SB	18	3-S2	5	16.0	4.3	32.8	3.9		
399	Childress SB	19	3-S2	5	17.3	4.3	31.3	4.2		
400	Childress SB	20	3-S2	5	16.7	4.3	33.6	4.1		
401	Childress SB	21	3-S2	5	19.5	4.6	28.5	4.1		
402	Childress SB	23	3-S2	5	17.8	4.4	33.0	4.1		
403	Childress SB	24	3-S2	5	17.7	4.3	33.4	4.1		
404	Childress SB	25	3-S2	5	18.6	4.7	37.1	4.5		
405	Childress SB	26	3-S2	5	17.1	4.3	31.6	4.1		
406	Childress SB	27	3-S2	5	20.2	4.3	34.4	4.1		
407	Childress SB	28	3-S2	5	17.3	4.3	33.3	4.2		
408	Childress SB	30	3-S2	5	18.0	4.2	33.3	3.9		
409	Childress SB	31	3-S2	5	17.6	4.3	32.5	4.2		
410	Childress SB	32	3-S2	5	16.5	4.4	33.8	4.1		
411	Childress SB	33	3-S2	5	16.5	4.3	34.5	4.0		
412	Childress SB	34	3-S2	5	16.8	4.4	34.6	4.1		
413	Childress SB	35	3-S2	5	19.8	4.6	31.8	4.2		
414	El Paso WB	1	3-S2	5	16.3	4.4	26.1	4.2		
415	El Paso WB	3	3-S2	5	14.9	4.6	32.9	4.3		
416	El Paso WB	5	3-S2	5	16.4	4.4	30.3	4.1		
417	El Paso WB	7	3-S2	5	11.3	4.4	33.2	4.0		
418	El Paso WB	8	3-S2	5	12.6	4.5	28.7	4.3		
419	El Paso WB	9	3-S2	5	10.5	4.4	34.7	4.0		
420	El Paso WB	10	3-S2	5	9.9	4.3				
421	El Paso WB	11	3-S2	5	10.6	4.6	29.8	3.8		
422	El Paso WB	12	3-S2	5	16.6	4.3	27.8	4.1		
423	El Paso WB	13	3-S2	5	9.4	4.4	33.8	3.9		
424	El Paso WB	14	3-S2	5	16.1	4.3	28.0	4.2		
425	El Paso WB	15	3-S2	5	10.3	4.3	31.4			
426	El Paso WB	16	3-S2	5	12.8	4.3	29.3	4.2		
427	El Paso WB	18	3-S2	5	13.6	4.4	33.1	4.2		
428	El Paso WB	19	3-S2	5	14.2	4.3	28.6	4.1		
429	El Paso WB	20	3-S2	5	10.5	4.3	32.0	4.1		
430	El Paso WB	21	3-S2	5	14.6	4.7	30.1	4.1		
431	El Paso WB	22	3-S2	5	17.3	4.3	32.9	3.9		
432	El Paso WB	23	3-S2	5	14.8	4.6	30.3	3.9		
433	El Paso WB	24	3-S2	5	11.7	4.3	30.7	4.1		

434	El Paso WB	25	3-S2	5	11.8	4.5	29.0	4.2		
435	El Paso WB	26	3-S2	5	10.3	4.3	33.7	3.8		
436	El Paso WB	27	3-S2	5	17.2	4.4	28.8	4.1		
437	El Paso WB	28	3-S2	5	9.3	4.5	30.1	4.2		
438	El Paso WB	29	3-S2	5	11.3	4.7	34.7	4.7		
439	El Paso WB	30	3-S2	5	17.1	4.4	30.3	4.5		
440	El Paso WB	32	3-S2	5	15.0	4.6	31.7	4.1		
441	El Paso WB	35	3-S2	5	9.8	4.3	34.5	4.3		
442	El Paso EB	1	3-S2	5	10.2	4.4	33.3	4.2		
443	El Paso EB	2	3-S2	5	12.8	4.4	29.7	4.2		
444	El Paso EB	3	3-S2	5	9.3	4.4	29.5	4.2		
445	El Paso EB	5	3-S2	5	10.8	4.2	33.2	4.0		
446	El Paso EB	7	3-S2	5	11.7	1.7	33.4	4.1		
447	El Paso EB	9	3-S2	5	10.3	4.3	34.8	4.2		
448	El Paso EB	11	3-S2	5	10.1	4.4	30.1	4.0		
449	El Paso EB	13	3-S2	5	9.6	4.4	35.2	4.0		
450	El Paso EB	14	3-S2	5	12.0	4.3	30.2	4.3		
451	El Paso EB	15	3-S2	5	11.1	4.3	29.3	4.2		
452	El Paso EB	16	3-S2	5	11.4	4.2	29.2	4.1		
453	El Paso EB	18	3-S2	5	14.6	4.3	23.0	4.1		
454	El Paso EB	19	3-S2	5	10.4	4.3	32.5	4.0		
455	El Paso EB	20	3-S2	5	11.4	4.3	31.0	4.1		
