Truck Characteristics Analysis

To

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Executive Summary

It is important to understand the physical characteristics of the nation's truck fleet for numerous reasons. Information about the nation's truck fleet is collected in various ways by different organizations. The methodologies used and data elements collected depend on several factors, including the needs of the organization, monetary and time constraints, and the availability and limitations of technology. The Federal Highway Administration's (FHWA) Office of Highway Policy Information funded this project as a follow-on to the "Truck Fleet Characteristics" study. Both projects seek to explore the scope of available sources of current information about the physical characteristics of trucks, with the goal of compiling unique data sources that will, at a minimum, assist in improving the accuracy and number of applications for data from automatic vehicle classifiers (AVC) and weigh-in-motion (WIM) devices, FHWA's primary goal for this project.

Analysis of Truck Body Type

One of the objectives of this study was to find patterns of axle spacings that correlate with specific body types, so that more information can be obtained from axle-based vehicle classification data. There are limited data sources available that contain body type along with axle spacing and other physical characteristics of trucks. The 1992 Truck Inventory and Use Survey (TIUS) contains individual vehicle records that distinguish eleven separate body types. Unfortunately, no axle spacing on the vehicles is available from that source, but there are numerous other physical characteristics included in TIUS that can be determined or inferred from AVC or WIM data. Frequency distributions for the eleven body types were prepared that identify the relationship of body type to the following truck characteristics: number of axles, number of lift axles, vehicle length, average gross vehicle weight (GVW), and the number of axles on trailers pulled by truck tractors and straight trucks. Number of axles was used because this is a prime determinant of most vehicle classification methodologies. Average GVW was used as a variable since weight data is generated from WIM data, and can therefore may be used to infer possible body types. Vehicle length is sometimes available from AVC data, so the possibility of a correlation between length and body type is explored as well.

Data concerning lift axles is not currently available from WIM and AVC data, but the distribution of body type to lift axles for the vehicle records in TIUS was determined nonetheless, so that if body type can be inferred in other ways, it may also be possible to infer the possible existence of lift axles. Within TIUS, many body types have lift axles. According to this source, the body types that are most likely to have lift axles are basic platforms, dump trucks, and concrete mixers. The dump truck is the most likely body type among vehicles with only one lift axle. Two lift axles are more commonly found on the basic platform, and three lift axles occur most on basic enclosed vans and drop frame vans. According to the results of the body type distributions based on number of axles, number of axles on the vehicle configuration can be a good indicator of body type. For configurations with three or fewer axles, the basic platform and basic enclosed vans were the most frequently occurring body types. For configurations with four or more axles, dump trucks and concrete mixers occurred most often.

As an individual criteria, vehicle length was somewhat less valuable in determining likely body types. There is a great deal of variation in the length possibilities for many body types, and a great deal of overlap in the body types within most length ranges. This makes it difficult to use length to identify specific body types. However, there are some length categories, particularly among the very short and the very long vehicles, in which some body types rarely or never occur, so this method may be more useful in eliminating the likelihood of certain body types according to certain length criteria, rather than in defining what body types they are. Gross vehicle weight, available from WIM data, can give an indication about possible body types. The lower weight categories of vehicles in the TIUS records are dominated by the basic platform body type. As the vehicles get heavier, dump trucks, basic enclosed vans, and liquid or gas tank trucks tend to be most predominant.

In addition to distributions of the body types across GVW categories, the median ranges for several body types are portrayed in this report to help identify the weight ranges in which these body types are most likely to be found. The data TIUS makes available about the configuration and number of axles on trailers pulled by combination vehicles, that is, semitrailers and full trailers pulled by straight trucks and truck tractors, provides even more information than the earlier distributions of body type based on number of axles. This makes it possible to infer to an even greater degree the possible body types on these vehicles. If the vehicle configuration can be determined from the axle-spacing data, then it should be possible to make some inferences about possible body types as well. The distributions of body types for specific configurations from sources such as TIUS can suggest likely distributions of body types from volume traffic data as well.

Vehicle Classification

A second task in this study is to propose improvements to common vehicle classification algorithms, in particular Scheme F. For this task, two databases were used, the Truck Index database from the "Truck Fleet Characteristics" study and a database developed as part of a 1995 study performed by the Georgia Department of Transportation (DOT), "Accuracy of Traffic Monitoring Equipment." The latter source contains actual traffic data, with all vehicle classes being represented, and also contains the necessary axle-spacing data for exploring the effectiveness of Scheme F and other possible classification approaches. S-Plus statistical software was used to develop an optimal data-defined sieve, an axle-based classification algorithm similar to the Scheme F methodology. The goal was to determine the optimal performance of the classification sieve, then compare the results to Scheme F in order to evaluate whether Scheme F can be improved significantly without adding other data inputs besides number of axles and axle spacing, or whether the achievement of significantly improved results requires a completely different methodology.

Running Scheme F on the Georgia dataset resulted in an overall misclassification rate of 20.6 percent. The best possible decision tree produced by the S-Plus software had an overall misclassification rate of 18.5 percent. The classification rate for every axle category except for 6-axle vehicles was improved. The number of misclassifications among two-axle vehicles decreased only minimally, but for 3-axle vehicles, the misclassifications dropped from 25.1 percent to 8.5 percent, and for 4-axle vehicles the misclassifications dropped from 26.4 percent to 14.6 percent. Despite such large reductions in the error rates for vehicles with higher numbers of axles, the overall error rate is similar between the two methods because of the relatively larger number of 2-axle vehicles. Based on the output from this dataset, the indication is that current axle-based classification algorithms cannot be greatly improved due to the tremendous overlap in the vehicle classes based on axle spacing alone. It may be worthwhile to consider classification method, or adjustments to the current axle-based sieve. For example, if other vehicle characteristics are considered along with axle spacing, a further delineation among the classes would be possible. Vehicle length or weight, axle weights, and front and rear overhang are some characteristics that if added to axle-based methods would increase the ability to accurately classify the vehicles. The use of proportional re-assignments of vehicles within existing classification bins based on the output of the S-Plus decision trees would also greatly increase classification accuracy.

Discriminate analysis was also used in this study to explore its potential for accurately classifying vehicles according to axle count and axle spacing. This method departs from the sieve-type approach, and instead uses the relationship of the axle spacing distances in order to identify vehicle class. This method, with the Georgia dataset as the source, produced a slightly lower misclassification rate than the sieve-type algorithms. The overall error rate was 18.4 percent, compared to 18.5 percent for the optimal tree, and 20.6 percent for Scheme F. The discriminate analysis also had the lowest misclassification rate for two, three, and seven-or-more axle vehicles. This method shows tremendous potential and versatility, since additional predictive variables can easily be added, such as vehicle lengths and weights. Moreover, this method could also be adapted to make predictions about other physical characteristics of trucks, such as body type and cargo carried, in the existence of available data sources for that information.

Data Editing

Data editing rules are designed to identify errors and anomalies, and their causes, in traffic data. The record-level analysis of vehicle traffic data is closely related to the types of analyses performed on the Georgia and Truck Index datasets for identifying vehicle class, and thus appropriate rules and limits for data values can be examined using the output of these classification methods. The types of scatter plots and box and whisker plots prepared from the Georgia dataset can also be useful in setting editing criteria, particularly when such charts are produced from regional or representative areas of data collection. Most suggested data editing criteria involve extreme test values. Providing a single value for a particular rule that is applied to all vehicles in the database may be too general in some cases, resulting in a large number of missed errors and anomalies, or in too many flagged records. By subdividing the editing criteria for use on subsets of the vehicle data stream, based on common characteristics of the data such as number of axles or vehicle class, it may be possible to develop greater relevance and specificity for the criteria.

Recommendations

There are a number of suggestions for follow-up work based on this study. Optimal tree-type classification sieves can be developed using additional physical characteristics, such as vehicle length and weight. Volume-based data editing criteria can be developed using frequency distributions and introducing errors of known bias to the distribution, for warning of possible classifier degradation. Per-vehicle data editing criteria can be determined from ground truth data sources that are specific to subsets of the vehicle population, thus increasing relevance and accuracy of the traffic data. Discriminate analysis can be used on sources such as TIUS to predict body type from other physical characteristics of trucks, such as length and weight, and also for predicting cargo carried. Discriminate analysis can also be on vehicle records containing axle spacing and length and/or weight data to determine vehicle class. The Georgia dataset can be modified by adding body type to the vehicle records based on the video, and then can be used to try to predict body type from axle-spacing and length data. The exploratory work conducted in the context of the "Truck Fleet Characteristics Analysis" and the "Truck Characteristics Analysis" has indicated that there is very limited data available for obtaining detailed yet comprehensive information about the national truck fleet. Based on the promising results of this study, further data collection efforts and analysis are recommended for improving the accuracy and usefulness of AVC and WIM data.

Introduction

The Truck Characteristics Study seeks to develop a better understanding of the physical characteristics of the national truck fleet. With automatic vehicle classifiers (AVC) and weigh-in-motion devices (WIM), only axle spacing and weight information is obtained. No information about body type or type of cargo carried is available. With a better understanding of the truck fleet, particularly some information about the truck body type, it should be possible to evaluate the relationship between body type, weights, axle spacings, and cargo carried. To accomplish this, we explored the scope of available sources of current information about the physical characteristics of trucks, compiled several data sources, and analyzed these sources for the purpose of improving the accuracy of automatic vehicle classifiers. The primary objective of the project was to find patterns of axle spacings that correlate with body types, which can then be used to improve algorithms used by axle-based automatic vehicle classifiers and to estimate travel by body type from axle-based vehicle classification data.

Automatic vehicle classifiers and weigh-in-motion devices depend upon knowledge about the relationship between what types of vehicles have what types of axle spacings. Algorithms are used to interpret axle spacings as vehicle classes, using the standard 13 Federal Highway Administration (FHWA) classes. The accuracy of classifying highway vehicles from axle count and axle spacing data is dependent upon two things: the accuracy of the measurements and the relevance of the classification parameters to the vehicle population. Because different vehicle configurations can have similar axle spacings, there is no precise way to identify the parameters. Having a better understanding of the types of trucks that have specific axle spacings should help improve the accuracy of data collected by WIM and AVC devices.

The first task of this study was to search for common patterns and correlations between vehicle axle spacings, vehicle class, body type, and other physical characteristics, and to perform statistical analyses to show the degree of confidence and limitations of these patterns and correlations. Distributions of truck configurations and body types for the national truck fleet were to be prepared. The goal was to obtain information about the truck fleet such so that the relationship between body type, weight of the vehicle, axle spacings and cargo carried could be evaluated, allowing for numerous interpolations from the limited data provided by AVC and WIM devices. The algorithms for determining vehicle class can be refined and improved, and more information can be obtained from axle-based vehicle classification data to a greater level of detail and accuracy than currently possible.

The second task was to propose improvements in common vehicle classification algorithms based on the results of the first task and other sources of information about the national truck fleet and trends such as the increasing use of split tandems. Particular emphasis was to be placed on recommendations for the “Scheme F” algorithm, since Scheme F as a classification method is widely used by the states.

The third task was to propose data editing criteria for AVC data based on the above analysis and sources of information. Improved data editing criteria will serve to decrease the number of vehicles that are categorized as unclassified, and also the number of vehicles that are improperly classified. The result is increased reliability of traffic estimates based on AVC and WIM data.

Two of the sources used for these tasks were databases developed during the project "Truck Fleet Characteristics" [1], also sponsored by the FHWA's Office of Highway Policy Information, and the 1996 Trucking Industry Profile (TIP) database from Polk [2]. The Trucking Industry Profile provides registration data for all trucks registered in the year 1996. The Truck Index [3], prepared from information in the annually published Truck Index Manuals, contains vehicle specifications, including axle spacing, for all major truck makes. Together, these databases are capable of providing many types of information about trucks, including number registered, axle spacing, weight, and length for most major truck models.

Two other databases used for these tasks were the 1992 Truck Inventory and Use Survey (TIUS) [4], and data from the 1995 study "Accuracy of Traffic Monitoring Equipment"[5] conducted by the Georgia Department of Transportation (DOT). Numerous statistical correlations and patterns based on physical and other characteristics of the national truck fleet can be determined from the 1992 TIUS. Some analyses possible using this data source include patterns and statistics concerning the 11 major body types identified in TIUS, such as principal products carried for each of the body types, vehicle miles traveled, common truck configuration for each body type, mean tare weights and average payload weights, and dimension and operating characteristics for selected body types. The database from the Georgia DOT study contains 40,686 vehicle records with ground truth measurements for number of axles and individual axle spacings, as well as FHWA vehicle class. This database allows for the application of various statistical procedures for exploring the effectiveness of different classification methodologies.

Chapter 1 of this report is an analysis of truck body types as defined in the 1992 Truck Inventory and Use Survey. Frequency distributions of 11 different body types are displayed in relation to number of axles on the configuration, the number of lift axles, vehicle length, average gross vehicle weight, and the number of axles on the trailers pulled by trucks and truck tractors. Chapter 2 describes the development for this project of a data-defined vehicle classification sieve based on number of axles and axle spacing, and compares the results of the data-defined sieve to the Scheme F classification algorithm. Chapter 3 examines the application and effectiveness of Scheme F to the Truck Index and Trucking Industry Profile databases. In Chapter 4, the use of discriminate analysis as a means for classifying vehicles from known axle count and spacing is described. This method is compared to the data-defined sieve from Chapter 2, and to the Scheme F algorithm. Chapter 5 utilizes the data output from the statistical analysis in the previous chapters to evaluate current data editing rules and to suggest refinements to existing rules, as well as new tests for WIM and AVC data.

Chapter 1

Analysis of Truck Body Type from the 1992 Truck Inventory and Use Survey

One objective of this study was to attempt to find patterns of axle spacings that correlate with specific body types, so that more information can be obtained about truck traffic from axle-based vehicle classification data, including possible speculation about cargo carried by trucks for which axle-based traffic data is collected. With current AVC and WIM devices, only axle spacing and weight information is obtained. No information about body type or cargo carried is available. If information can be obtained about the truck fleet so that the relationship between body type, weight, and cargo carried can be evaluated, then numerous interpolations could be made from the limited data provided by AVC and WIM devices.

1.1 Introduction

There are limited data sources available that contain body type in association with individual vehicle records. No comprehensive data sources were found that have information about both body type and axle spacing. Of the data sources explored for value in achieving the objectives of this task, two sources were considered. The Truck Index contains a great deal of information about the physical characteristics of trucks. Along with length, axle spacing, and weight data, body type is also included for some of the records, but not enough to be useful for correlating body type and axle spacing. The second data source considered, the 1992 TIUS [3], has body type defined for almost all vehicle records, with a total of eleven distinctly defined types, and it also has a great deal of other information about the physical characteristics of the vehicles from the survey. TIUS does not include variables for individual axle spacing, so a direct correlation between axle spacing and body type is not possible. However, other correlations between body type and vehicle types can be explored using TIUS. It is worthwhile to examine these for patterns or relationships in seeing whether body types can be identified or surmised from WIM or AVC data. Specifically, the following vehicle characteristics are reviewed for possible relationship to truck or trailer body types: total number of axles, the number of lift axles, total vehicle length, average gross vehicle weight (GVW), the number of axles on trailers pulled by truck tractors, and the number of axles on trailers pulled by straight trucks. These factors are addressed from the 1992 TIUS, which means that the data is reviewed only in the context of the number of surveyed vehicles for which responses are given, and not with regard to vehicle miles traveled, geographical or seasonal differences, or other aspects of vehicle usage.

The distribution of body types within the 1992 TIUS are such that the most frequently occurring body type is the basic platform. The majority (63 percent) of the platform trucks in TIUS are pre-1982 vehicles. Twenty-three percent of all trucks in the database have the basic platform body type, with the next most common body type being the basic enclosed van (17 percent), and the dump truck (12 percent). The higher relative numbers of these truck body types in TIUS is reflected when relating body type to other variables. Since the number of axles on the vehicle is a prime determinant of vehicle class with most vehicle classification methodologies, and because this information is available in TIUS and from WIM and AVC data, we used variables in TIUS related to number of axles, including total number of axles, number of lift axles, and the number of axles on trailers, in attempting to identify a relationship between number of axles and body type. Average GVW is also examined in TIUS for its relationship to body type, since weight data is generated from WIM devices. Because vehicle length is also sometimes available due to loop sensors deployed in conjunction with AVC devices, total vehicle length in TIUS is evaluated for its relationship to body type. The results of these analyses were mixed. The five most frequently occurring body types for each variable are presented and discussed in the following sections. In addition, detailed data for every possible body type in TIUS for the variables are contained in Appendix A, along with a brief description of each body type from the survey form.

1.2 Total Number Axles

There are four axle categories in TIUS representing the total number of axles on the vehicles in the 1992 TIUS database: two axles with four tires, two axles with six tires, three axles, and four or more axles. The top five body types for trucks by number of axles from TIUS are in Table 1.2.1 Basic enclosed van and basic platform are among the top three body types for each of the 2-axle four-tire, 2-axle six-tire, and 3-axle trucks. The multi-stop or step van is also a common 2-axle four-tire body type, at 20 percent for that axle configuration. Dump trucks are among the top three most common body types for 2-axle six tire, 3-axle, and 4-axle or more trucks. For 4- or more axle trucks, dump trucks comprise 42 percent of all vehicles, with concrete mixers at 20 percent. This seems to indicate that number of axles, particularly for trucks with more axles, can be a fairly good indicator of some body types.

1.3 Lift Axles

This section identifies what truck body types are more likely to have lift axles, and how many lift axles they may have. Lift axles can be an important consideration in correctly identifying trucks by WIM or AVC data, for several reasons. In part, this is because lift axles can cause confusion in identification since the vehicle class assigned is affected by axle configuration, which may change depending on whether the lift axle is up or down. Lift axles are also an important regulatory issue, since they are used on heavy vehicles that are more prone to oversize/overweight violations, and the lift axles themselves are sometimes subject to misuse, increasing the risk of violating regulations and increasing damage to roads and pavement. The body types that most frequently have lift axles, according to TIUS, are basic platforms (27 percent), dump trucks (21 percent), and concrete mixers (13 percent). Lift axles are also found on many other types of trucks as well, including platforms, grain bodies, multi-stop or step vans, wreckers, pole, logging, and pipe trucks, and tank body types.

Table 1.2.1 Body Type by Total Number of Axles on the Vehicles

2-Axle, Four-Tire Trucks

Body Type by Rank	Number of Vehicles	Percent of Total
Basic Platform	13,546	31.28%
Multi-stop or Step Van	8,583	19.82%
Basic Enclosed Van (Dry Product)	5,747	13.27%
Dump Truck	2,616	6.04%
Utility Truck	2,230	5.15%
Other	10,587	24.45%
Total	43,309	100%

2-Axle, Six-Tire Trucks

Body Type by Rank	Number of Vehicles	Percent of Total
Basic Platform	26,022	26.60%
Basic Enclosed Van (Dry Product)	16,921	17.29%
Dump Truck	10,251	10.48%
Mult-stop or Step Van	7,289	7.45%
Platform with Devices	5,950	6.08%
Other	31,408	32.10%
Total	97,841	100%

3-Axle Trucks

Body Type by Rank	Number of Vehicles	Percent of Total
Basic Enclosed Van (Dry Product)	9,965	19.99%
Basic Platform	7,297	14.63%
Dump Truck	6,523	13.08%
Liquid or Gas Tank Truck	4,576	9.18%
Insulated, Refrigerated Van	4,104	9.03%
Other	17,395	34.89%
Total	49,860	100%

4- or-More-Axle Trucks

Body Type by Rank	Number of Vehicles	Percent of Total
Dump Truck	2,427	41.81%
Concrete Mixer	1,109	19.11%
Pole, Logging, Pipe Trucks	591	10.18%
Grain Bodies	341	5.87%
Basic Platform	263	4.53%
Other	1,074	18.50%
Total	5,805	100%

Source: 1992 Truck Inventory and Use Survey
Note: Number of Vehicles is the number of sampled vehicles from the survey

The top five body types for each lift axle configuration are given in Table 1.3.1. For trucks with one lift axle, the most frequent body type (at 29 percent) is the dump truck. For two lift axles, the basic platform is most common at 75 percent of that vehicle population. The most common body types correlated with three lift axles are fairly evenly distributed between basic enclosed vans and drop frame vans, followed by low boy platform and liquid or gas tank trucks.