456	El Paso EB	21	3-S2	5	11.4	4.3	29.8	4.1		
457	El Paso EB	22	3-S2	5	11.8	4.4	29.4	4.1		
458	El Paso EB	23	3-S2	5	10.2	4.3	32.2	3.9		
459	El Paso EB	24	3-S2	5	17.6	4.3	28.6	4.2		
460	El Paso EB	27	3-S2	5	9.2	4.3	32.0	4.1		
461	El Paso EB	28	3-S2	5	10.8	4.3	29.1	4.2		
462	El Paso EB	34	3-S2	5	17.3	4.3	16.9	4.0		
463	Laredo Columbia Bridge	1	3-S2	5	10.5	4.5	32.4	4.0		
464	Laredo Columbia Bridge	4	3-S2	5	12.3	4.3	33.8	4.0		
465	Laredo Columbia Bridge	5	3-S2	5	11.3	4.4	31.3	4.0		
466	Laredo Columbia Bridge	6	3-S2	5	9.8	4.3	34.7	3.9		
467	Laredo Columbia Bridge	8	3-S2	5	9.3	4.3	31.3	4.0		
468	Laredo Columbia Bridge	10	3-S2	5	11.2	4.3	30.7	4.1		
469	Laredo Columbia Bridge	11	3-S2	5	14.7	4.3	26.0	4.4		
470	Laredo Columbia Bridge	16	3-S2	5	9.3	4.3	32.7	4.1		
471	Laredo Columbia Bridge	18	3-S2	5	9.4	4.2	32.2	4.0		
472	Laredo Columbia Bridge	23	3-S2	5	8.6	4.5	35.6	4.1		
473	Laredo Columbia Bridge	26	3-S2	5	10.3	4.3	34.3	4.5		
474	Laredo Columbia Bridge	27	3-S2	5	8.8	4.2	28.0	4.0		
475	Laredo Columbia Bridge	33	3-S2	5	12.1	3.4	33.3	4.0		
476	Laredo Columbia Bridge	35	3-S2	5	15.7	4.3	29.2	4.1		
477	Brownsville NB	3	3-S2	5	14.4	4.5	25.5	4.4		
478	Brownsville NB	7	3-S2	5	17.2	4.4	31.6	4.0		
479	Brownsville NB	9	3-S2	5	15.2	4.4	17.1	4.3		
480	Brownsville NB	15	3-S2	5	16.2	4.3	28.3	4.1		
481	Brownsville NB	16	3-S2	5	17.6	4.3	33.5	4.0		
482	Brownsville NB	18	3-S2	5	12.3	4.6	30.1	4.2		

483	Brownsville NB	19	3-S2	5	11.2	4.3	32.9	4.0		
484	Brownsville NB	21	3-S2	5	13.8	4.3	31.8	4.1		
485	Brownsville NB	22	3-S2	5	15.0	4.2	27.2	4.0		
486	Brownsville NB	23	3-S2	5	19.0					
487	Brownsville NB	24	3-S2	5	11.5	4.5	34.2	3.8		
488	Brownsville NB	25	3-S2	5	12.1	4.3	30.9	4.2		
489	Brownsville NB	26	3-S2	5	11.1	4.3	35.3	4.3		
490	Brownsville NB	27	3-S2	5	11.8	4.3	38.3	4.0		
491	Brownsville NB	28	3-S2	5	15.7	4.5	34.4	3.9		
492	Brownsville NB	29	3-S2	5	11.8	4.4	37.3	4.2		
493	Brownsville NB	30	3-S2	5	13.5	4.2	32.7	4.1		
494	Brownsville NB	31	3-S2	5	15.3	4.5	32.1	3.8		
495	Brownsville NB	33	3-S2	5	12.4	4.6	33.8	4.1		
496	Brownsville NB	35	3-S2	5	16.6	4.2	33.5	4.2		
497	Mount Pleasant WB	3	3-S2 spread	5	15.3	4.4	30.7	10.3		
498	Mount Pleasant WB	28	3-S2 spread	5	19.5	4.5	29.7	10.2		
499	Mount Pleasant WB	30	3-S2 spread	5	18.3	4.2	31.2	10.1		
500	Mount Pleasant WB	31	3-S2 spread	5	11.2	4.3	28.8	9.8		
501	Mount Vernon EB	7	3-S2 spread	5	18.2	4.3	30.8	10.2		
502	Mount Vernon EB	10	3-S2 spread	5	20.8	4.3	31.0	10.1		
503	Mount Vernon EB	12	3-S2 spread	5	20.2	4.3	30.4	10.3		
504	Denison SB	25	3-S2 spread	5	17.2	4.3	30.6	10.2		
505	Denison SB	30	3-S2 spread	5	19.2	4.0	27.1	10.3		
506	Katy EB	9	3-S2 spread	5	20.8	4.4	30.8	10.0		
507	Katy EB	34	3-S2 spread	5	20.0	4.5	29.3	10.2		
508	Victoria SB	16	3-S2 spread	5	17.4	4.0	27.8	10.0		
509	Centerville SB	9	3-S2 spread	5	19.5	4.4	27.3	10.2		
510	Centerville SB	18	3-S2 spread	5	15.3	4.7	29.3	10.1		
511	Riviera NB	5	3-S2 spread	5						
512	Riviera NB	8	3-S2 spread	5	20.3	4.4	30.1	8.3		
513	Riviera NB	17	3-S2 spread	5	17.3	4.0	28.3	10.3		
514	Riviera NB	24	3-S2 spread	5	17.3	4.3	32.0	10.4		
515	Riviera NB	31	3-S2 spread	5	17.3	4.2	30.2	10.4		

516	Falfurrias SB	6	3-S2 spread	5	18.8	4.3	29.7	10.0		
517	Falfurrias SB	29	3-S2 spread	5	19.3	4.3	32.3	8.2		
518	Odessa WB	15	3-S2 spread	5	18.4	4.3	32.0	10.0		
519	Odessa WB	19	3-S2 spread	5	15.3	3.3	30.8	8.8		
520	Odessa WB	27	3-S2 spread	5	19.4	4.2	28.3	10.3		
521	Odessa EB	3	3-S2 spread	5	17.1	4.2	28.3	10.1		
522	Odessa EB	6	3-S2 spread	5	16.7	4.3	30.0	8.4		
523	Odessa EB	20	3-S2 spread	5	18.0	4.4	29.9	10.2		
524	Odessa EB	25	3-S2 spread	5	20.4	4.3	30.5	9.9		
525	Childress SB	1	3-S2 spread	5	19.6	4.4	31.3	1.1		
526	Childress SB	29	3-S2 spread	5	21.3	4.2	30.1	10.1		
527	Laredo Columbia Bridge	28	3-S2 spread	5	9.9	4.2	29.2	8.4		
528	Brownsville NB	32	3-S2 spread	5	15.6	4.6	32.0	10.1		
529	Centerville SB	12	3-S3	6	17.3	4.4	24.3	4.5	4.7	
530	Centerville SB	19	3-S3	6	15.6	4.7	20.3	5.0	5.0	
531	Falfurrias SB	18	3-S3	6	15.4	4.5	27.8	4.1	4.2	
532	San Marcos NB	13	3-S3	6	15.1	4.4	14.2	4.2	4.1	
533	Brownsville NB	1	3-S3	6	13.7	4.7	22.5	4.2	4.0	
534	Brownsville NB	2	3-S3	6	15.8	4.3	22.0	4.2	4.1	
535	Brownsville NB	4	3-S3	6	15.0	4.3	23.3	4.1	4.2	
536	San Marcos NB	6	4-S3	7	13.3	4.6	4.6	34.3	4.5	4.6
537	Mount Pleasant WB	8	SU-2	2	17.5					
538	Mount Pleasant WB	21	SU-2	2	15.5					
539	Denison SB	29	SU-2	2	19.7					
540	Katy EB	4	SU-2	2	18.8					
541	Victoria SB	23	SU-2	2	21.3					
542	Victoria SB	35	SU-2	2	12.6					
543	Centerville SB	29	SU-2	2	20.3					
544	Centerville SB	35	SU-2	2	22.8					
545	Three Rivers SB	35	SU-2	2	16.1					
546	Falfurrias SB	12	SU-2	2	17.9					
547	Falfurrias SB	17	SU-2	2	21.2					
548	Falfurrias SB	19	SU-2	2	15.1					
549	Falfurrias SB	33	SU-2	2	18.1					
550	San Marcos SB	4	SU-2	2	21.3					
551	San Marcos SB	16	SU-2	2	15.4					
552	San Marcos SB	19	SU-2	2	21.3					
553	San Marcos SB	28	SU-2	2	15.7					

554	San Marcos NB	8	SU-2	2	15.9					
555	San Marcos NB	16	SU-2	2	21.1					
556	San Marcos NB	22	SU-2	2	22.0					
557	San Marcos NB	23	SU-2	2	18.5					
558	San Marcos NB	32	SU-2	2	22.3					
559	Odessa WB	7	SU-2	2	21.3					
560	El Paso WB	2	SU-2	2	16.7					
561	El Paso WB	4	SU-2	2	18.8					