Table 1.3.1 Body Type by Number of Lift Axles

Trucks and Trailers with One Lift Axle

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Dump Truck	1,530	29.07%
Concrete Mixer	772	14.66%
Pole, Logging, Pipe Trucks	538	10.23%
Wrecker	482	9.15%
Grain Bodies	462	8.79%
Other	1,479	28.10%
Total	5,263	100%

Trucks and Trailers with Two Lift Axles

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	2,078	74.89%
Concrete Mixer	290	10.47%
Dump Truck	198	7.15%
Multi-Stop or Step Van	107	3.86%
Basic Enclosed Van (Dry Product)	29	1.04%
Other	72	2.60%
Total	2,774	100%

Trucks and Trailers with Three Lift Axles

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Product)	39	29.78%
Drop Frame Van	36	27.27%
Low Boy Platform	23	17.59%
Liquid or Gas Tank Truck	22	16.32%
Concrete Mixer	12	9.05%
Other	0	0.00%
Total	132	100%

Source: 1992 Truck Inventory and Use Survey
Note: Number of Vehicles is the number of sampled vehicles from the survey

1.4 Total Vehicle Length

TIUS provides information about vehicle length in the form of 14 separate length bins, with all but the outside bins between three to eight feet. The results in relating length to body type are in Table 1.4.1 for the top five body types by rank for each length category. There is a great deal of variation in the length possibilities for many body types, making this a somewhat less valuable criteria for identifying body type. For example, the basic enclosed van occurs in the five most frequently occurring body types for 13 of the 14 length bins, basic platform in 12 of the 14 bins, and dump truck in 11 of the 14 bins. This criteria may be more useful by virtue of eliminating certain less commonly occurring body types from some length categories rather than in predicting body type. For example, multi-stop or step vans, utility trucks, service trucks, and concrete mixers are unlikely to be over the length of 45 feet. Conversely, automobile transport trucks are generally at least 28 feet in length, and livestock trucks, drop frame vans, open top vans, beverage trucks, garbage trucks, concrete mixers, and tank trucks are generally longer than 16 feet. Only five body types were found to be less than 13 feet in length, and 40 percent of these were wreckers. In the longest five length categories, which comprise all vehicles over 55 feet long, the basic enclosed van is by far the most common body type.

Table 1.4.1 Body Type by Total Length of the Vehicle

Total Length 13.0 to 15.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Multi-Stop or Step Van	1,419	23%
Basic Platform	1,086	18%
Dump Truck	862	14%
Utility Truck	792	13%
Basic Enclosed Van (Dry Product)	607	10%
Other	1,321	22%
Total	6,087	100%

Total Length 16.0 to 19.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	20,248	38%
Multi-Stop or Step Van	9,748	18%
Dump Truck	6,878	13%
Basic Enclosed Van (Dry Product)	3,317	6%
Service Truck	3,154	6%
Other	9,632	18%
Total	52,977	100%

Total Length 20.0 to 27.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	14,558	23%
Basic Enclosed Van (Dry Product)	9,219	14%
Grain Bodies	8,409	13%
Dump Truck	7,957	12%
Multi-Stop or Step Van	4,355	7%
Other	19,703	31%
Total	64,201	100%

Table 1.4.1 Body Type by Total Length of the Vehicle (continued)

Total Length 28.0 to 35.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Product)	3,691	20%
Grain Bodies	2,081	11%
Basic Platform	1,979	11%
Dump Truck	1,397	8%
Concrete Mixer	1,181	6%
Other	8,058	44%
Total	18,387	100%

Total Length 36.0 to 40.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Product)	1,837	24%
Utility Truck	1,469	19%
Basic Platform	1,122	15%
Dump Truck	1,030	14%
Concrete Mixer	653	9%
Other	1,435	19%
Total	7,546	100%

Total Length 41.0 to 44.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Dump Truck	762	42%
Beverage Truck	198	11%
Multi-Stop or Step Van	120	7%
Liquid or Gas Tank Truck	115	6%
Basic Enclosed Van (Dry Product)	106	6%
Other	513	28%
Total	1,814	100%

Total Length 45.0 to 49.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	1,092	29%
Dump Truck	615	16%
Low Boy Platform	684	15%
Basic Enclosed Van (Dry Product)	314	8%
Pole, Logging, Pipe Truck	283	7%
Other	801	21%
Total	3,789	100%

Total Length 50.0 to 54.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Dump Truck	1,598	23%
Basic Enclosed Van (Dry Product)	1,413	21%
Liquid or Gas Tank Truck	725	11%
Low Boy Platform	696	10%
Basic Platform	509	7%
Other	1,939	28%
Total	6,880	100%

Table 1.4.1 Body Type by Total Length of the Vehicle (continued)

Total Length 55.0 to 59.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Product)	3,795	32%
Basic Platform	2,007	17%
Liquid or Gas Tank Truck	1,600	13%
Insulated, Refrigerated Van	1,069	9%
Dump Truck	1,020	9%
Other	2,469	21%
Total	11,960	100%

Total Length 60.0 to 64.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Cargo)	3,376	32%
Drop Frame Van	1,819	17%
Basic Platform	1,777	17%
Liquid or Gas Tank Truck	662	6%
Low Boy Platform	550	5%
Other	2,383	23%
Total	10,567	100%

Total Length 65.0 to 69.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Cargo)	2,881	39%
Basic Platform	1,339	18%
Insulated, Refrigerated Van	989	13%
Low Boy Platform	779	11%
Automobile Transport	301	4%
Other	1,086	15%
Total	7,375	100%

Total Length 70.0 to 74.9 Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Cargo)	1,516	62%
Insulated, Refrigerated Van	356	15%
Basic Platform	263	11%
Low Boy Platform	84	3%
Pole, Logging, Pipe Trucks	51	2%
Other	170	7%
Total	2,440	100%

Total Length 75.0 or More Feet

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Cargo)	767	39%
Insulated, Refrigerated Van	231	12%
Pole, Logging, Pipe Trucks	171	9%
Basic Platform	97	5%
Dump Truck	83	4%
Other	619	31%
Total	1,968	100%

Source: 1992 Truck Inventory and Use Survey
Note: Number of Vehicles is the number of sampled vehicles from the survey

1.5 Average Gross Vehicle Weight

TIUS distributes vehicles into 14 weight bins by average Gross Vehicle Weight (GVW). GVW can give an indication about probable body types. The top five ranking of body type for each weight bin are in Table 1.5.4. The categories, and the most prevalent body type in each weight category and the applicable percentage, are given in Table 1.5.1 below.

The truck types that are more prevalent overall tend to dominate the top five rankings. A broader picture can be obtained by viewing the distribution of individual body types across the weight categories, and also by looking at the average weight for various body types. TIUS collects average operating GVW for the trucks surveyed, then weight bins are formed with ranges of approximately 2,000 to 6,000 pounds. For some body types, the distribution is spread widely across the weight ranges. In these cases, weight may not be a good indicator of body type. Some examples of body types in which GVW is not a good indicator, due to a broad distribution of weights across the population with these body types are livestock trucks, drop frame vans, winch or crane trucks, oil field trucks, yard tractors, and dump trucks.

Low-boy platforms, multi-stop or step vans, beverage trucks, wreckers, service trucks, grain bodies, concrete mixers, and garbage trucks all have the appearance of skewed distributions. The median weight ranges for these body types are listed in Table 1.5.2.

The remainder of the body type GVW distributions are not normal distributions, but have one or more distinctive outlying weight ranges within which a large number of vehicle records fall. The weight bins within which the greatest number of these body types are represented are in Table 1.5.3 below.

The median is the same, 60,000 to 80,000 pounds, for the body types for low-boy platforms, dry bulk tankers, liquid or gas tank trucks, auto transporter, pole, logging, and pipe trucks, basic enclosed van, open top vans, insulated, refrigerated vans, and insulated, non-refrigerated vans.

Table 1.5.1 Most Common Truck Body Type in Each TIUS Average Gross Vehicle Weight Category

Weight Category (lbs.)	Most Common Body Type	Percent in Weight Category
6,000 lbs. or less	Basic Platform	44%
6,001 to 10,000	Basic Platform	33%
10,001 to 14,000	Basic Platform	29%
14,001 to 16,000	Basic Platform	31%
16,001 to 19,500	Basic Platform	24%
19,501 to 26,000	Basic Platform	21%
26,001 to 33,000	Basic Platform	14%
33,001 to 40,000	Basic Enclosed Van	21%
40,001 to 50,000	Dump Truck	20%
50,001 to 60,000	Basic Enclosed Van	24%
60,001 to 80,000	Basic Enclosed Van	27%
80,001 to 100,000	Dump Truck	25%
100,001 to 130,000	Liquid or Gas Tank Truck	22%
130,001 and over	Dump Truck	50%

Source: 1992 Truck Inventory and Use Survey

Table 1.5.2 Median Weight Ranges for Body Types with Skewed Average GVW Distributions

Body Type	Median Weight Range (lbs.)	Percent of the Body Type Population in Weight Range
Multi-Stop or Step Vans	6,000 to 10,000	53%
Wreckers	6,000 to 10,000	46%
Grain Bodies	19,500 to 26,000	29%
Beverage Trucks	26,000 to 33,000	32%
Garbage Trucks	40,000 to 50,000	24%
Concrete Mixers	50,000 to 60,000	33%
Low-Boy Platforms	60,000 to 80,000	33%

Source: 1992 Truck Inventory and Use Survey

Table 1.5.3 Body Types with Non-Normal Distributions Across the GVW Ranges

Body Type	Weight Range (lbs.)	Percent of Body Type Population in the Weight Range
Utility Trucks	6,000 to 10,000	28%
Utility Trucks	19,501 to 26,000	20%
Liquid or Gas Tank Trucks	19,500 to 26,000	23%
Liquid or Gas Tank Trucks	60,000 to 80,000	27%
Platform with Devices	19,501 to 26,000	24%
Automobile Transport Trucks	60,000 to 80,000	61%
Basic Enclosed Van	60,000 to 80,000	27%
Dry Bulk Tank Trucks	60,000 to 80,000	50%
Insulated, Refrigerated Van	60,000 to 80,000	43%
Insulated, Non-Refrigerated Van	60,000 to 80,000	37%
Open Top Van	60,000 to 80,000	37%
Pole, Logging, or Pipe Trucks	60,000 to 80,000	52%

Source: 1992 Truck Inventory and Use Survey

Table 1.5.4 Body Type by Average Gross Vehicle Weight

Average GVW of 6,000 lbs or Less

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	157,339	44%
Multi-Stop or Step Van	93,190	26%
Service Truck	30,070	8%
Basic Enclosed Van (Dry Cargo)	17,107	5%
Platform or Devices	15,119	4%
Other	47,919	13%
Total	360,744	100%

Average GVW of 6,001 to 10,000 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	319,508	33%
Multi-Stop or Step Van	217,026	22%
Basic Enclosed Van (Dry Cargo)	88,546	7%
Dump Truck	72,223	7%
Service Truck	65,888	5%
Other	202,277	21%
Total	965,468	100%

Average GVW of 10,001 to 14,000 lbs

Body Type by Rank	Number of Vehicles for the Body Type	Percent of Vehicles with Average GVW of 6,001 to 10,000 lbs
Basic Platform	147,500	29%
Multi-Stop or Step Van	72,876	14%
Basic Enclosed Van (Dry Cargo)	59,801	12%
Dump Truck	53,065	10%
Platform with Devices	31,597	6%
Other	150,188	29%
Total	515,027	100%

Average GVW of 14,001 to 16,000

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	80,102	31%
Dump Truck	36,104	14%
Basic Enclosed Van (Dry Cargo)	34,157	13%
Platform with Devices	20,450	8%
Grain Bodies	12,731	5%
Other	72,198	28%
Total	255,742	100%

Table 1.5.4 Body Type by Average Gross Vehicle Weight (continued)

Average GVW of 16,001 to 19,500 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	65,116	24%
Basic Enclosed Van (Dry Cargo)	51,638	19%
Dump Truck	35,898	13%
Platform with Devices	24,284	9%
Grain Bodies	17,150	6%
Other	72,575	27%
Total	266,661	100%

Average GVW of 19,501 to 26,000 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	153,577	21%
Basic Enclosed Van (Dry Cargo)	104,661	14%
Dump Truck	93,389	13%
Grain Bodies	90,822	12%
Platform with Devices	70,666	10%
Other	219,240	30%
Total	732,355	100%

Average GVW of 26,001 to 33,000 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	53,001	14%
Dump Truck	52,824	14%
Basic Enclosed Van (Dry Cargo)	48,595	13%
Grain Bodies	48,412	13%
Platform with Devices	34,002	9%
Other	150,337	39%
Total	387,171	100%

Average GVW of 33,001 to 40,000 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Cargo)	48,965	21%
Dump Truck	32,125	14%
Basic Platform	30,348	13%
Grain Bodies	21,670	9%
Liquid or Gas Tank Truck	14,671	6%
Other	84,791	36%
Total	232,570	100%

Table 1.5.4 Body Type by Average Gross Vehicle Weight (continued)

Average GVW of 40,001 to 50,000 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Dump Truck	68,087	20%
Basic Enclosed Van (Dry Cargo)	61,498	18%
Grain Bodies	38,656	11%
Basic Platform	36,650	11%
Platform with Devices	17,819	5%
Other	115,930	34%
Total	338,640	100%

Average GVW of 50,001 to 60,000 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Cargo)	55,073	24%
Dump Truck	42,153	19%
Concrete Mixer	20,332	9%
Basic Platform	19,214	8%
Garbage Truck	14,487	6%
Other	75,442	33%
Total	226,701	100%

Average GVW of 60,001 to 80,000 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Cargo)	212,899	27%
Basic Platform	115,552	15%
Insulated, Refrigerated Van	87,334	13%
Dump Truck	99,696	11%
Liquid or Gas Tank Truck	62,631	8%
Other	202,951	26%
Total	781,063	100%

Average GVW of 80,001 to 100,000 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Dump Truck	8,488	25%
Low-Boy Platform	5,451	16%
Liquid or Gas Tank Truck	3,375	10%
Pole, Logging, Pipe Truck	3,323	10%
Basic Platform	3,283	10%
Other	9,408	28%
Total	33,328	100%

Average GVW of 100,001 to 130,000 lbs

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Liquid or Gas Tank Truck	2,722	22%
Dump Truck	2,715	22%
Low-Boy Platform	1,932	16%
Basic Platform	1,472	12%
Grain Bodies	690	6%
Other	2,796	23%
Total	12,327	100%

Table 1.5.4 Body Type by Average Gross Vehicle Weight (continued)

Average GVW of 130,001 lbs and Over

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Dump Truck	2,326	50%
Low-Boy Platform	725	16%
Basic Platform	643	14%
Liquid or Gas Tank Truck	287	6%
Basic Enclosed Van (Dry Cargo)	116	3%
Other	518	11%
Total	4,615	100%

Source: 1992 Truck Inventory and Use Survey
Note: Number of Vehicles is the number of sampled vehicles from the survey

1.6 Types of Trailers Pulled by Truck Tractors

In addition to the number of axles, TIUS also provides information about the configuration and number of axles for the trailers pulled by combination vehicles, that is, semitrailers and full trailers pulled by straight trucks and truck tractors. For truck tractors, TIUS includes the following configurations: one axle on one semi-trailer, two axles on one semi-trailer, three or more axles on one semi-trailer, three axles on two trailers, four axles on two trailers, five axles on two trailers, six axles on two trailers, and five axles on three trailers. The five most common body types for those configurations in TIUS are in Table 1.6.1.

The basic enclosed van is the most frequently occurring trailer body type pulled by truck tractors for the configuration of one semi-trailer with one or two axles pulled by a truck tractor. When there are three axles on the single semi-trailer, the low-boy platform is most common, making up 37 percent of all body types, followed by the basic enclosed van at 19 percent. Fifty-five percent of one-axle semi-trailers and 30 percent of all 2-axle semi-trailers pulled by truck tractors are basic enclosed vans. The basic enclosed van body type is also the most common when there are three axles on two trailers pulled by a truck tractor (a one-axle semi-trailer followed by a 2-axle full trailer). Sixty-five percent of vehicles with this configuration are basic enclosed vans. Second most common, at 17 percent, are basic platforms. For double-trailer configurations with larger numbers of axles, many other body types are more prevalent than the van body type. For four axles on two trailers pulled by a truck tractor, the distributions of body types is fairly even between grain bodies (17 percent), basic platforms (17 percent), liquid or gas tank trucks (16 percent), vans (13 percent), and low-boy platforms (13 percent).

Basic platforms and low-boy platforms are most common when there are five axles on two trailers pulled by a truck tractor, combined totaling 44 percent of that configuration. The basic platform is also most common when there are six axles on two trailers, making up 48 percent of the total. For triples, with five axles on three trailers, the Basic Enclosed Van is the only body type in the database. It appears that the van is more common for configurations with fewer numbers of axles on the trailers, indicating that these are used for less dense cargo than the platform body types, which are the most prevalent for trailer combinations with larger numbers of axles.

Table 1.6.1 Body Type by Number of Axles on Trailers Pulled by Truck Tractors

One-Axle Semitrailer Pulled by a Truck Tractor

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Cargo)	1,948	55%
Beverage Truck	502	14%
Insulated, Refrigerated Van	269	7%
Low-Boy Platform	255	7%
Basic Platform	252	7%
Other	309	9%
Total	3,535	100%

Two-Axle Semitrailer Pulled by a Truck Tractor

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van (Dry Cargo)	10,860	30%
Basic Platform	5,065	14%
Insulated, Refrigerated Van	4,375	12%
Liquid or Gas Tank Truck	3,275	9%
Dump Truck	2,617	7%
Other	9,614	27%
Total	35,806	100%

Three-or-More Axle Semitrailer Pulled by a Truck Tractor

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Low-Boy Platform	1,035	37%
Basic Enclosed Van (Dry Cargo)	530	19%
Basic Platform	354	13%
Dump Truck	305	11%
Liquid or Gas Tank Truck	104	4%
Other	499	18%
Total	2,827	100%

Three Axles on Two Trailers Pulled by a Truck Tractor

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van	2,161	65%
Basic Platform	557	17%
Dump Truck	238	7%
Insulated, Refrigerated Van	161	5%
Grain Bodies	134	4%
Other	69	2%
Total	3,320	100%

Table 1.6.1 Body Type by Number of Axles on Trailers Pulled by Truck Tractors (continued)

Four Axles on Two Trailers Pulled by a Truck Tractor

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Grain Bodies	33	17%
Basic Platform	32	17%
Liquid or Gas Tank Truck	30	16%
Basic Enclosed Van	26	13%
Low-Boy Platform	24	12%
Other	47	25%
Total	192	100%

Five Axles on Two Trailers Pulled by a Truck Tractor

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	32	25%
Low-Boy Platform	24	19%
Open Top Van	19	15%
Insulated, Refrigerated Van	9	7%
Dump Truck	9	7%
Other	33	26%
Total	126	100%

Six Axles on Two Trailers Pulled by a Truck Tractor

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Platform	154	48%
Dump Truck	62	19%
Insulated, Refrigerated Van	56	18%
Basic Enclosed Van	29	9%
Dry Bulk Tank Truck	8	2%
Other	9	2%
Total	318	100%

Five Axles on Three Trailers Pulled by a Truck Tractor

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Basic Enclosed Van	38	100%
Total	38	100%

Source: 1992 Truck Inventory and Use Survey

Note: Number of Vehicles is the number of sampled vehicles from the survey

1.7 Number of Axles on Trailers Pulled by Straight Trucks

TIUS also includes information about body types on trailers pulled by straight trucks. The categories for the trailer combinations are: one axle on a trailer shorter than 20 feet, two axles on a trailer shorter than 20 feet, three axles on a trailer shorter than 20 feet, two axles on a full trailer or semi-trailer, three axles on a full trailer or semi-trailer, and 4- or more axles on a full trailer or semi-trailer. The ranking of the five most common body types on trailers pulled by straight trucks are in Table 1.7.1. For trailers less than 20 feet with only one axle, the utility trailer is by far the most common (60 percent). For trailers less than 20 feet with two axles pulled by a straight truck, dump bodies (30 percent), basic platforms (25 percent), and utility trailers (23 percent) are the most frequently occurring. Dump bodies (68 percent) and basic platforms (32 percent) are the only body types identified for three-axle trailers shorter than 20 feet.

For full trailers, the axle configurations are two axles, three axles, and 4- or more axles on single trailers. The dump body type is the most frequently occurring body type for 2-axle trailers, and second most common among 3-axle trailers. Low-boy platforms are most common for 3-axle trailers (44 percent). For 4-or-more-axle trailers pulled by straight trucks, the only body type occurring in TIUS is the liquid or gas tank truck.

One hundred percent of multi-stop or step vans, insulated non-refrigerated vans, wreckers, and garbage trucks pulled by truck tractors are in the configuration one trailer with two axles. This is also the most common configuration overall for truck tractors (78 percent). Other body types that frequently use this configuration are platforms with devices (89 percent), livestock trucks (93 percent), insulated refrigerated vans (89 percent), drop frame vans (83 percent), open top vans (81 percent), pole, logging and pipe trucks (95 percent), automobile transport trucks (99 percent), oil field trucks (95 percent), dump trucks (81 percent), liquid or gas tank trucks (96 percent), and dry bulk tankers (86 percent).

Some body types also pull other trailer configurations with truck tractors to a significant degree, even though the single two-axle semi-trailer is still the most common. Low-boy platforms, basic enclosed vans, beverage trucks, and winch or crane trucks are often found on one-axle semi-trailers. Three or more axles on one semi-trailer are often platforms with devices, low-boy platforms, open top vans, winch or crane trucks, dump trucks, and dry bulk tank trucks. Few body types are used in double configurations. Those that are most likely to be used with four, five, or six axles across two trailers are open top vans (8.7 percent), grain bodies (4 percent), and dry bulk containers (4 percent).

Table 1.7.1 Body Type by Type of Trailers Pulled by Straight Trucks

One Axle on Trailer < 20 Feet Pulled by a Straight Truck

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Utility Truck	1,154	59.98%
Basic Platform	380	19.77%
Platform with Devices	169	8.77%
Insulated, Refrigerated Van	123	6.40%
Grain Bodies	39	2.05%
Other	58	3.03%
Total	1,923	100%

Two Axles on Trailer < 20 Feet Pulled by a Straight Truck

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Dump Truck	1,067	30.08%
Basic Platform	886	24.99%
Utility Truck	820	23.11%
Platform with Devices	272	7.68%
Service Truck	263	7.41%
Other	240	6.73%
Total	3,548	100%

Three Axles on Trailer < 20 Feet Pulled by a Straight Truck

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Dump Truck	247	67.84%
Basic Platform	117	32.16%
Total	365	100%

Two Axles on Full Trailer or Semi-Trailer Pulled by a Straight Truck

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Dump Truck	1,012	26.18%
Basic Platform	953	24.64%
Low-Boy Platform	608	15.74%
Basic Enclosed Van	405	10.49%
Utility Truck	318	8.23%
Other	569	14.72%
Total	3,865	100%

Three Axles on Full Trailer or Semi-Trailer Pulled by a Straight Truck

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Low-Boy Platform	74	43.78%
Dump Truck	47	27.78%
Liquid or Gas Tank Truck	25	14.68%
Basic Platform	14	8.30%
Other	10	5.46%
Total	170	100%

Table 1.7.1 Body Type by Type of Trailers Pulled by Straight Trucks (continued)

Four or More Axles on Full Trailer or Semi-Trailer Pulled by a Straight Truck

Body Type by Rank	Number of Vehicles	Percent of Vehicles
Liquid or Gas Tank Truck	9	100.00%
Total	9	100%

Source: 1992 Truck Inventory and Use Survey

Note: Number of Vehicles is the number of sampled vehicles from the survey

1.8 Summary

Five vehicle characteristics were evaluated in relation to body type in determining whether data from vehicle classification devices can predict vehicle body type. These five characteristics were: total number of axles, number of lift axles, total vehicle length, average GVW, the number of axles on trailers pulled by truck tractors, and the number of axles on trailers pulled by straight trucks. These variables, out of all those available in the TIUS database, were selected for analysis due to the potential availability of the necessary data from traffic data collection devices, which are capable of collecting the axle count, axle spacing, weight, and length information.

Based on the number of axles, TIUS categorizes vehicles according to whether there are 2 axles with four tires, 2 axles with six tires, 3 axles, or 4-or-more axles. The basic platform was the most common body type for all 2-axle vehicles, the basic enclosed van was most common for 3-axle vehicles, and dump trucks for 4-or-more axle vehicles. Information about trucks with lift axles is also available in TIUS, indicating there are zero, one, two, or three lift axles. Lift axles are important in axle-based vehicle classification data because these axles are often missed by vehicle classification equipment. In attempting to predict body type from such classification data, it can be assumed that body types that are more likely to have lift axles may be misclassified more often than others. Dump trucks were the most common type of truck with one lift axle. The basic platform represented 75 percent of the vehicles with two lift axles within TIUS, and the van body type represented 57 percent of the vehicles with three lift axles. Overall, the body types most likely to have lift axles were basic platforms, dump trucks, and concrete mixers. TIUS contains information about vehicle length in 14 length categories. There is a great deal of variation in the possible lengths for many body types, which results in this criteria not being a very good indicator of body type when considered independently of any other criteria. Average gross vehicle weight also varies widely for many body types, but some body types occur more predominantly in certain weight ranges. The basic platform was the most common body type for vehicles with a GVW of 33,000 pounds or less. Basic enclosed van was most common for vehicles with a GVW of between 33,000 to 40,000 pounds and between 50,000 and 80,000 pounds. Dump trucks were most common for gross vehicle weights of between 40,000 and 50,000 pounds, between 80,000 and 100,000 pounds, and over 130,000 pounds.

There is also data in TIUS about the body type in relation to the number of axles on trailers pulled by trucks and truck tractors. If the vehicle configuration can be determined by whatever vehicle classification methodology is used, there is great potential for the configuration to be useful in making inferences about body type. This is because for some vehicle configurations, one or two body types are found on the majority of the vehicles for that configuration. For example, for configurations with one axle on a trailer less than 20 feet in length pulled by a truck, 60 percent of the vehicles in the TIUS database were utility trucks. For 3 axles on trailers less then 20 feet in length, the majority were dump trucks. Likewise, for trailers pulled by truck tractors, 55 percent of the one-axle semi-trailers and 65 percent of the configurations with three axles on two trailers were basic enclosed vans hauling dry cargo. Even when a single body type did not predominate, generally only two to four body types (out of eleven possible types) made up most of each configuration type, which makes vehicle configuration and the number of axles on trailers more predictive of body type than the other variables in this analysis.

The best way to discern vehicle body type from traffic data is to use as many variables as available that can be linked to body type in accordance with data sources such as the Truck Inventory and Use Survey. When the availability of the variables is known, a methodology can be developed using those variables, similar to the methods discussed in this report for classifying vehicles from axle-based traffic data, such as sieve-type algorithms, classification trees combined with a probabilistic assignment of body type, or a discriminate analysis function. The drawbacks of predicting body type in this way would be the same as for predicting class based on axle-based traffic data; primarily that there are significant overlaps in the body types that are possible for any given set of variables. There would also be concerns about the applicability of any assignment methodology based on testing data if that data does not adequately represent the population. However, if the necessary variables are available, there is potential to make predictions about body type from vehicle traffic data.

Chapter 2

Decision Trees and Vehicle Classification

The accuracy of classifying highway vehicles from axle count and axle spacing data is dependent upon the relevance of the classification parameters to the vehicle population. This task is particularly difficult in part because different vehicle types can have similar or even identical axle spacings, so there is no precise way to determine the parameters. Automatic vehicle classifiers and WIM equipment depend primarily on algorithms that interpret axle spacings as vehicle classes, using the standard 13 FHWA classes. A major goal of this study is to propose improvements to common vehicle classification algorithms, in particular Scheme F.

2.1 Introduction

A search for available sources of current information about truck types and physical characteristics of trucks yielded only two databases that contained a large volume of vehicle records that contained the required information of axle spacing, number of axles, and an accurate identification of the applicable FHWA class. These were a database created from the Truck Index manuals, which contains a range of possible manufacturer-supplied axle spacing for single-unit truck models, and a database developed as part of a 1995 study performed by the Georgia DOT. Sponsored by the FHWA Office of Highway Information Management, the study "Accuracy of Traffic Monitoring Equipment" tested 13 sensors and classifier configurations from ten commercially available equipment vendors to determine their accuracy in classifying vehicles into the 13 FHWA classes. Tests provided comparisons of the vehicle data from the classifiers with ground truth data obtained from a videotape of the traffic stream. Vehicle classes and measurements were obtained from the videotape though the use of a computer-aided data reduction system developed specifically for the project. The resulting ground truth dataset that was developed for the study included 40,686 individual vehicle records containing date and time records, the actual FHWA class based on the video, and ground truth measurements from the video of overall length, wheelbase, number of axles, and individual axle spacings. Although not a nationally representative sample, this data source does contain multiple configurations with all vehicle classes being represented, and has the necessary axle spacing data to explore the effectiveness of Scheme F and other possible classification approaches.

2.2 Comparison of the Data-Defined Sieve to Scheme F

The S-Plus statistical software was used to develop an optimal data-defined sieve, an axle-based classification algorithm similar to the Scheme F methodology. The goal was to determine the optimal performance of the classification sieve to evaluate whether Scheme F can be improved on without significantly using a completely different methodology or other data inputs to the sieve besides the number of axles and axle spacing.

A hierarchical decision tree procedure was used to develop an optimal data-defined sieve, an axle-based classification algorithm similar to the Scheme F methodology. The first such tree produced had too many decision branches to be practical, most of them had redundancies in terms of the class assignments at the terminal nodes. A procedure called “pruning” was applied to reduce the number of branches. Although there were far fewer branches on the pruned tree, the misclassification rate was nearly the same as that of the original tree. For both trees, in comparison to Scheme F, some of the relevant classes were not represented. Classes 1 and 4 for 2-axle vehicles, class 2 for 3-axle vehicles, class 2 and 7 for 4-axle vehicles, class 3 for 5-axle vehicles, and all class 13 trucks for 7 or more axle vehicles were not represented on the pruned tree despite the fact that these vehicles are in the database. A possible explanation for them not being identified as nodes in the tree is that there are relatively few such vehicles in the database. The statistical procedure used automatically searches for the method that will provide the highest rate of successful identifications, so those classes that are not represented in great volumes in the data source, unless highly distinct according to the classification criteria, are not likely to be assigned.

Prior to the generation of the aforementioned sieve-type trees, the vehicle records in the Georgia database were assigned to the 13 FHWA classes in accordance with the parameters of the Scheme F algorithm. Scheme F, like the S-Plus-produced decision tree, also uses the number of axles and the spacing between designated axles to assign a FHWA class. For the Georgia data, number of axles and the axle spacing for each record were measured using the video images. There are over 40,000 vehicles in the Georgia dataset. For the purpose of evaluation, these vehicles are categorized by number of axles, into 2, 3, 4, 5, 6, and 7 or more axle bins. In Tables 2.2.1 through 2.2.3, the number and percent of the total number of records shown, along with the number and percent of vehicles that are classified correctly and incorrectly by each classification method. The last column shows the percentage of errors weighted by the number of vehicles in that axle bin relative to the number of total records in the dataset. This shows the effect of the larger volume of 2-axle vehicles on overall classification accuracy. Table 2.2.1 is a breakdown of number of vehicles by number of axles, and how many of these were correctly or incorrectly identified using the Scheme F algorithm. The overall misclassification rate was 20.6 percent.

By comparison, the “best” decision tree produced by the statistical process had a misclassification rate of 18.5 percent (Table 2.2.2). It improved the classification rate for every axle category except 6-axle trucks, which had the same rate for both methods. The number of misclassifications for 2-axle vehicles decreased only minimally, but for 3-axle vehicles, the misclassifications dropped from 25.1 percent to 8.5 percent, and for 4-axle vehicles from 26.4 percent to 14.6 percent. Despite these large drops in the error rates for higher numbers of axles, the total error rate is similar because of the relatively larger number of 2-axle vehicles.

Table 2.2.1. Classification of Vehicles in the Georgia Database Using the Scheme F Algorithm

Number of Axles	Number of Observations	Percent of Total Observations	Number of Vehicles Classified Correctly	Percent of Vehicles Classified Correctly	Number of Vehicles Classified Incorrectly	Percent of Vehicles Classified Incorrectly	Weighted Errors
2	31,227	76.8%	23,533	75.4%	7,694	24.6%	18.9%
3	1,302	3.2%	975	74.9%	327	25.1%	0.8%
4	897	2.2%	660	73.6%	237	26.4%	0.6%
5	7,090	17.4%	7,017	99.0%	73	1.0%	0.2%
6	120	0.3%	115	95.8%	5	4.2%	0.0%
7 or More	22	0.1%	1	4.5%	21	95.5%	0.1%
Total/ Average	40,658	100.0%	32,301	79.4%	8,357	20.6%	20.6%

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 2.2.2. Classification of Vehicles in the Georgia Database Using the S-Plus Decision Tree: Best Tree

Number of Axles	Number of Observations	Percent of Total Observations	Number of Vehicles Classified Correctly	Percent of Vehicles Classified Correctly	Number of Vehicles Classified Incorrectly	Percent of Vehicles Classified Incorrectly	Weighted Errors
2	31,227	76.8%	23,992	76.8%	7,235	23.2%	17.8%
3	1,302	3.2%	1,191	91.5%	111	8.5%	0.3%
4	897	2.2%	766	85.4%	131	14.6%	0.3%
5	7,090	17.4%	7,063	99.6%	27	0.4%	0.1%
6	120	0.3%	115	95.8%	5	4.2%	0.0%
7 or More	22	0.1%	21	95.5%	1	4.5%	0.0%
Total/ Average	40,658	100.0%	33,148	81.5%	7,510	18.5%	18.5%

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 2.2.3. Classification of Vehicles in the Georgia Database Using the S-Plus Decision Tree: "Pruned" Tree

Number of Axles	Number of Observations	Percent of Total Observations	Number of Vehicles Classified Correctly	Percent of Vehicles Classified Correctly	Number of Vehicles Classified Incorrectly	Percent of Vehicles Classified Incorrectly	Weighted Errors
2	31,227	76.8%	23,943	76.7%	7,284	23.3%	17.9%
3	1,302	3.2%	1,172	90.0%	130	10.0%	0.3%
4	897	2.2%	739	82.4%	158	17.6%	0.4%
5	7,090	17.4%	7,058	99.5%	32	0.5%	0.1%
6	120	0.3%	115	95.8%	5	4.2%	0.0%
7 or More							
Total/ Average	40,636	99.9%	33,027	81.3%	7,609	18.7%	18.7%

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

The error rates in Table 2.2.3, for the pruned decision tree, are very close to those for the unpruned decision tree, the total error rate increasing only from 18.5 percent to 18.7 percent. In applying this process, a category for 7 or more axles was not incorporated. Since there are only 22 such vehicles in the dataset, this does not materially affect the overall results. In evaluating the effect of applying the pruning process to the first tree, it is readily apparent that the pruned tree is not significantly less effective or accurate as a classification mechanism, yet it has the benefit of making the algorithm more robust.

Comparing either of the Decision Trees to the Scheme F algorithm shows that Scheme F is very similar to these theoretically "best" algorithms that can be produced using the Georgia dataset. A direct comparison of the error rates for each method is in Table 2.2.4. Both decision trees perform better or equal to Scheme F in every axle category, but the differences are not very large. Based on this one dataset, it indicates that current axle-based vehicle classification algorithms cannot be greatly improved upon. It would also suggest that it may be worthwhile to consider some other method, or adjustments be made to the axle-based methods, of vehicle identification. The basic difficulty is that there is often tremendous overlap in the population for vehicle classification categories based on axle spacing distances. If other vehicle characteristics are considered, along with number of axles and axle spacing, it may serve to further delineate the vehicle classes. For example, adding total vehicle length, axle weights, total vehicle weight, and/or front or rear overhang to the algorithm may increase the ability to accurately classify a greater proportion of any vehicle population.

Table 2.2.4. Comparison of Error Rates for Different Classification Methods

Number of Axles	Scheme F Error Rates	"Best" Tree Error Rates	"Pruned" Tree Error Rates
2	24.6%	23.2%	23.3%
3	25.1%	8.5%	10.0%
4	26.4%	14.6%	17.6%
5	1.0%	0.4%	0.5%
6	4.2%	4.2%	4.2%
7 or More	95.5%	4.5%	
Total/Average	20.6%	18.5%	18.7%

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

2.3 2-Axle Vehicles

The use of proportional assignments of vehicles within each of the classification bins could also enhance the effectiveness of the current axle-based methods. The output of the S-Plus decision trees indicates where proportional re-assignments to different classes within existing bins, based upon additional distinctions in the axle spacing, could be made. The output of the original statistical procedure is reproduced in Table 2.3.1, the unpruned classification tree. For 2-axle vehicles, there are nine terminal nodes, in which the vehicles are assigned to four different classes, Classes 1, 2, 3 and 5. The misclassification error rate is 23.17 percent, and the residual mean deviance is 1.001.

Table 2.3.1. Classification Trees and Error Rates for All Available Spacing Variables: 2-Axle Vehicles

Number of terminal nodes: 9
Residual Mean Deviance: 1.001 = 31,260 / 31,220
Misclassification Error Rate: 0.2317 = 7,235 / 31,227

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)					
				Class 1	Class 2	Class 3	Class 4	Class 5	Class 7
1) Root	31,227	50,380.0	2	0.17	60.46	35.93	0.21	3.23	0.00
2) Axle 1-2 < 9.865	23,988	27,640.0	2	0.22	75.47	24.22	0.00	0.10	0.00
4) Axle 1-2 < 9.045	15,580	14,020.0	2	0.34	84.44	15.21	0.00	0.01	0.00
8) Axle 1-2 < 6.9	82	129.8	1	64.63	4.88	30.49	0.00	0.00	0.00
9) Axle 1-2 > 6.9	15,498	13,210.0	2	0.00	84.86	15.13	0.00	0.01	0.00
18) Axle 1-2 < 8.405	6,054	3,757.0	2	0.00	90.72	9.27	0.00	0.02	0.00
36) Axle 1-2 < 7.565	345	422.3	2	0.00	69.86	30.14	0.00	0.00	0.00
37) Axle 1-2 > 7.565	5,709	3,203.0	2	0.00	91.98	8.01	0.00	0.02	0.00
19) Axle 1-2 > 8.405	9,444	9,174.0	2	0.00	81.10	18.89	0.00	0.01	0.00
5) Axle 1-2 > 9.045	8,408	11,650.0	2	0.00	58.85	40.90	0.00	0.25	0.00
3) Axle 1-2 > 9.865	7,239	11,180.0	3	0.00	10.75	74.75	0.90	13.59	0.01
6) Axle 1-2 < 12.105	5,949	6,065.0	3	0.00	13.08	84.25	0.05	2.62	0.00
12) Axle 1-2 < 10.455	2,515	3,179.0	3	0.00	27.91	71.41	0.04	0.64	0.00
13) Axle 1-2 > 10.455	3,434	1,927.0	3	0.00	2.21	93.65	0.06	4.08	0.00
7) Axle 1-2 > 12.105	1,290	2,061.0	5	0.00	0.00	30.93	4.81	64.19	0.08
14) Axle 1-2 < 17.285	839	1,247.0	5	0.00	0.00	47.56	0.83	51.49	0.12
15) Axle 1-2 > 17.285	451	334.5	5	0.00	0.00	0.00	12.20	87.80	0.00

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

The first column of Table 2.3.1 shows the axle spacing criteria for each split or each branch of the tree, along with the procedural number that the statistical program assigned to the splits. The second column is the number of vehicles assigned to that branch. For example, the first row, called the “root”, contains the total number of record being considered, which is the 31,227 vehicles that have only two axles. The second row is the next split, number 2, which is the first axle spacing based designation, all vehicles with a distance less than 9.865 feet between the two axles. There are, according to the second column, 23,988 vehicles in this category. The first column, the splits, are indented to show where the sub-categorizations exist, so the second row is indented two spaces from the root. To find the “leftover” vehicles from the first axle-spacing split, find the row that is indented to a degree parallel to node 2, and that is assigned the next highest value numerically. That is node 3, which consists of all vehicles with a distance between the two axles greater than 9.865 feet. All other splits are subcategories of these first three nodes. This is represented diagrammatically, in flow chart form, in Figure 2.3.1. The third column of Table 2.3.1 is the deviance related to each split, and the fourth column is the class that is assigned to each node based on the probability associated with a vehicle falling into each of the classes based on all the axle spacing criteria for each row. Those probabilities are shown in the remaining columns to the right. The class each node is determined by the location of the highest probability in the population (number of vehicles assigned) in that row. Although each node in Table 2.3.1 is assigned a class, in practice only the terminal nodes relegate the vehicles to a class, after the criteria in that row as well as all relevant preceding criteria have been met. These terminal node class assignments can be easily identified in the Figure 2.3.1 flowchart as the nine diamond-shaped, shaded nodes.

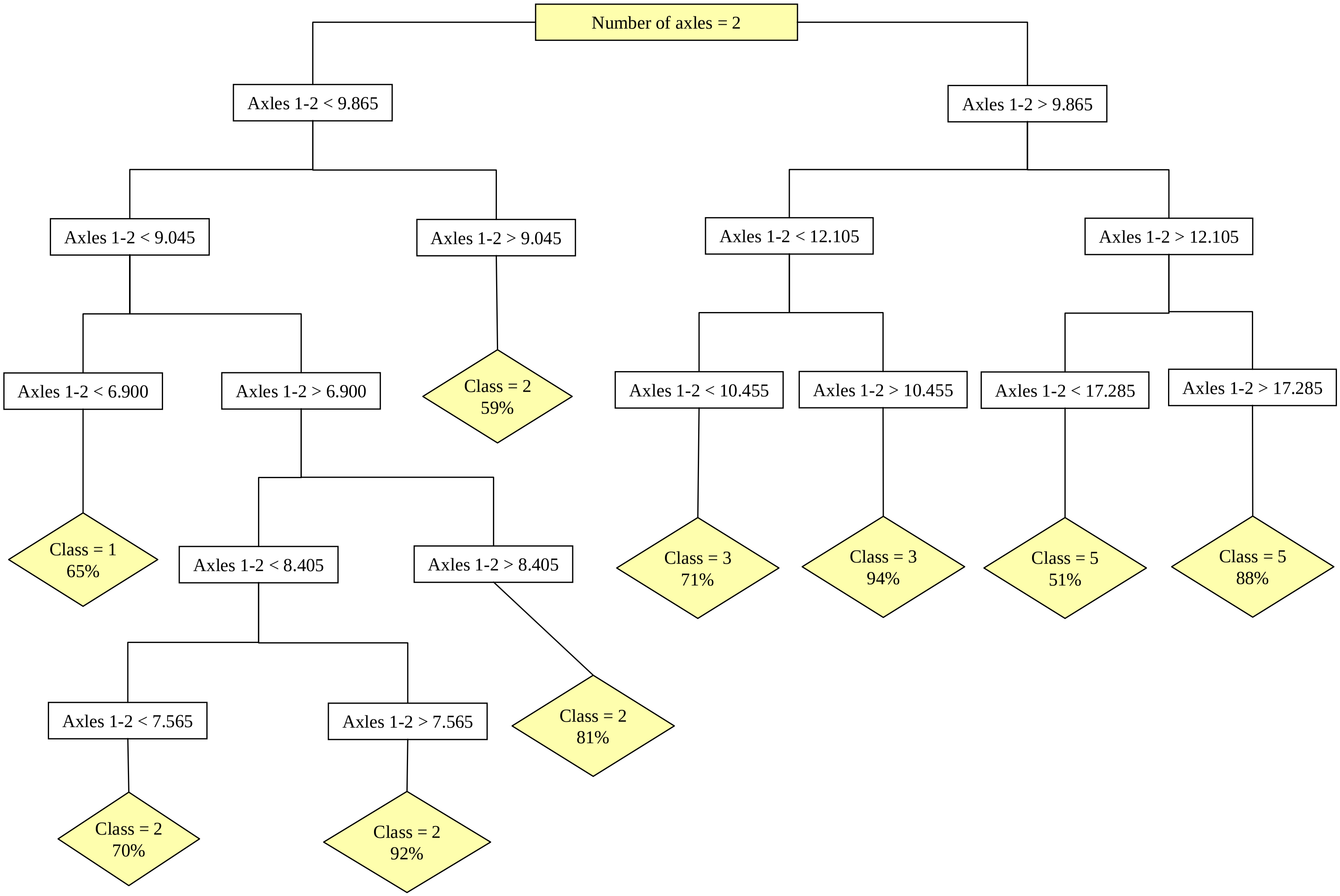

Figure 2.3.1. Classification Tree for 2-Axle Vehicles: All Available Axle Spacing Variables (in feet)

The flowchart also makes it apparent that there are redundancies in the tree produced by the statistical program. Although upon first consideration these redundancies may seem irrelevant, the occurrence of additional “extra” branches on the tree can be used to increase the accuracy of class assignments if a probabilistic assignment to classes is used, which is a method that would be easy to apply with the information provided by this statistical program. With such a method, as many or as few axle spacing criteria could be used as desired, with additional nodes increasing the accuracy of the distributions. For example, at node 2 in Table 2.3.1, 75.47 percent of the 27,640 vehicles would be correctly identified as Class 2, with the remaining 24.53 percent misclassified as Class 2. At node 37, however, 91.98 percent of the 3,203 vehicles are correctly identified as Class 2, leaving a much lower misclassification rate of only 8.2 percent.

The complication of a probabilistic assignment is that accuracy is very contingent upon the similarity of the testing data to the actual population upon which the resultant criteria and probabilities are applied. This would indicate the benefits, if not the need, for periodic collection of ground truth testing data from the actual or similar sites at which this method would be utilized for classification purposes. Even without that step, however, using a probabilistic approach with an algorithm and probabilities has tremendous potential to increase classification accuracy, particularly if based on as many relevant sources of data as possible.

Pruning the classification tree for 2-axle vehicles reduces the number of terminal nodes from nine to five, nearly half the number by eliminating two terminal nodes for Class 2, one for Class 5, and the Class 1 terminal node. The misclassification error rate, however, increases only 0.16 percent, from 23.17 percent to 23.33 percent (Table 2.3.2). The reduction in the number of nodes and branches, and the overall simplification of the algorithm for 2-axle vehicles becomes very apparent when comparing Figure 2.3.1 to Figure 2.3.2. However, there are still redundancies in the process. These classification redundancies are removed in Table 2.3.3 and the corresponding flow chart, in Figure 2.3.3. In the process, the number of terminal nodes are reduced to three, one each for Classes 2, 3, and 5. The flow charts include a percentage in each diamond-shaped terminal node, which represents the accuracy of the preceding criteria for each terminal node in predicting the assigned class.

Table 2.3.2. Pruned Classification Trees and Error Rates: 2-Axle Vehicles

Number of terminal nodes: 5
Residual Mean Deviance: 1.051 = 32,830/31,220
Misclassification Error Rate: 0.2333 = 7,284/31,227

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)					
				Class 1	Class 2	Class 3	Class 4	Class 5	Class 7
1) Root	31,227	50,380.0	2	0.17	60.46	35.93	0.21	3.23	0.00
2) Axle 1-2 < 9.865	23,988	27,640.0	2	0.22	75.47	24.22	0.00	0.10	0.00
4) Axle 1-2 < 9.045	15,580	14,020.0	2	0.34	84.44	15.21	0.00	0.01	0.00
5) Axle 1-2 > 9.045	8,408	11,650.0	2	0.00	58.85	40.90	0.00	0.25	0.00
3) Axle 1-2 > 9.865	7,239	11,180.0	3	0.00	10.75	74.75	0.90	13.59	0.01
6) Axle 1-2 < 12.105	5,949	6,065.0	3	0.00	13.08	84.25	0.05	2.62	0.00
12) Axle 1-2 < 10.455	2,515	3,179.0	3	0.00	27.91	71.41	0.04	0.64	0.00
13) Axle 1-2 > 10.455	3,434	1,927.0	3	0.00	2.21	93.65	0.06	4.08	0.00
7) Axle 1-2 > 12.105	1,290	2,061.0	5	0.00	0.00	30.93	4.81	64.19	0.08

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 2.3.3. Classification Trees will All Redundancies Removed: 2-Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)					
				Class 1	Class 2	Class 3	Class 4	Class 5	Class 7
1) Root	31,227	50,380.0	2	0.17	60.46	35.93	0.21	3.23	0.00
2) Axle 1-2 < 9.865	23,988	27,640.0	2	0.22	75.47	24.22	0.00	0.10	0.00
3) Axle 1-2 > 9.865	7,239	11,180.0	3	0.00	10.75	74.75	0.90	13.59	0.01
7) Axle 1-2 > 12.105	1,290	2,061.0	5	0.00	0.00	30.93	4.81	64.19	0.08

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

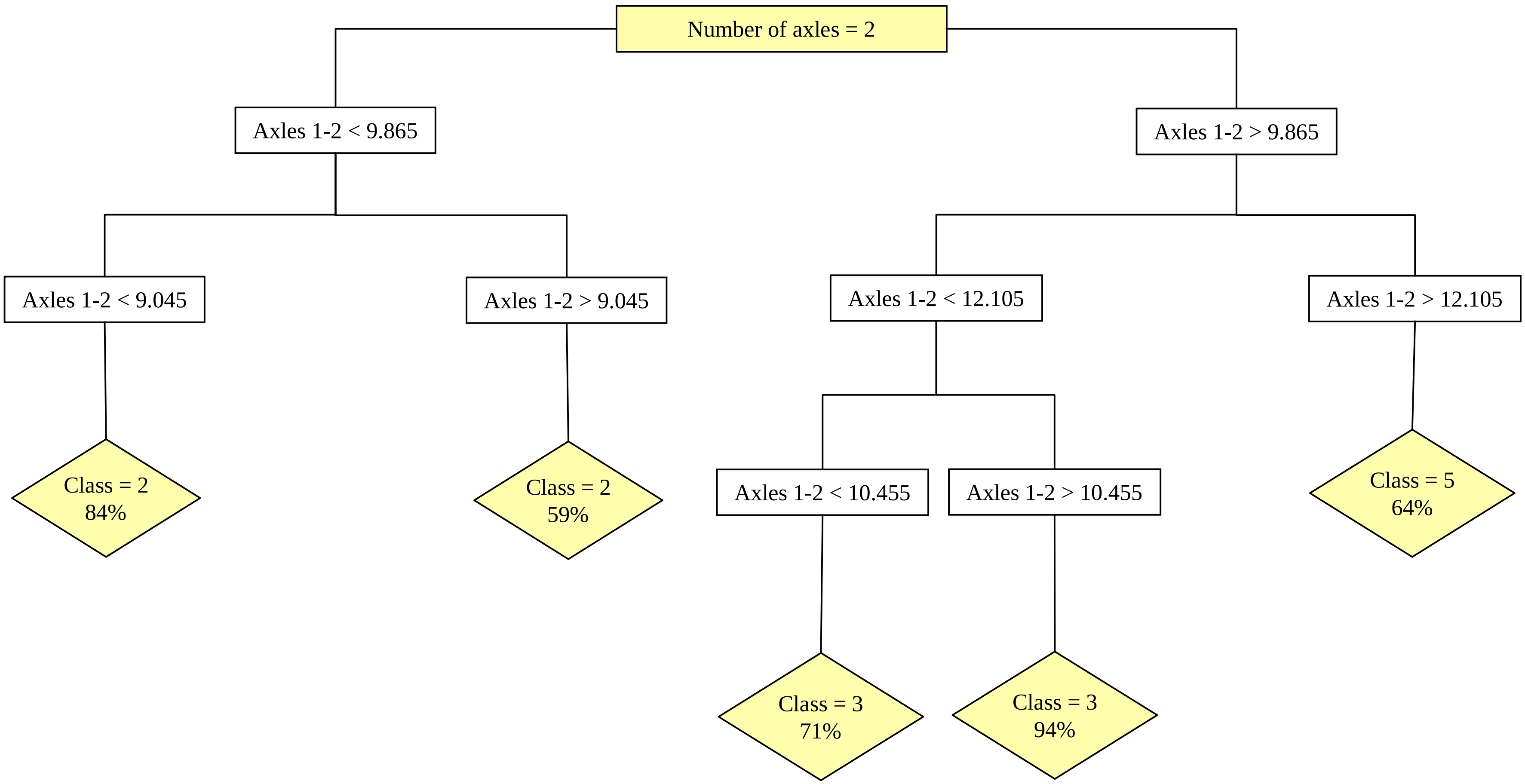

Figure 2.3.2 Pruned Classification Tree for 2-Axle Vehicles (axle spacing in feet).

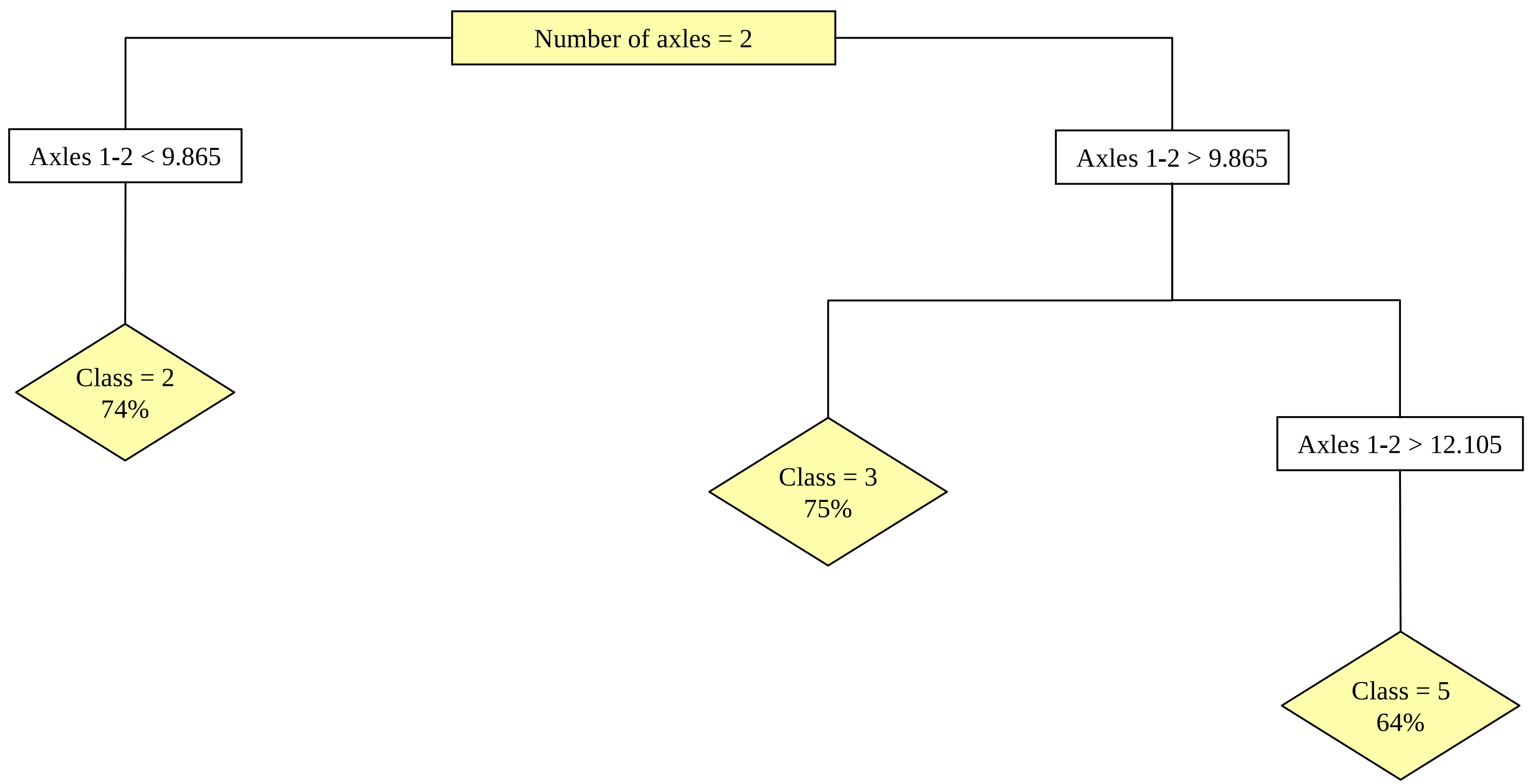

Figure 2.3.3 Classification Tree for 2-Axle Vehicles: All Redundancies Removed (axle spacing in feet).

2.4 3-Axle Vehicles

The original tree for 3-axle vehicles, like the one for 2-axle vehicles, also contains nine terminal nodes. Classes 3, 4, 5, 6 and 8 are assigned, although there are also probabilities assigned to Classes 1 and 2. The misclassification error rate is 8.53 percent, a great improvement over the performance of Scheme F for 3-axle vehicles. The algorithm produced by the statistical procedure considers the distance between axles 2 and 3 first in the hierarchy, as shown in the flowchart (Figure 2.4.1). It later also looks at the distance between axles 1 and 2 in determining the appropriate class. The pruning process reduces the number of terminal nodes to five. It also reduced the total number of different levels in the decision tree process from six to five (Figure 2.4.2), and the total number of nodes from 26 to 14, thereby simplifying the process considerably. The misclassification error rate, however, increases only 1.46 percent, from 8.53 percent to 9.99 percent. Removing the single redundancy of two terminal nodes assigning Class 3 decreases the number of levels in the tree another level, from five to four (Figure 2.4.3), with those four terminal nodes assigning, respectively, Classes 6 (with 100 percent accuracy), Class 4, Class 3, and Class 8. The results of the analysis are summarized in Tables 2.4.1 through 2.4.3.

Table 2.4.1. Classification Trees and Error Rates for All Available Spacing Variables: 3-Axle Vehicles

Number of terminal nodes: 9
Residual Mean Deviance: 0.4631 = 598.7/1,293
Misclassification Error Rate: 0.08525 = 111/1,302

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)						
				Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 8
1) Root	1,302	3,254.0	6	0.08	3.30	28.49	4.46	1.84	52.38	9.45
2) Axles 2-3 < 5.795	741	432.0	6	0.00	0.00	0.14	7.69	0.00	92.04	0.14
4) Axles 1-2 < 18.75	649	15.0	6	0.00	0.00	0.15	0.00	0.00	99.85	0.00
5) Axles 1-2 > 18.75	92	131.3	4	0.00	0.00	0.00	61.96	0.00	36.96	1.09
10) Axles 1-2 < 22.415	49	72.2	6	0.00	0.00	0.00	34.69	0.00	63.27	2.04
11) Axles 1-2 > 22.415	43	21.8	4	0.00	0.00	0.00	93.02	0.00	6.98	0.00
3) Axles 2-3 > 5.795	561	1,078.0	3	0.18	7.67	65.95	0.18	4.28	0.00	21.75
6) Axles 2-3 < 20.895	422	516.7	3	0.24	9.95	83.65	0.24	4.03	0.00	1.90
12) Axles 1-2 < 10.96	326	287.6	3	0.31	12.88	86.20	0.00	0.00	0.00	0.61
24) Axles 1-2 < 9.53	175	192.4	3	0.57	21.14	78.29	0.00	0.00	0.00	0.00
25) Axles 1-2 > 9.53	151	65.1	3	0.00	3.31	95.36	0.00	0.00	0.00	1.33
13) Axles 1-2 > 10.96	96	142.7	3	0.00	0.00	75.00	1.04	17.71	0.00	6.25
7) Axles 2-3 > 20.895	139	168.4	8	0.00	0.72	12.23	0.00	5.04	0.00	82.01
14) Axles 1-2 < 14.49	128	111.7	8	0.00	0.78	13.28	0.00	0.00	0.00	85.94
28) Axles 1-2 < 10.88	25	41.5	3	0.00	4.00	52.00	0.00	0.00	0.00	44.00
29) Axles 1-2 > 10.88	103	33.8	8	0.00	0.00	3.88	0.00	0.00	0.00	96.12
15) Axles 1-2 > 14.49	11	14.4	5	0.00	0.00	0.00	0.00	63.64	0.00	36.36

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 2.4.2. Pruned Classification Trees and Error Rates: 3-Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)						
				Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 8
1) Root	1,302	3,254.0	6	0.08	3.30	28.49	4.46	1.84	52.38	9.45
2) Axles 2-3 < 5.795	741	432.0	6	0.00	0.00	0.14	7.69	0.00	92.04	0.14
4) Axles 1-2 < 18.75	649	15.0	6	0.00	0.00	0.15	0.00	0.00	99.85	0.00
5) Axles 1-2 > 18.75	92	131.3	4	0.00	0.00	0.00	61.96	0.00	36.96	1.09
3) Axles 2-3 > 5.795	561	1,078.0	3	0.18	7.67	65.95	0.18	4.28	0.00	21.75
6) Axles 2-3 < 20.895	422	516.7	3	0.24	9.95	83.65	0.24	4.03	0.00	1.90
12) Axles 1-2 < 10.96	326	287.6	3	0.31	12.88	86.20	0.00	0.00	0.00	0.61
13) Axles 1-2 > 10.96	96	142.7	3	0.00	0.00	75.00	1.04	17.71	0.00	6.25
7) Axles 2-3 > 20.895	139	168.4	8	0.00	0.72	12.23	0.00	5.04	0.00	82.01

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 2.4.3 Classification Trees with All Redundancies Removed: 3-Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)						
				Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 8
1) Root	1,302	3,254.0	6	0.08	3.30	28.49	4.46	1.84	52.38	9.45
2) Axles 2-3 < 5.795	741	432.0	6	0.00	0.00	0.14	7.69	0.00	92.04	0.14
4) Axles 1-2 < 18.75	649	15.0	6	0.00	0.00	0.15	0.00	0.00	99.85	0.00
5) Axles 1-2 > 18.75	92	131.3	4	0.00	0.00	0.00	61.96	0.00	36.96	1.09
3) Axles 2-3 > 5.795	561	1,078.0	3	0.18	7.67	65.95	0.18	4.28	0.00	21.75
7) Axles 2-3 > 20.895	139	168.4	8	0.00	0.72	12.23	0.00	5.04	0.00	82.01

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Figure 2.4.1. Classification Tree for 3-Axle Vehicles: All Available Axle Spacing Variables (in feet).

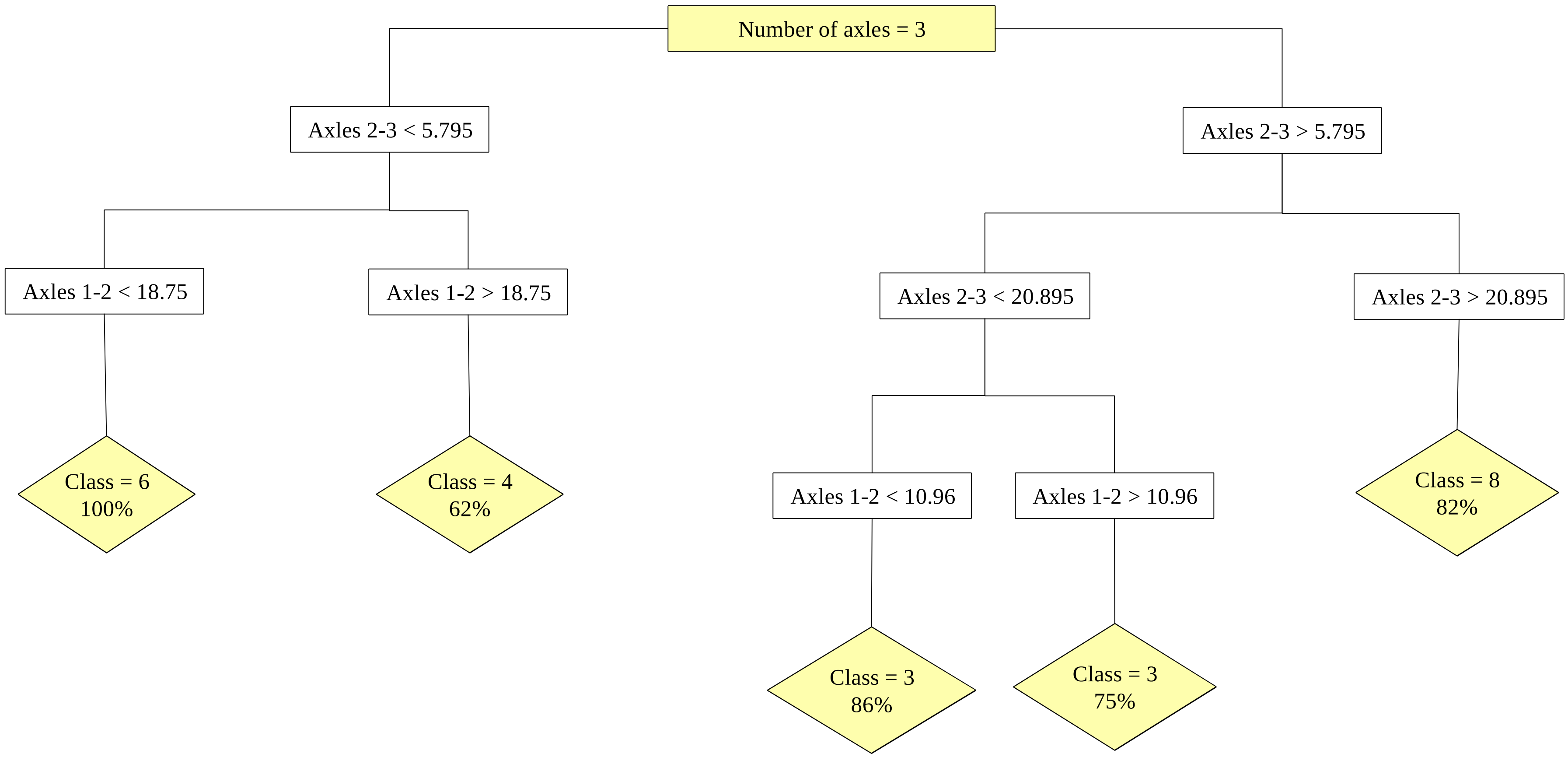

Figure 2.4.2 Pruned Classification Tree for 3-Axle Vehicles (axle spacing in feet).

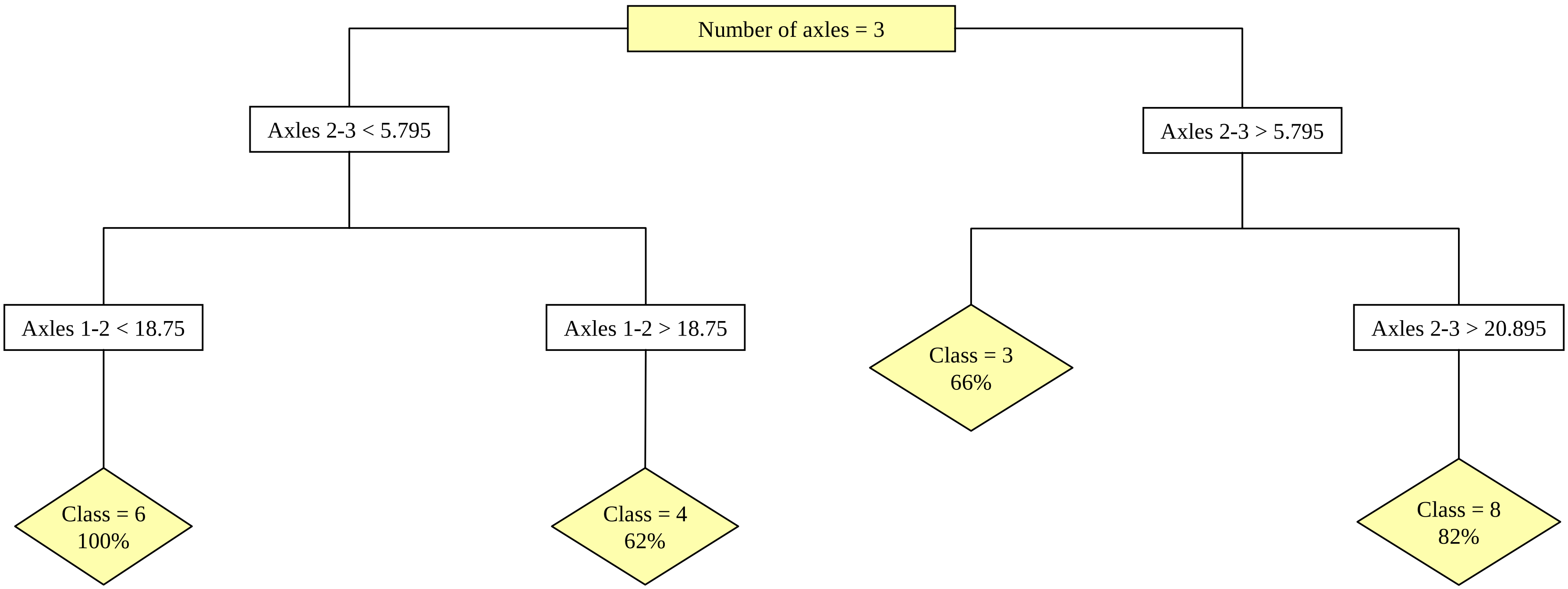

Figure 2.4.3 Classification Tree for 3-Axle Vehicles: All Redundancies Removed (axle spacing in feet).

2.5 4-Axle Vehicles

The tree produced for 4-axle vehicles also considers the distance from axle 2 to axle 3 first, followed in both of the resultant branches by a comparison of the axle 3 to 4 spacing. The distance between axles 1 and 2 is also considered in part of the tree. The classes assigned are Classes 3, 5, and 8, with Classes 2, 4, 6, 7, and 11 also being assigned probabilities. The misclassification rate is higher than that for 3-axle vehicles, but still much lower than the rate for 2-axle vehicles.

The number of terminal nodes is again nine with the original tree (Table 2.5.1 and Figure 2.5.1), and reduced to five with the pruned tree. The error rate increases 3.01 percent in the pruning process, from 14.6 percent to 17.6 percent. Since there are no redundancies in the criteria that lead to the same class assignments in a final split, the tables and flow charts of 4-axle vehicles for the pruned tree (Table 2.5.2 and Figure 2.5.2) and the tree containing no redundancies (Table 2.5.3 and Figure 2.5.3) are identical.

Table 2.5.1. Classification Trees and Error Rates for All Available Spacing Variables: 4-Axle Vehicles

Number of terminal nodes: 9
Residual Mean Deviance: 0.7169 = 636.6/888
Misclassification Error Rate: 0.146 = 131/897

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent) Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 11
1) Root	897	1,927.0	8	1.56	31.88	0.11	11.04	0.45	0.33	54.29	0.33
2) Axle 2-3 < 24.715	470	1,067.0	3	2.98	60.00	0.21	19.15	0.85	0.64	15.53	0.64
4) Axle 3-4 < 12.55	424	829.3	3	3.30	66.51	0.00	21.23	0.00	0.71	7.55	0.71
8) Axle 1-2 < 11.355	255	372.9	3	5.49	80.78	0.00	6.67	0.00	1.18	5.88	0.00
16) Axle 2-3 < 22.09	229	267.9	3	6.11	84.72	0.00	7.42	0.00	1.31	0.44	0.00
17) Axle 2-3 > 22.09	26	35.9	8	0.00	46.15	0.00	0.00	0.00	0.00	53.85	0.00
9) Axle 1-2 > 11.355	169	346.3	3	0.00	44.97	0.00	43.20	0.00	0.00	10.06	1.78
18) Axle 3-4 < 3.695	100	148.4	5	0.00	48.00	0.00	51.00	0.00	0.00	1.00	0.00
19) Axle 3-4 > 3.695	69	166.4	3	0.00	40.58	0.00	31.88	0.00	0.00	23.19	4.35
38) Axle 3-4 < 7.68	28	45.1	8	0.00	3.57	0.00	39.29	0.00	0.00	57.14	0.00
39) Axle 3-4 > 7.68	41	67.2	3	0.00	65.85	0.00	26.83	0.00	0.00	0.00	7.32
5) Axle 3-4 > 12.55	46	36.6	8	0.00	0.00	2.17	0.00	8.70	0.00	89.13	0.00
3) Axle 2-3 > 24.715	427	132.4	8	0.00	0.94	0.00	2.11	0.00	0.00	96.96	0.00
6) Axle 3-4 < 3.795	35	54.0	8	0.00	5.74	0.00	25.71	0.00	0.00	68.57	0.00
12) Axle 2-3 < 29.11	11	10.4	5	0.00	18.18	0.00	81.82	0.00	0.00	0.00	0.00
13) Axle 2-3 > 29.11	24	--	8	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
7) Axle 3-4 > 3.795	392	25.1	8	0.00	0.51	0.00	0.00	0.00	0.00	99.49	0.00

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 2.5.2. Pruned Classification Trees and Error Rates: 4-Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent) Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 11
1) Root	897	1,927.0	8	1.56	31.88	0.11	11.04	0.45	0.33	54.29	0.33
2) Axle 2-3 < 24.715	470	1,067.0	3	2.98	60.00	0.21	19.15	0.85	0.64	15.53	0.64
4) Axle 3-4 < 12.55	424	829.3	3	3.30	66.51	0.00	21.23	0.00	0.71	7.55	0.71
8) Axle 1-2 < 11.355	255	372.9	3	5.49	80.78	0.00	6.67	0.00	1.18	5.88	0.00
16) Axle 2-3 < 22.09	229	267.9	3	6.11	84.72	0.00	7.42	0.00	1.31	0.44	0.00
17) Axle 2-3 > 22.09	26	35.9	8	0.00	46.15	0.00	0.00	0.00	0.00	53.85	0.00
9) Axle 1-2 > 11.355	169	346.3	3	0.00	44.97	0.00	43.20	0.00	0.00	10.06	1.78
5) Axle 3-4 > 12.55	46	36.6	8	0.00	0.00	2.17	0.00	8.70	0.00	89.13	0.00
3) Axle 2-3 > 24.715	427	132.4	8	0.00	0.94	0.00	2.11	0.00	0.00	96.96	0.00

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 2.5.3. Classification Trees with all Redundancies Removed: 4-Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent) Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 11
1) Root	897	1,927.0	8	1.56	31.88	0.11	11.04	0.45	0.33	54.29	0.33
2) Axle 2-3 < 24.715	470	1,067.0	3	2.98	60.00	0.21	19.15	0.85	0.64	15.53	0.64
4) Axle 3-4 < 12.55	424	829.3	3	3.30	66.51	0.00	21.23	0.00	0.71	7.55	0.71
8) Axle 1-2 < 11.355	255	372.9	3	5.49	80.78	0.00	6.67	0.00	1.18	5.88	0.00
16) Axle 2-3 < 22.09	229	267.9	3	6.11	84.72	0.00	7.42	0.00	1.31	0.44	0.00
17) Axle 2-3 > 22.09	26	35.9	8	0.00	46.15	0.00	0.00	0.00	0.00	53.85	0.00
9) Axle 1-2 > 11.355	169	346.3	3	0.00	44.97	0.00	43.20	0.00	0.00	10.06	1.78
5) Axle 3-4 > 12.55	46	36.6	8	0.00	0.00	2.17	0.00	8.70	0.00	89.13	0.00
3) Axle 2-3 > 24.715	427	132.4	8	0.00	0.94	0.00	2.11	0.00	0.00	96.96	0.00

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

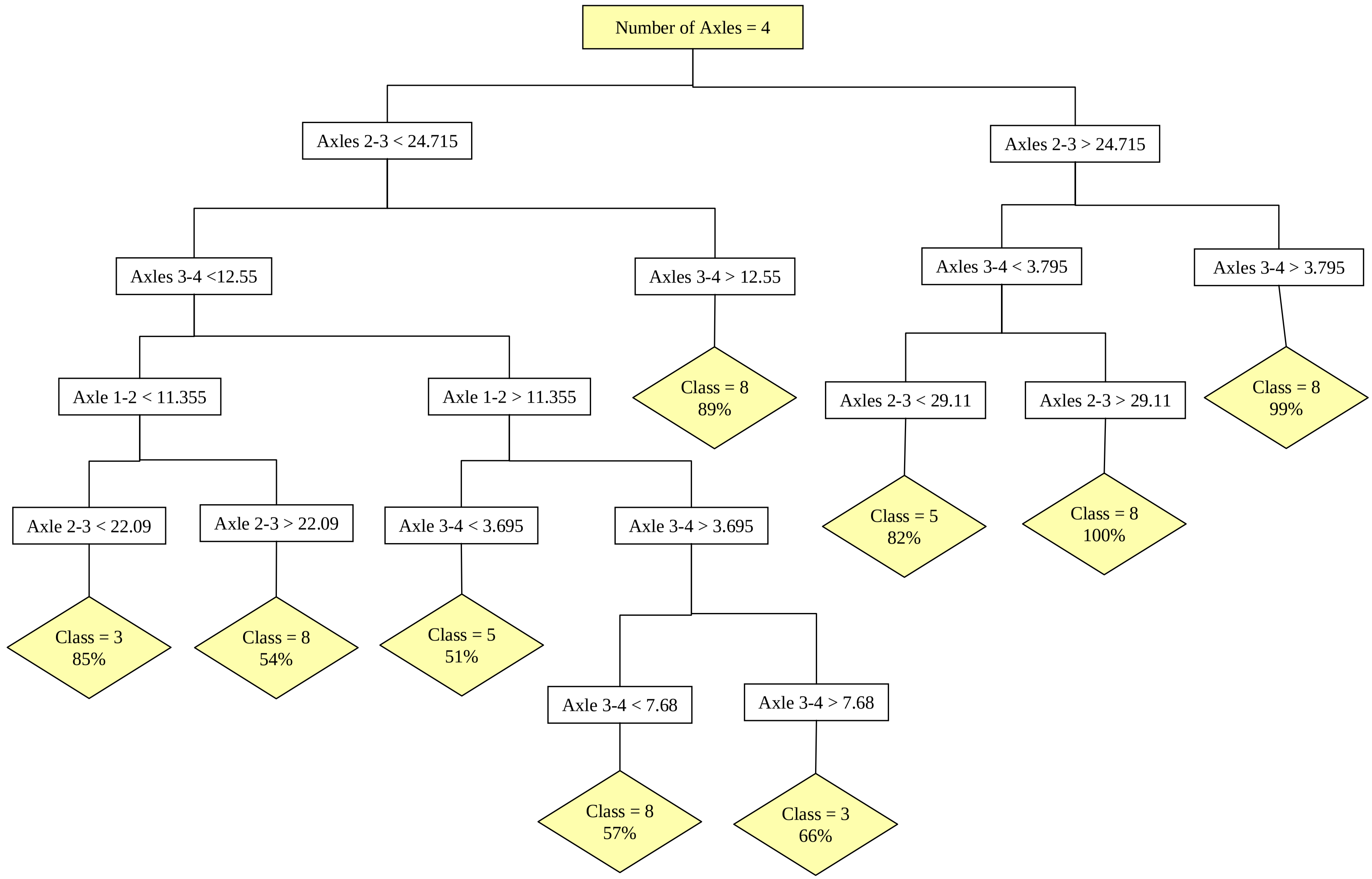

Figure 2.5.1. Classification Tree for 4-Axle Vehicles: All Available Axle Spacing Variables (in feet).

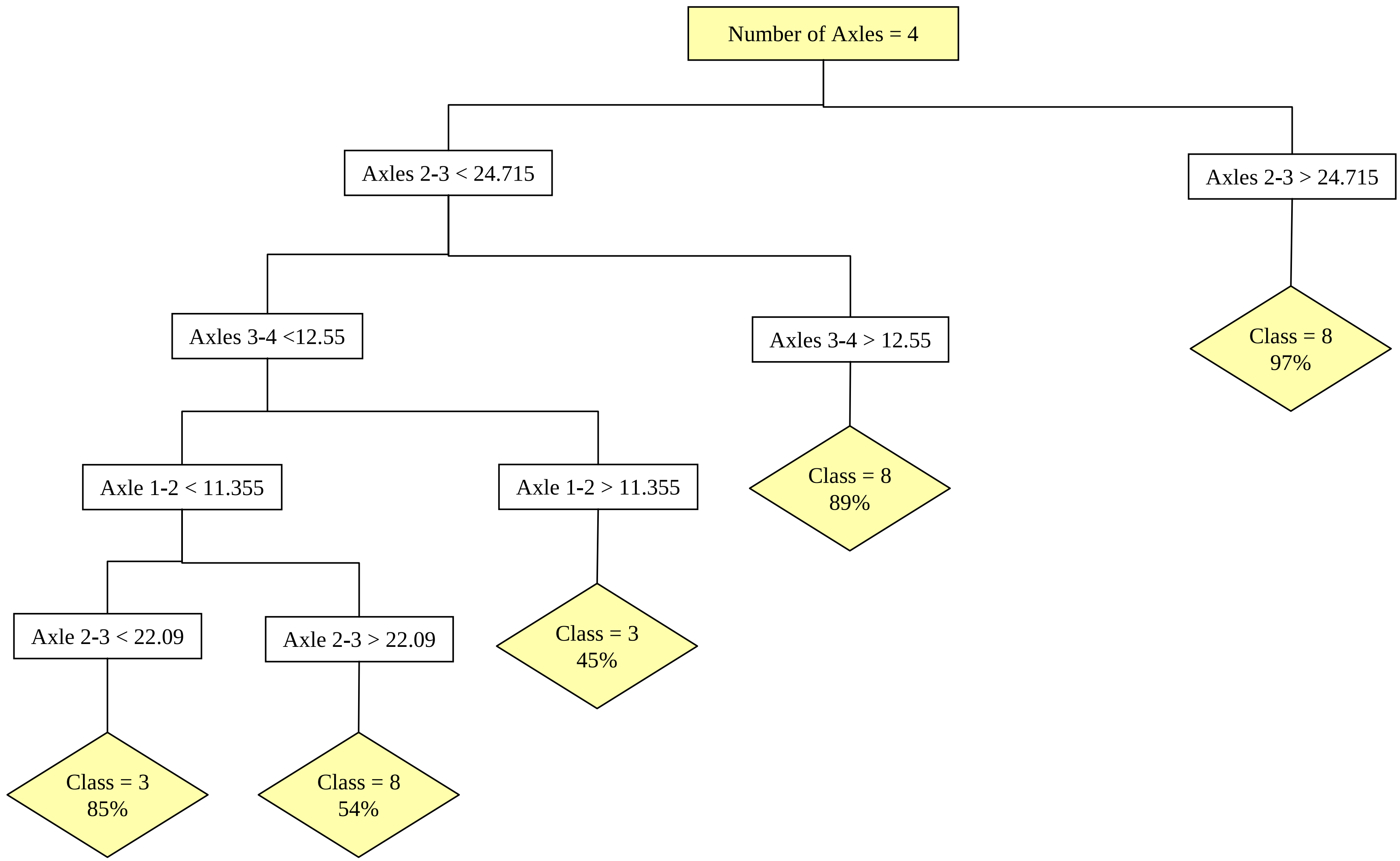

Figure 2.5.2 Pruned Classification Tree for 4-Axle Vehicles (axle spacing in feet).

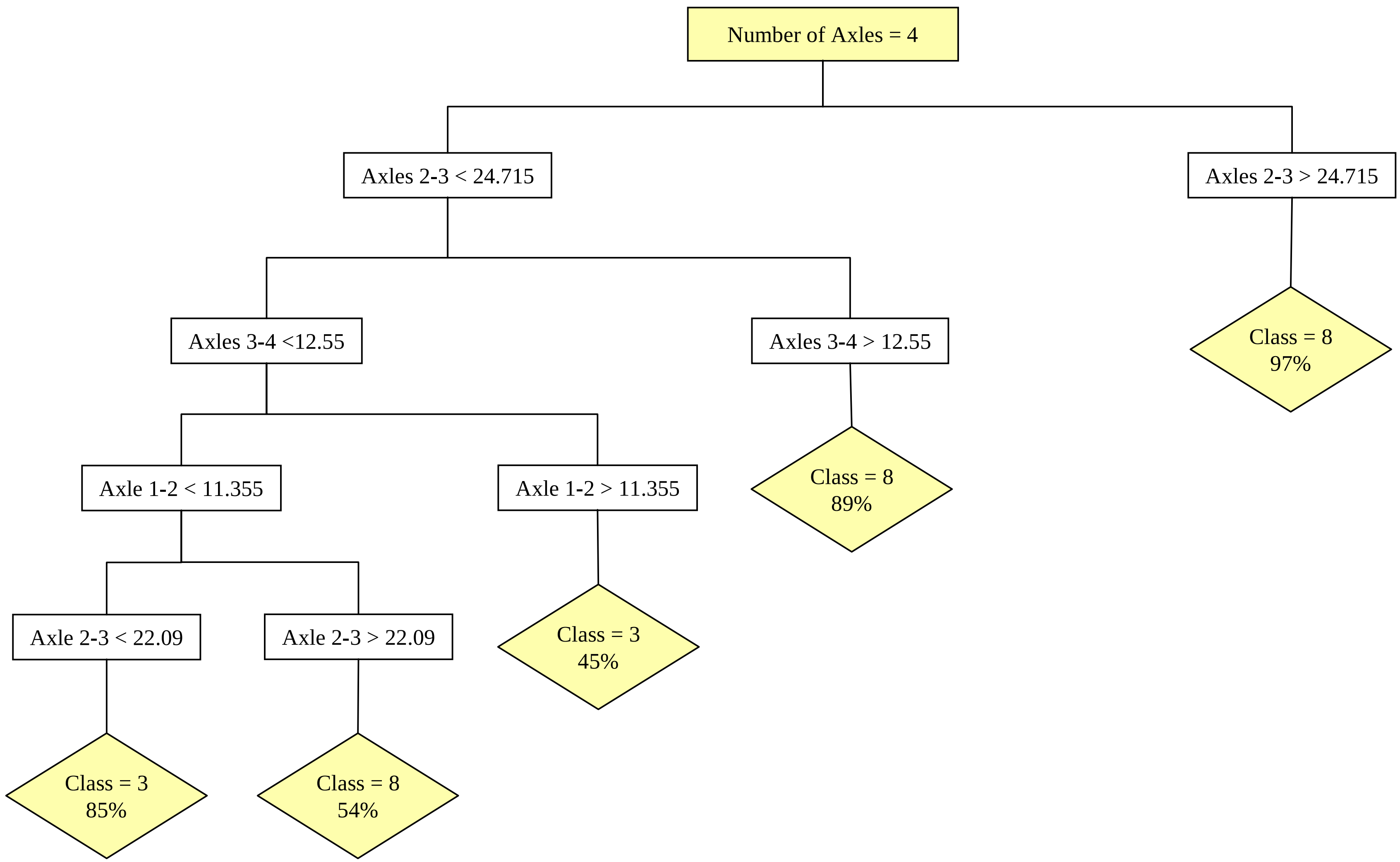

Figure 2.5.3 Classification Tree for 4-Axle Vehicles: All Redundancies Removed (axle spacing in feet).

2.6 5-Axle Vehicles

For 5-axle vehicles, Figure 2.6.1 and Table 2.6.1 show that there are eight terminal nodes for the original tree, and an error rate of 3.8 percent. Four different classes are assigned, Classes 5, 6, 9, and 11. Classes 3 and 4 are also assigned probabilities. As with 4-axle vehicles, the distance between axles 2 and 3 is considered first in the hierarchy, followed by the axle 3 to 4 spacing. The spacing between axles 1 to 2 and axles 4 to 5 are also considered in part of the tree. Reducing the number of terminal nodes to five (Figure 2.6.2 and Table 2.6.2) increases the error rate only 0.7 percent, from 3.81 percent to 4.51 percent. There are again no redundancies in class assignments at any final splits in the pruned tree (Figure 2.6.3 and Table 2.6.3).

Table 2.6.1. Classification Trees and Error Rates for All Available Spacing Variables: 5-Axle Vehicles

Number of terminal nodes: 8
Residual Mean Deviance: 0.03379 = 239.3/7,082
Misclassification Error Rate: 0.003808 = 27/7,090

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)					
				Class 3	Class 4	Class 5	Class 6	Class 9	Class 11
1) Root	7090	2,557.0	9	0.11	0.01	0.32	0.34	96.46	2.75
2) Axle 2-3 < 9.865	6,849	358.6	9	0.00	0.01	0.00	0.35	99.62	0.01
4) Axle 3-4 < 23.28	126	114.8	9	0.00	0.79	0.00	11.90	86.51	0.79
8) Axle 4-5 < 6.115	116	69.6	9	0.00	0.86	0.00	6.90	92.24	0.00
16) Axle 4-5 < 3.56	6	5.4	6	0.00	16.67	0.00	83.33	0.00	0.00
17) Axle 4-5 > 3.56	110	27.5	9	0.00	0.00	0.00	2.73	97.27	0.00
9) Axle 4-5 > 6.115	10	16.0	6	0.00	0.00	0.00	70.00	20.00	10.00
5) Axle 3-4 > 23.28	6,723	137.1	9	0.00	0.00	0.00	0.13	99.87	0.00
10) Axle 1-2 < 13.775	3,528	--	9	0.00	0.00	0.00	0.00	100.00	0.00
11) Axle 1-2 > 13.775	3,195	123.7	9	0.00	0.00	0.00	0.28	99.72	0.00
3) Axle 2-3 > 9.865	241	333.5	11	3.32	0.00	9.54	0.00	6.64	80.50
6) Axle 3-4 < 6.58	45	91.2	5	17.78	0.00	51.11	0.00	31.11	0.00
12) Axle 2-3 < 31.705	32	44.3	5	25.00	0.00	71.88	0.00	3.13	0.00
13) Axle 2-3 > 31.705	13	--	9	0.00	0.00	0.00	0.00	100.00	0.00
7) Axle 3-4 > 6.58	196	22.3	11	0.00	0.00	0.00	0.00	1.02	98.98

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 2.6.2. Pruned Classification Trees and Error Rates: 5-Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)					
				Class 3	Class 4	Class 5	Class 6	Class 9	Class 11
1) Root	7090	2,557.0	9	0.11	0.01	0.32	0.34	96.46	2.75
2) Axle 2-3 < 9.865	6,849	358.6	9	0.00	0.01	0.00	0.35	99.62	0.01
4) Axle 3-4 < 23.28	126	114.8	9	0.00	0.79	0.00	11.90	86.51	0.79
5) Axle 3-4 > 23.28	6,723	137.1	9	0.00	0.00	0.00	0.13	99.87	0.00
3) Axle 2-3 > 9.865	241	333.5	11	3.32	0.00	9.54	0.00	6.64	80.50
6) Axle 3-4 < 6.58	45	91.2	5	17.78	0.00	51.11	0.00	31.11	0.00
12) Axle 2-3 < 31.705	32	44.3	5	25.00	0.00	71.88	0.00	3.13	0.00
13) Axle 2-3 > 31.705	13	--	9	0.00	0.00	0.00	0.00	100.00	0.00
7) Axle 3-4 > 6.58	196	22.3	11	0.00	0.00	0.00	0.00	1.02	98.98

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 2.6.3. Classification Trees with All Redundancies Removed: 5-Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)					
				Class 3	Class 4	Class 5	Class 6	Class 9	Class 11
1) Root	7090	2,557.0	9	0.11	0.01	0.32	0.34	96.46	2.75
2) Axle 2-3 < 9.865	6,849	358.6	9	0.00	0.01	0.00	0.35	99.62	0.01
4) Axle 3-4 < 23.28	126	114.8	9	0.00	0.79	0.00	11.90	86.51	0.79
5) Axle 3-4 > 23.28	6,723	137.1	9	0.00	0.00	0.00	0.13	99.87	0.00
3) Axle 2-3 > 9.865	241	333.5	11	3.32	0.00	9.54	0.00	6.64	80.50
6) Axle 3-4 < 6.58	45	91.2	5	17.78	0.00	51.11	0.00	31.11	0.00
12) Axle 2-3 < 31.705	32	44.3	5	25.00	0.00	71.88	0.00	3.13	0.00
13) Axle 2-3 > 31.705	13	--	9	0.00	0.00	0.00	0.00	100.00	0.00
7) Axle 3-4 > 6.58	196	22.3	11	0.00	0.00	0.00	0.00	1.02	98.98

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

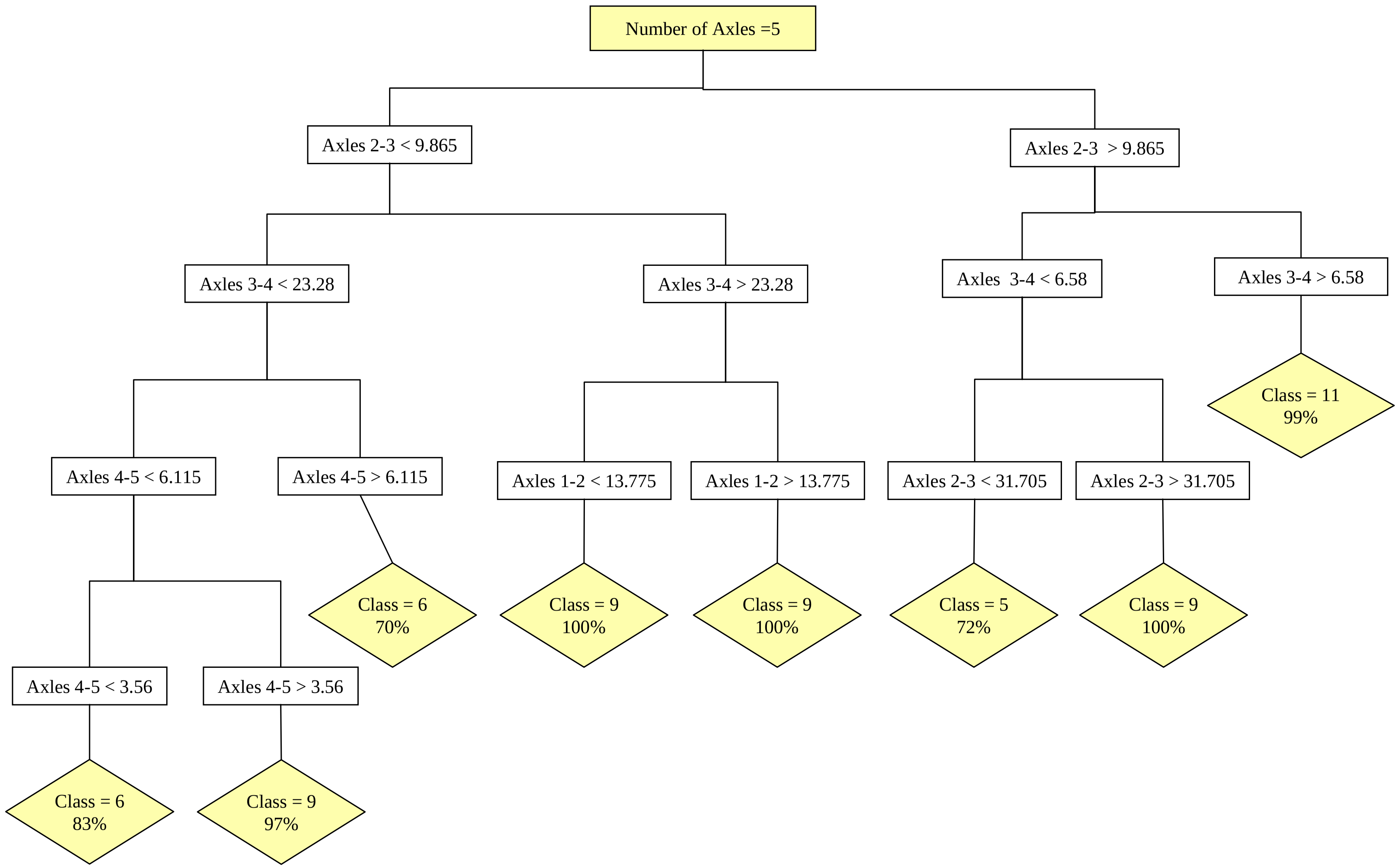

Figure 2.6.1. Classification Tree for 5-Axle Vehicles: All Available Axle Spacing Variables (in feet).

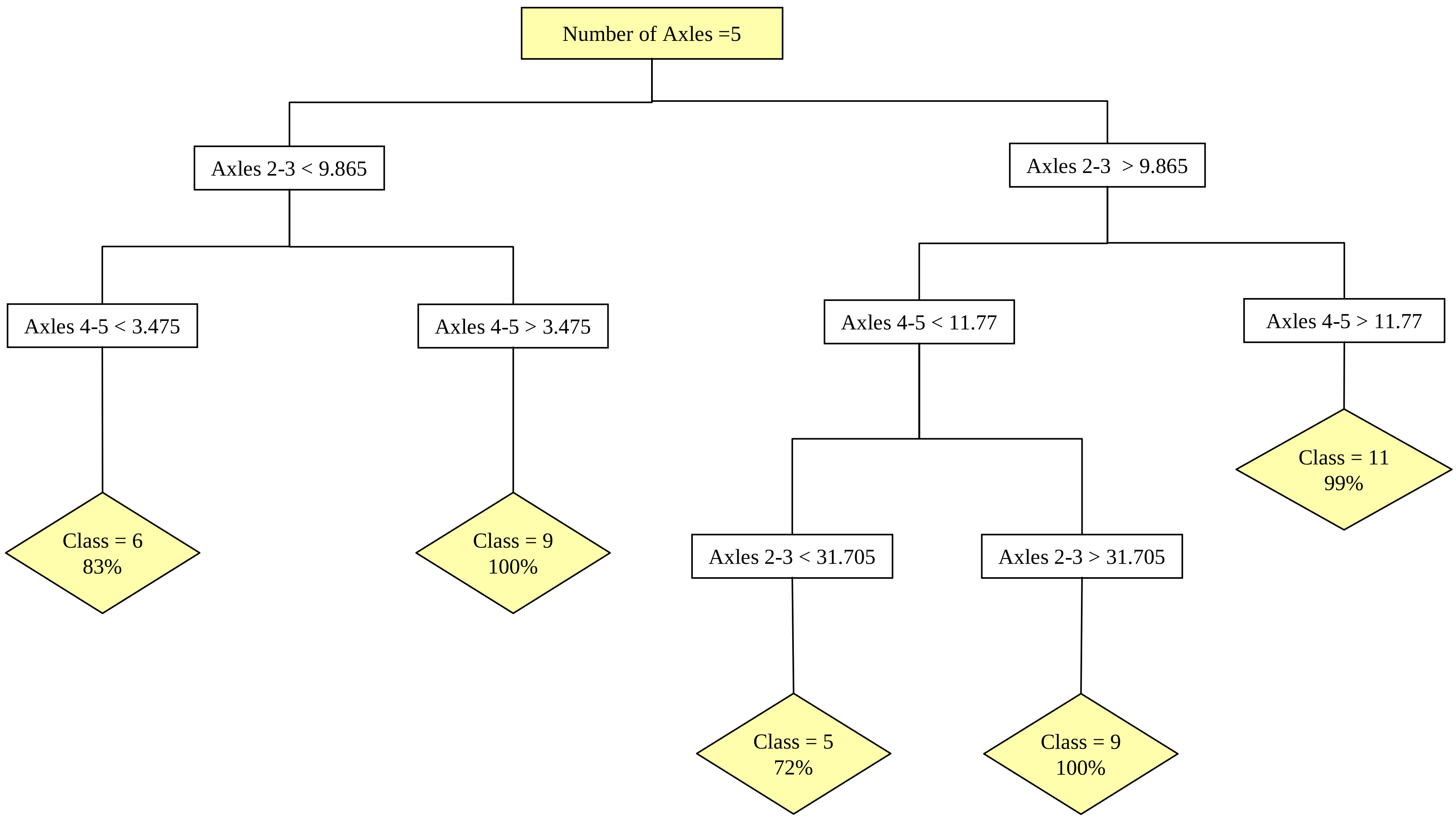

Figure 2.6.2 Pruned Classification Tree for 5-Axle Vehicles (axle spacing in feet).

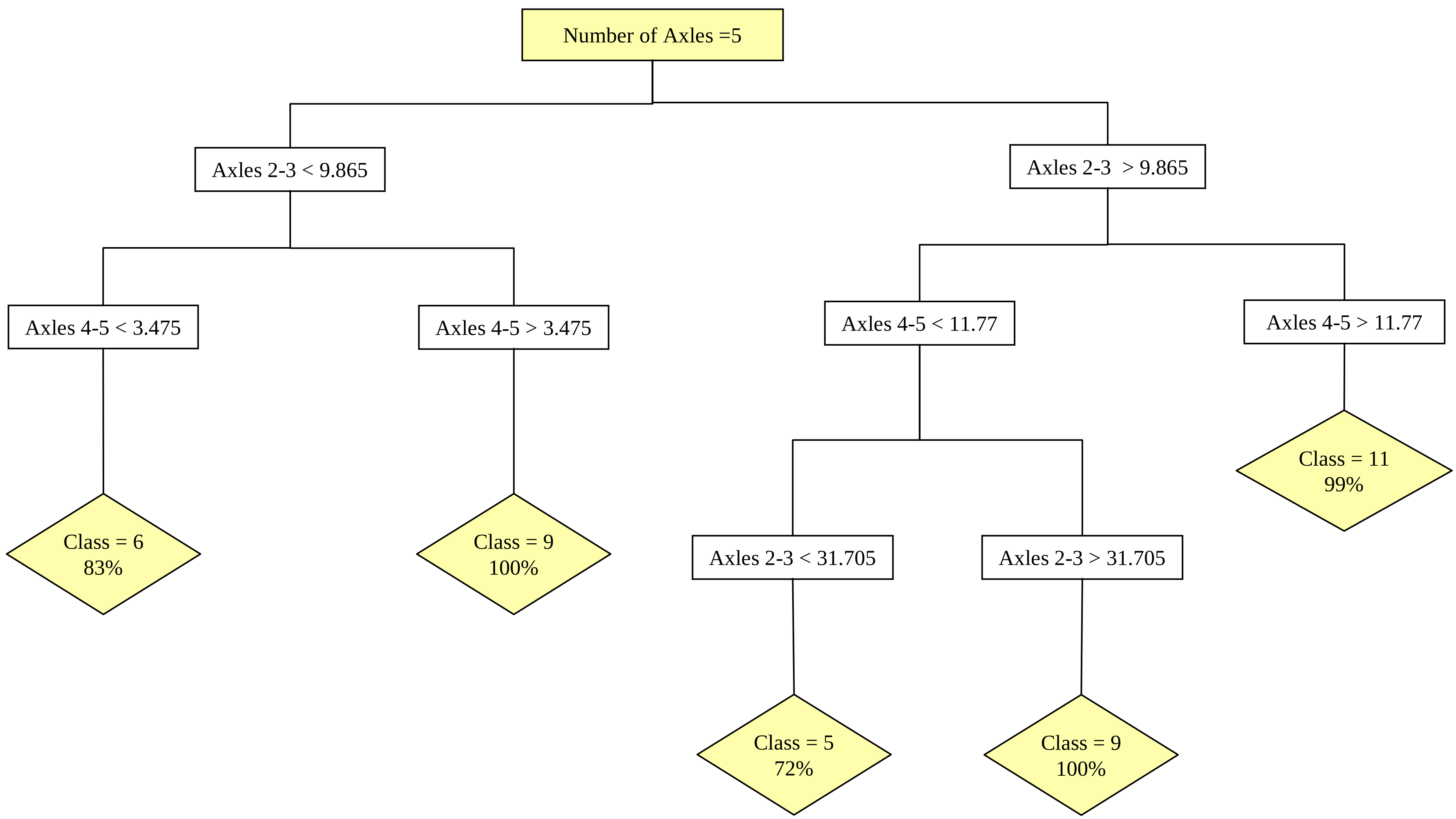

Figure 2.6.3 Classification Tree for 5-Axle Vehicles: All Redundancies Removed (axle spacing in feet).

2.7 6-Axle Vehicles

There are five terminal nodes for both the original and the pruned classification trees for 6-axle vehicles (Figures 2.7.1 and 2.7.2). The misclassification rate is 4.17 percent (Tables 2.7.1 and 2.7.2). Only two classes are assigned to 6-axle trucks, Classes 10 and 12, with probabilities also assigned to Classes 5, 6, and 9. When all redundant assigning criteria are removed, there are only two branches to this tree (Figure 2.7.3), with the only criteria being a spacing of less than or greater than 12.74 feet between axles 5 and 6 deciding the class assignment of 10 or 12 (Table 2.7.3).

Table 2.7.1. Classification Trees and Error Rates for All Available Spacing Variables: 6-Axle Vehicles

Number of terminal nodes: 5
Residual Mean Deviance: 0.2029 = 23.33/115
Misclassification Error Rate: 0.04167 = 5/120

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)				
				Class 5	Class 6	Class 9	Class 10	Class 12
1) Root	120	211.5	10	0.83	1.67	1.67	48.33	47.50
2) Axle 5-6 < 12.74	62	38.0	10	1.61	1.61	3.23	93.55	0.00
4) Axle 4-5 < 2.805	5	13.3	10	20.00	20.00	20.00	40.00	0.00
5) Axle 4-5 > 2.805	57	10.1	10	0.00	0.00	1.75	98.25	0.00
10) Axle 4-5 < 20.55	52	--	10	0.00	0.00	0.00	100.00	0.00
11) Axle 4-5 > 20.55	5	5.0	10	0.00	0.00	20.00	80.00	0.00
3) Axle 5-6 > 12.74	58	10.1	12	0.00	1.72	0.00	0.00	98.28
6) Axle 1-2 < 14.96	53	--	12	0.00	0.00	0.00	0.00	100.00
7) Axle 1-2 > 14.96	5	5.0	12	0.00	20.00	0.00	0.00	80.00

Table 2.7.2. Pruned Classification Trees and Error Rates: 6-Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)				
				Class 5	Class 6	Class 9	Class 10	Class 12
1) Root	120	211.5	10	0.83	1.67	1.67	48.33	47.50
2) Axle 5-6 < 12.74	62	38.0	10	1.61	1.61	3.23	93.55	0.00
4) Axle 4-5 < 2.805	5	13.3	10	20.00	20.00	20.00	40.00	0.00
8) Axle 5-6 < 2.94	7	11.2	10	14.29	14.29	0.00	71.43	0.00
9) Axle 5-6 > 2.94	48	—	10	0.00	0.00	0.00	100.00	0.00
5) Axle 4-5 > 4.425	7	8.4	10	0.00	0.00	28.57	71.43	0.00
3) Axle 5-6 > 12.74	58	10.1	12	0.00	1.72	0.00	0.00	98.28
6) Axle 1-2 < 14.96	53	—	12	0.00	0.00	0.00	0.00	100.00
7) Axle 1-2 > 14.96	5	5.0	12	0.00	20.00	0.00	0.00	80.00

Table 2.7.3. Classification Trees with All Redundancies Removed: 6-Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)				
				Class 5	Class 6	Class 9	Class 10	Class 12
1) Root	120	211.5	10	0.83	1.67	1.67	48.33	47.50
2) Axle 5-6 < 12.74	62	38.0	10	1.61	1.61	3.23	93.55	0.00
3) Axle 5-6 > 12.74	58	10.1	12	0.00	1.72	0.00	0.00	98.28

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

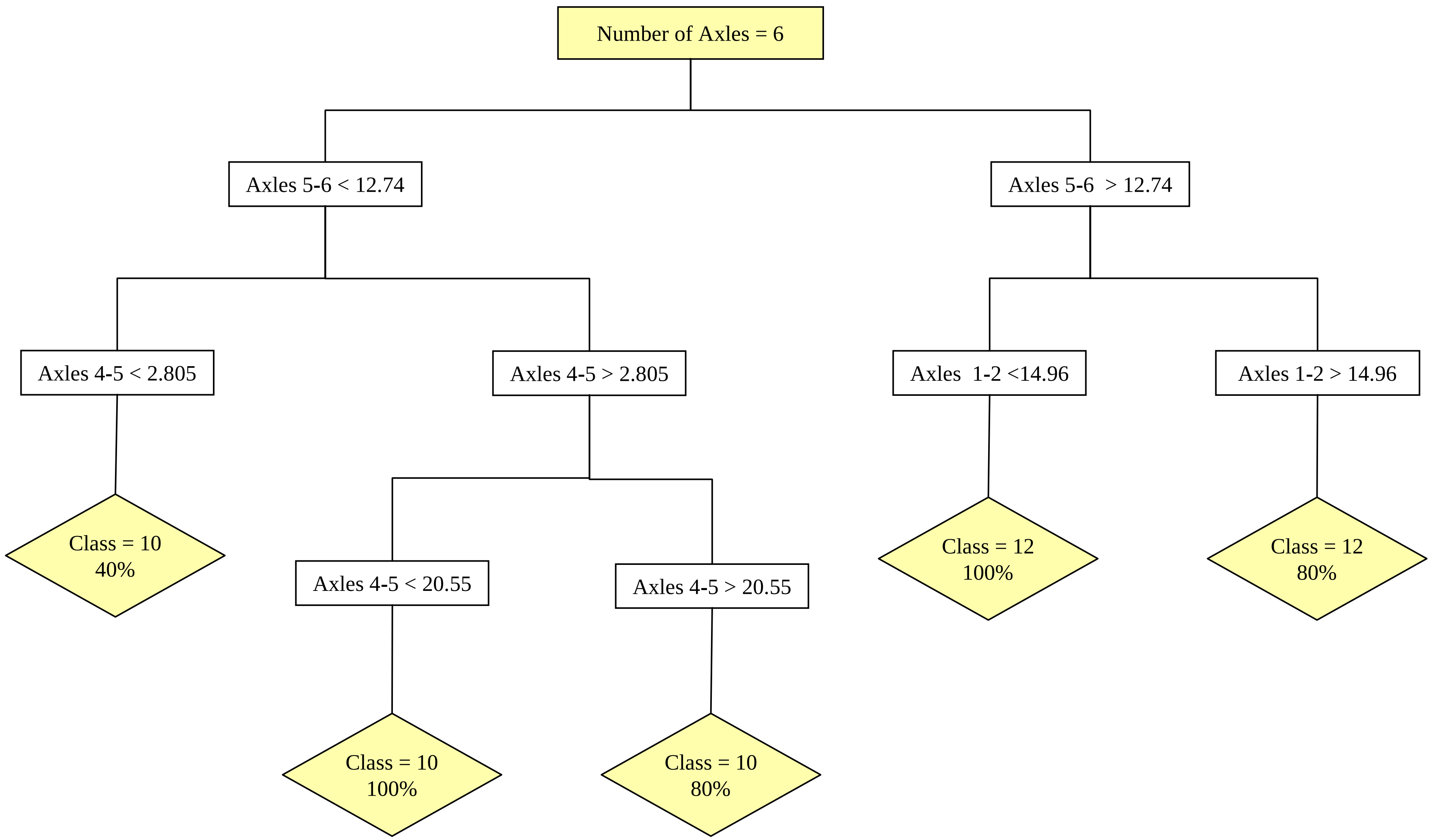

Figure 2.7.1. Classification Tree for 6-Axle Vehicles: All Available Axle Spacing Variables (in feet).

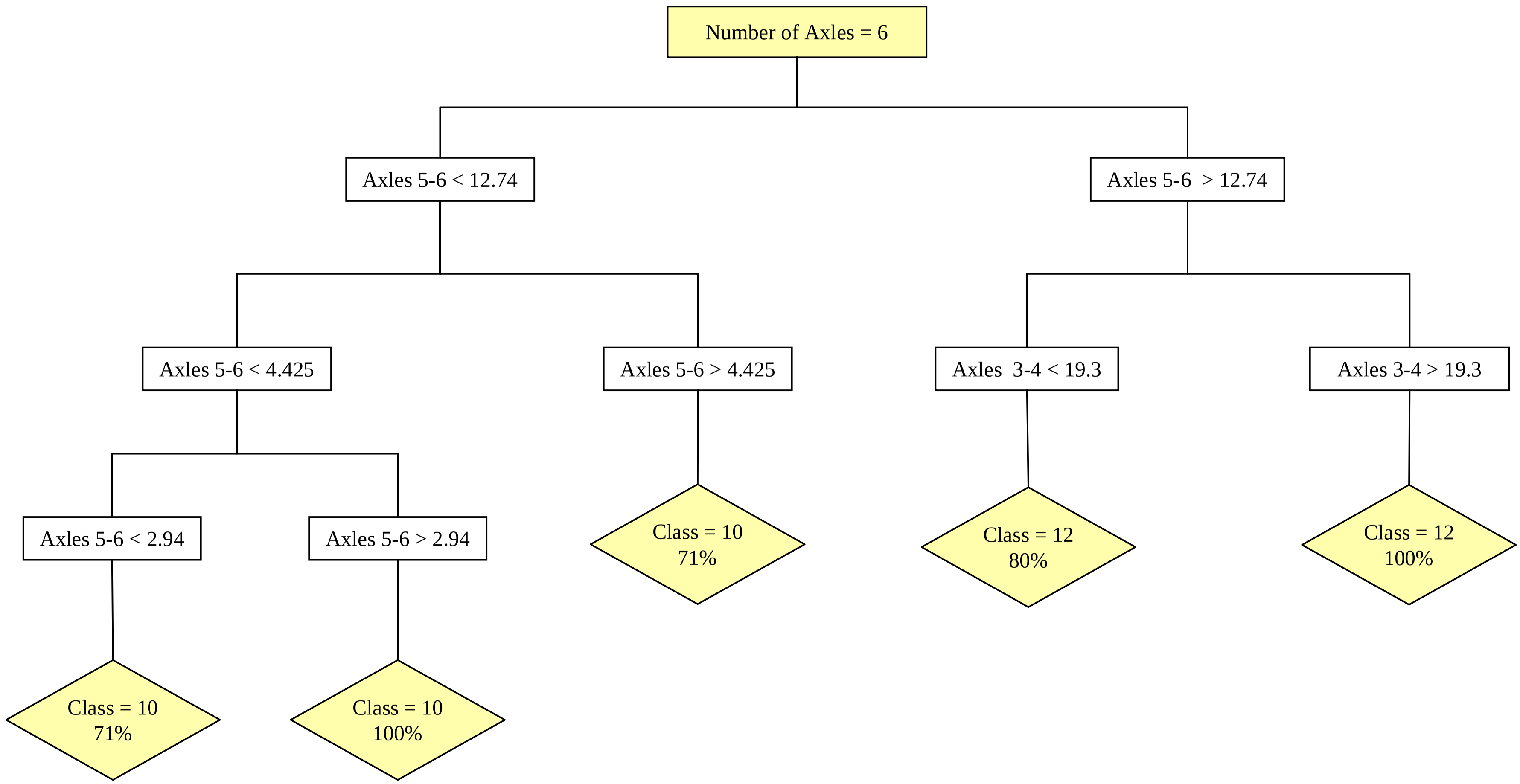

Figure 2.7.2 Pruned Classification Tree for 6-Axle Vehicles (axle spacing in feet).

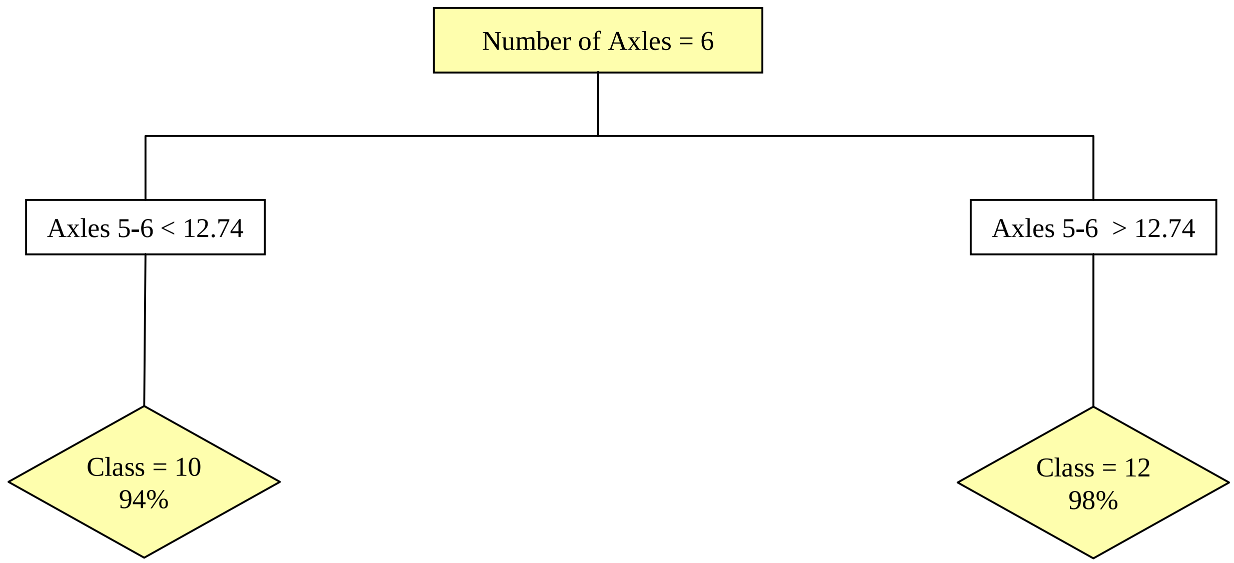

Figure 2.7.3 Classification Tree for 6-Axle Vehicles: All Redundancies Removed (axle spacing in feet).

2.8 7-or-more Axle Vehicles

The original and pruned classification trees are also identical for 7 or more axle vehicles (Figures 2.8.1 and 2.8.2). There are only two terminal nodes, and only one class assigned, Class 10, with an error rate of 4.55 percent (Tables 2.8.1 and 2.8.2). There are two branches on the tree, and the criteria is the spacing between axles 5 and 6. With the single redundancy removed, there is only one branch, which simply assigns all 7 or more axle vehicles to Class 10 (Figure 2.8.3 and Table 2.8.3).

Table 2.8.1. Classification Trees for All Available Spacing Variables: 7 or More Axle Vehicles

Number of terminal nodes: 2
Residual Mean Deviance: 0.2502 = 5.004/20
Misclassification Error Rate: 0.04545 = 1/22

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)	
				Class 10	Class 13
1) Root	22	8.136	10	0.9545	0.04545
2) Axle 5-6 < 4.125	5	5.004	10	0.8	0.2
3) Axle 5-6 > 4.125	17	0.000	10	1	0

Table 2.8.2. Pruned Classification Trees and Error Rates: 7 or More Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)	
				Class 10	Class 13
1) Root	22	8.1	10	95.45	4.55
2) Axle 5-6 < 4.125	5	5.0	10	8.00	20.0
3) Axle 5-6 > 4.125	17	0.0	10	100.00	0

Table 2.8.3. Classification Trees with All Redundancies Removed: 7 or More Axle Vehicles

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Probability (percent)	
				Class 10	Class 13
1) Root	22	8.1	10	95.00	5.00

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

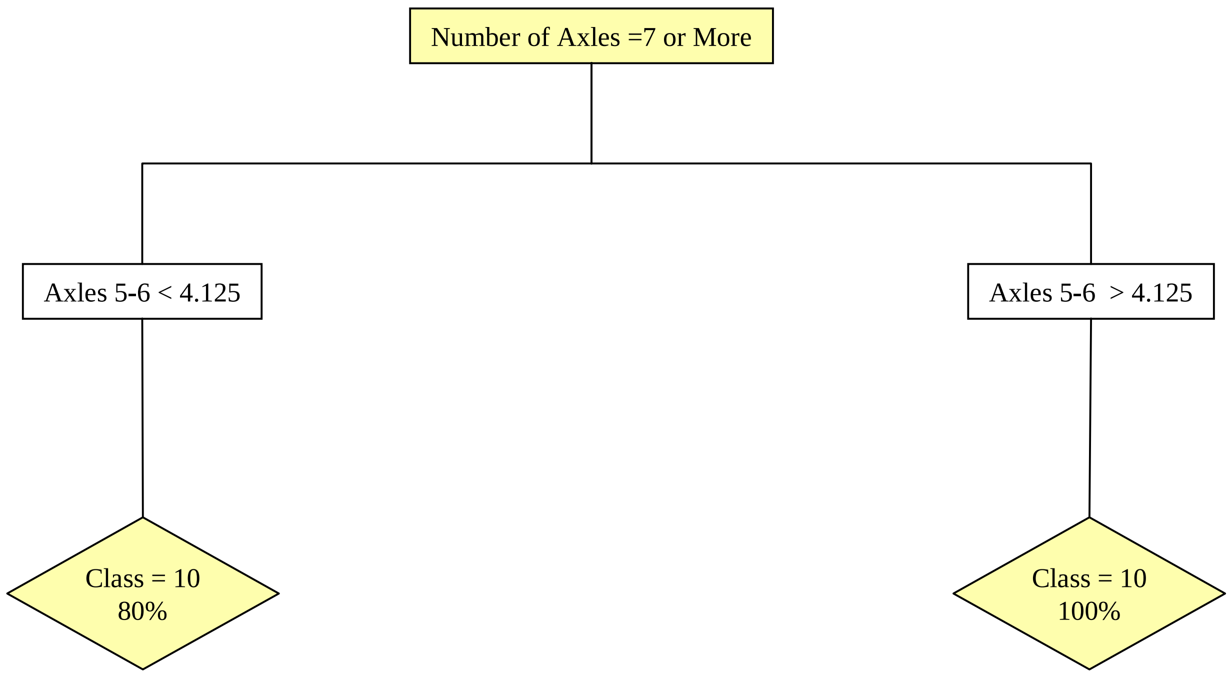

Figure 2.8.1. Classification Tree for 7 or More Axle Vehicles: All Available Axle Spacing Variables (in feet).

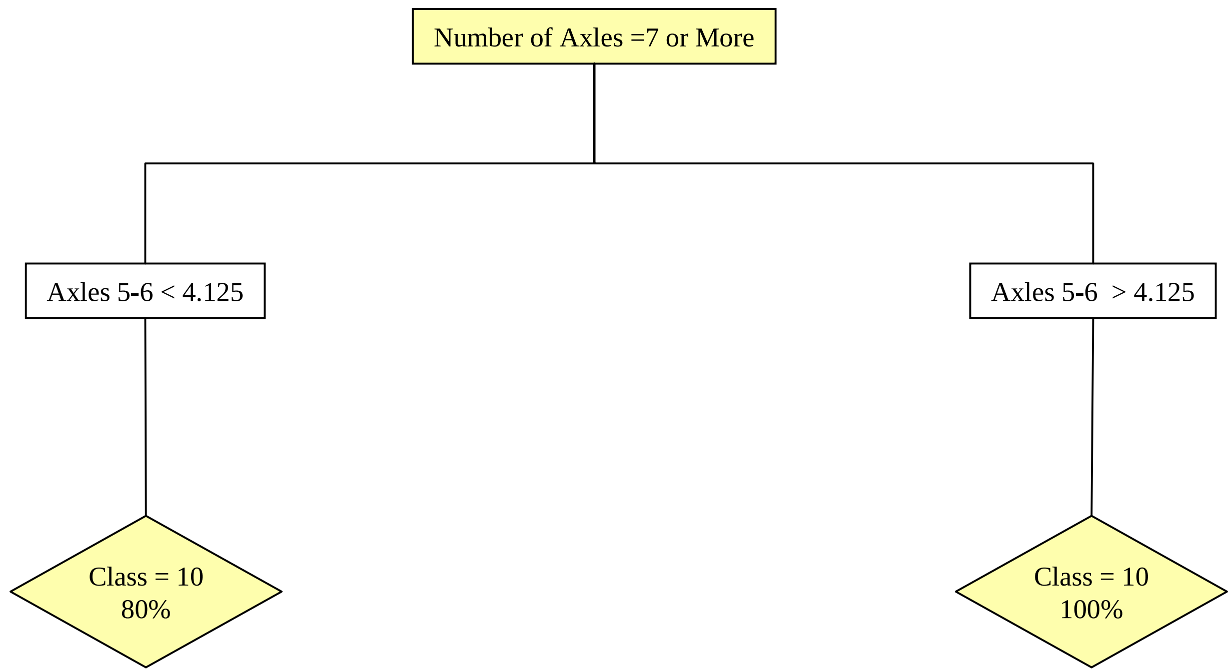

Figure 2.8.2 Pruned Classification Tree for 7 or More Axle Vehicles (axle spacing in feet).

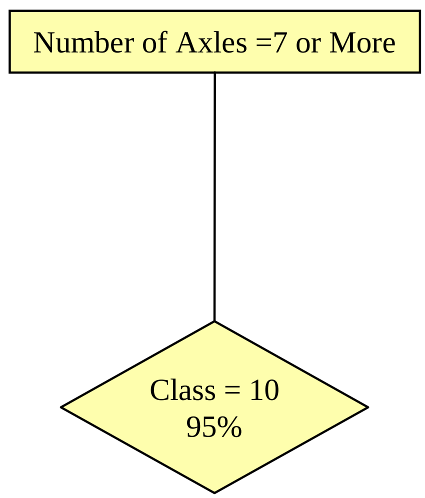

Figure 2.8.3 Classification Tree for 7 or More Axle Vehicles: All Redundancies Removed (axle spacing in feet).

2.9 The Data-Defined Sieve and the Truck Index Database

The statistical process that created the best axle-based classification criteria for the vehicles in the Georgia dataset was also used to create a classification tree for 2-axle vehicles in the Truck Index dataset. The resultant criteria are summarized in Table 2.9.1 and Figure 2.9.1. There are seven terminal nodes, representing Classes 4 and 5. It should be noted that Class 3 vehicles are only minimally represented in the Truck Index database, and there are no Class 2 vehicles at all. All vehicle dimensions were obtained from the Truck Index manuals for Diesel, Gasoline, and Import Trucks, which provide manufacturing specifications for most major truck makes and models. 3-axle vehicles, for the purposes of this study, were also not sufficiently represented to create a tree because axle-spacing dimensions were not available for the majority of these trucks from the Truck Index manuals. Another limitation of this source for creating useable and accurate axle-based classification criteria is that only single-unit trucks, no combinations, are incorporated. However, it was a useful exercise despite these limitations to compare the 2-axle classification criteria from this source to Scheme F and the S-Plus trees created using the Georgia dataset. This was particularly useful in attempting to define a criteria for Class 4 vehicles (buses), which were not assigned to a terminal node when using the Georgia dataset.

Table 2.9.1. S-Plus Classification Tree Based on the Truck Index: 2-Axle Trucks

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Percent			
				Class 3	Class 4	Class 5	Class 6
1) Root	8,523	8,635.0	5	6.57	7.26	86.05	0.12
2) Axles 1-2 < 19.54	7,340	6,375.0	5	7.18	4.09	88.62	0.11
4) Axles 1-2 < 12.41	1,766	784.2	5	4.93	0.40	94.68	0.00
5) Axles 1-2 > 12.41	5,574	5,444.0	5	7.89	5.26	86.71	0.14
10) Axles 1-2 < 12.63	380	443.2	5	2.90	17.11	80.00	0.00
20) Axles 1-2 < 12.54	317	203.1	5	3.47	4.10	92.43	0.00
21) Axles 1-2 > 12.54	63	58.4	4	0.00	82.54	17.46	0.00
11) Axles 1-2 > 12.63	5,194	4,910.0	5	8.26	4.39	87.20	0.15
22) Axles 1-2 < 15.54	2,620	1,816.0	5	7.86	1.11	90.88	0.15
23) Axles 1-2 > 15.54	2,574	2,939.0	5	8.66	7.73	83.45	0.16
3) Axles 1-2 > 19.54	1,183	1,688.0	5	2.79	26.97	70.08	0.17
6) Axles 1-2 < 22.04	1,087	1,377.0	5	2.21	21.44	76.17	0.18
7) Axles 1-2 > 22.04	96	70.7	4	9.38	89.58	1.04	0.00

Source: Truck Index Manuals

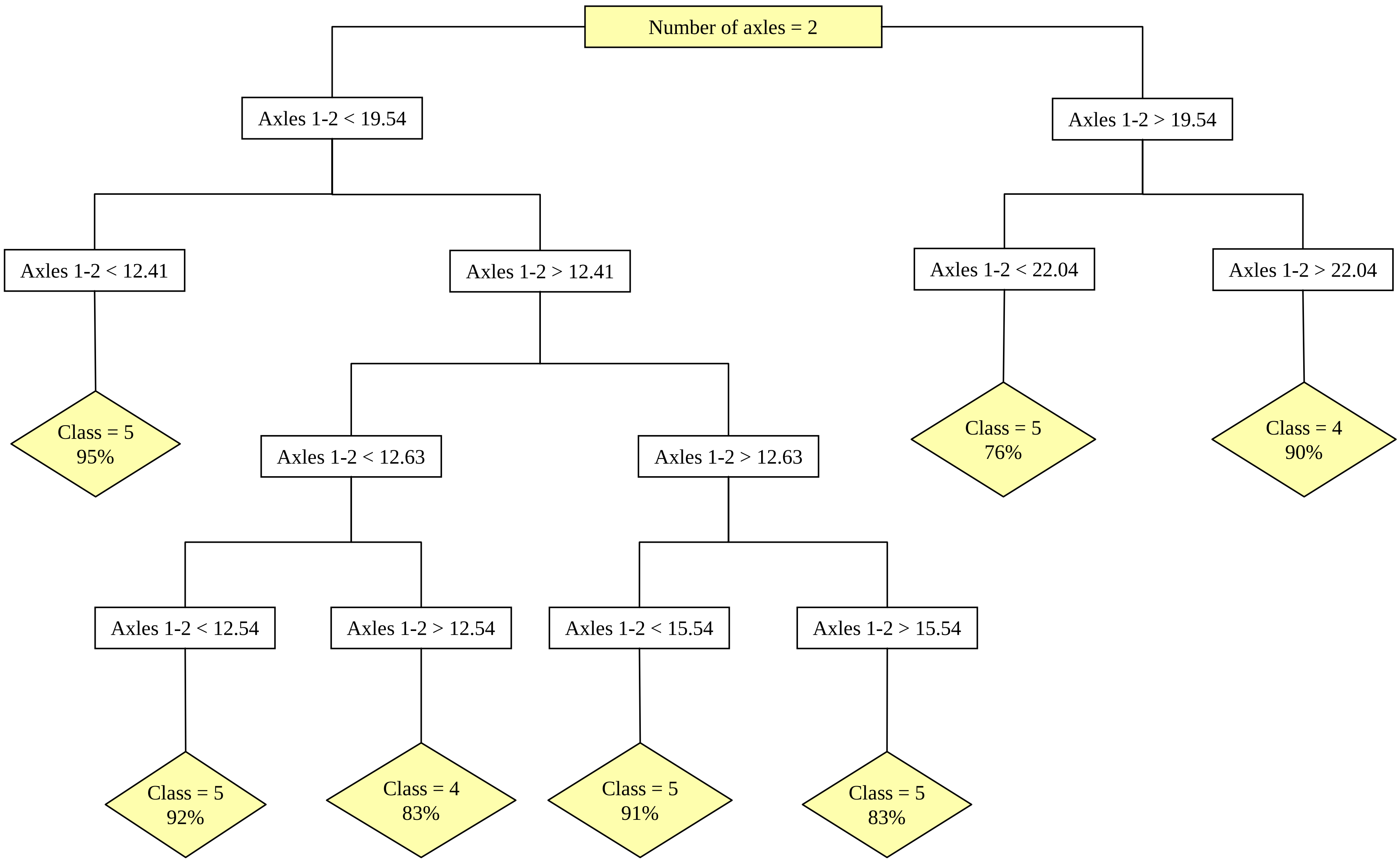

Figure 2.9.1 Classification Tree for 2-Axle Vehicles: Truck Index Database (axle spacing in feet).

The pruned version of the classification tree for the truck index is shown in Table 2.9.2, and in flow chart form in Figure 2.9.2. The pruning process leaves two major branches which assign Classes 4 and 5.

Table 2.9.2. S-Plus Classification Tree Based on the Truck Index, With No Redundancies: 2-Axle Trucks

Axle Spacing Split (in feet)	Number of Vehicles	Deviance	Assigned Class	Percent			
				Class 3	Class 4	Class 5	Class 6
1) Root	8,523	8,635.0	5	6.57	7.26	86.05	0.12
2) Axles 1-2 < 19.54	7,340	6,375.0	5	7.18	4.09	88.62	0.11
20) Axles 1-2 < 12.54	317	203.1	5	3.47	4.10	92.43	0.00
21) Axles 1-2 > 12.54	63	58.4	4	0.00	82.54	17.46	0.00
3) Axles 1-2 > 19.54	1,183	1,688.0	5	2.79	26.97	70.08	0.17
6) Axles 1-2 < 22.04	1,087	1,377.0	5	2.21	21.44	76.17	0.18
7) Axles 1-2 > 22.04	96	70.7	4	9.38	89.58	1.04	0.00

Source: Truck Index Manuals

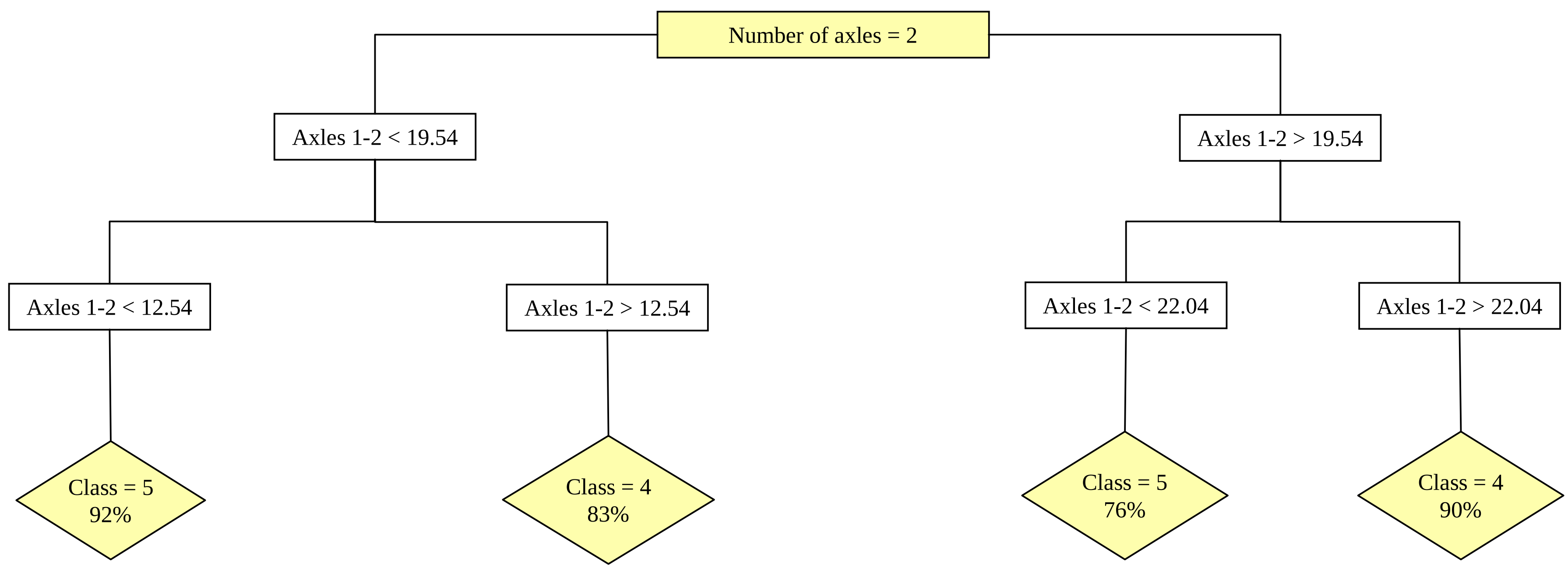

Figure 2.9.2 Truck Index Classification Tree for 2-Axle Vehicles: All Redundancies Removed (axle spacing in feet).

The final decision matrices for the algorithms produced using the statistical procedure are summarized in Table 2.9.3 (for the algorithm based on the Georgia dataset) and in Table 2.9.4 (for the 2-axle algorithm based on the Truck Index dataset). These can be compared to the Scheme F classification criteria in Table 2.9.5.

Table 2.9.3 Decision Matrix Derived from S-Plus "Pruned" Classification Tree

# Axles	Axles 1-2 (feet)	Axles 2-3 (feet)	Axles 3-4 (feet)	Axles 4-5 (feet)	Axles 5-6 (feet)	FHWA Class
2	< 9.87					2
	9.875 to 12.11					3
	> 12.11					5
3	< 18.75	< 5.80				6
	> 18.75	< 5.80				4
		5.80 to 20.90				3
		> 20.90				8
4	< 11.36	< 22.09	<12.55			3
	< 11.36	22.09 to 24.715	< 12.55			8
	>11.36	< 24.72	< 12.55			3
		< 24.72	> 12.55			8
		> 24.72				8
5		< 9.87		< 3.48		6
		< 9.87		> 3.48		9
		9.87 to 31.71		< 11.77		5
		> 31.71		< 11.77		9
		> 9.87		> 11.77		11
6					< 12.74	10
					> 12.74	12
7 or More						10

Note: Some relevant classes are excluded due to a reduction in the number of nodes on each branch of the tree, and due to the existence of relatively few vehicles of certain classes in the originating database. Namely, excluded are Classes 1 and 4 for two-axle vehicles, Class 2 for three-axle vehicles, Classes 2 and 7 for four-axle vehicles, Class 3 for five-axle vehicles, and all 7-axle or more Class 13 trucks.

Table 2.9.4 Decision Matrix Derived from S-Plus "Pruned" Classification Tree for the Truck Index Database

# Axles	Axles 1-2 (feet)	FHWA Class
2	< 12.54	5
2	12.54 to 19.54	4
2	19.54 to 22.04	5
2	> 22.04	4

Note: Class 3 is excluded due to relatively fewer number Class 3 trucks in the database.

Table 2.9.5 Scheme "F" Classification Criteria

# Axles	Wheelbase (feet)	Axles 1-2 (feet)	Axles 2-3 (feet)	Axles 3-4 (feet)	Axles 4-5 (feet)	Axles 5-6 (feet)	Types of Vehicles
2	< 6'						1 Motorcycle
	6' to 10'						2 Light Pickup, Van
	10' to 15'						3 Heavy Duty Pickup
	15' to 20'						5 2-axle Truck
	> 20'						4 Bus
3		< 10'	10' to 18'				2 Car with trailer
		10' to 15'	10' to 18'				3 Pickup with trailer
		> 19'					4 Bus
			> 18'				8 2S1 tractor semitrailer
		All others					6 3-axle Truck
4		< 10'		< 3.5'			2 Car with trailer
		10' to 15'		< 3.5'			3 Pickup with trailer
			> 5'	> 3.5'			8 2S2 tractor semitrailer
			< = 5'	> 10'			8 3S1 tractor semitrailer
		All Others					7 Other 4-axle vehicles
5			> 6'				11 2S1-2
			< 6.1		3.5' to 8'		9 3S2
		9.9' to 15'			< 3.5'		3 Pickup with 3-axle trailer
		14.9' to 20'			< 3.5'		5 Truck with 3-axle trailer
		All Others					9 Tandem with 2-axle trailer
6				3.5' to 5'			10 6-axle combination
						> 10'	12 3S1-2
		All Others					10 3S3
7	All Others						13 All other vehicles

Source: Field Evaluation of FHWA Vehicle Classification Categories

2.10 Summary

For 2-axle vehicles, comparing the criteria in Scheme F to those in the pruned S-Plus tree, the most readily apparent difference is that there is no category for Classes 1 or 4 in the S-Plus tree. For Class 2, the upper delimiter is very similar for both methods: 10 feet for Scheme F, 9.88 feet for the S-Plus tree. These distances also serve, respectively, as the lower delimiters for identifying Class 3. The demarcation point between Classes 3 and 5 shows a greater difference between the methods. Scheme F uses 15 feet, whereas the S-Plus tree differentiates Classes 3 and 5 at 12.11 feet. In fact, anything greater than 12.11 feet with 2 axles is defined as Class 5 in the S-Plus tree, but Scheme F creates another demarcation at greater than 20 feet for Class 4. The Truck Index-based tree also includes a category for an axle 1 to 2 spacing for Class 4 vehicles for a spacing greater than 22.04 feet. The relatively greater proportion of buses in this database also result in an allocation in the range of 12.54 to 19.54 feet for the wheelbase. The fact that both methods seem to classify the 2-axle vehicles similarly, and both have the highest misclassification rate in that category, indicates that this may be the hardest category to classify for any vehicle population due to large areas of overlap in vehicle types for any axle-spacing ranges defined. The similarities in the classification criteria for 2-axle vehicles are reflected in the similar misclassification error rates for the two methods in that category. The categories with 3 axles and more all had substantially lower error rates using the S-Plus method, which again was reflected in the largely different criteria that were used in those cases.

There are also a few similarities for 3-axle vehicles. Both algorithms consider vehicles with a larger axle 2 to 3 spacing to be Class 8. For the S-Plus tree, a distance greater than 20.9 feet identifies Class 8 trucks, for Scheme F the distance is 18 feet. The S-Plus tree does not recognize Class 2 (cars with trailers) in the 3-axle category. Scheme F considers the spacing between both axles 1 to 2 and axles 2 to 3, whereas the S-Plus tree considers only the axle 2 to 3 spacing, anything greater than 5.8 feet but less than 20.9 feet (anything greater is Class 8, as previously mentioned). The S-Plus