562	El Paso WB	17	SU-2	2	16.8					
563	El Paso WB	33	SU-2	2	19.0					
564	El Paso WB	34	SU-2	2	18.8					
565	El Paso EB	6	SU-2	2	21.8					
566	El Paso EB	10	SU-2	2	17.3					
567	El Paso EB	25	SU-2	2	19.2					
568	El Paso EB	26	SU-2	2	19.9					
569	El Paso EB	33	SU-2	2	19.7					
570	El Paso EB	35	SU-2	2	21.0					
571	Laredo Columbia Bridge	14	SU-2	2	18.3					
572	Brownsville NB	10	SU-2	2	18.5					
573	Brownsville NB	12	SU-2	2	20.3					
574	Brownsville NB	17	SU-2	2	20.6					
575	Brownsville NB	34	SU-2	2	17.0					
576	Denison SB	10	SU-3	3	18.0	4.4				
577	Katy EB	10	SU-3	3	16.0	4.4				
578	Victoria SB	6	SU-3	3	13.3	4.0				
579	Victoria SB	26	SU-3	3	15.2	4.4				
580	Victoria SB	30	SU-3	3	18.0	4.4				
581	Victoria SB	33	SU-3	3	16.5	4.3				
582	Riviera NB	13	SU-3	3	18.0	4.4				
583	Riviera NB	22	SU-3	3	14.8	4.1				
584	Riviera NB	25	SU-3	3	15.8	4.1				
585	Riviera NB	28	SU-3	3	18.3	4.3				
586	Falfurrias SB	7	SU-3	3	20.9	4.6				
587	Falfurrias SB	9	SU-3	3	17.3	4.4				
588	Falfurrias SB	31	SU-3	3	18.9	4.3				
589	San Marcos SB	10	SU-3	3	15.5	4.5				
590	Childress SB	4	SU-3	3	16.2	4.6				
591	El Paso WB	6	SU-3	3	15.6	4.7				
592	El Paso WB	31	SU-3	3	12.5	4.3				
593	El Paso EB	8	SU-3	3	11.9	4.5				
594	El Paso EB	12	SU-3	3	13.2	4.1				
595	El Paso EB	17	SU-3	3	13.5	4.3				
596	El Paso EB	29	SU-3	3	9.9	4.4				
597	El Paso EB	30	SU-3	3	12.3	4.3				
598	El Paso EB	31	SU-3	3	18.7	4.7				
599	Laredo Columbia Bridge	2	SU-3	3	12.9	4.3				
600	Laredo Columbia Bridge	3	SU-3	3	12.8	4.3				
601	Laredo Columbia Bridge	7	SU-3	3	10.3	6.0				
602	Laredo Columbia Bridge	9	SU-3	3	16.4	4.3				

603	Laredo Columbia Bridge	12	SU-3	3	18.0	4.3				
604	Laredo Columbia Bridge	15	SU-3	3	9.3	4.5				
605	Laredo Columbia Bridge	17	SU-3	3	9.2	4.5				
606	Laredo Columbia Bridge	19	SU-3	3	12.8					
607	Laredo Columbia Bridge	20	SU-3	3	8.8	4.1				
608	Laredo Columbia Bridge	21	SU-3	3	9.7	4.2				
609	Laredo Columbia Bridge	22	SU-3	3	9.7	4.3				
610	Laredo Columbia Bridge	24	SU-3	3	9.6	4.3				
611	Laredo Columbia Bridge	25	SU-3	3	11.7	4.3				
612	Laredo Columbia Bridge	29	SU-3	3	16.6	4.5				
613	Laredo Columbia Bridge	30	SU-3	3	10.9	4.3				
614	Laredo Columbia Bridge	31	SU-3	3	10.2	4.3				
615	Laredo Columbia Bridge	32	SU-3	3	17.0	4.5				
616	Laredo Columbia Bridge	34	SU-3	3	8.4	4.3				
617	Brownsville NB	6	SU-3	3	11.6	4.3				
618	Brownsville NB	8	SU-3	3	11.8	4.4				
619	Brownsville NB	11	SU-3	3	18.7	4.2				
620	Brownsville NB	13	SU-3	3	11.5	4.5				
621	Brownsville NB	14	SU-3	3	15.0	4.3				
622	Brownsville NB	20	SU-3	3	11.6	4.3				
623	Three Rivers SB	32	SU-4	4	16.6	6.9	4.3			

2nd Trailer: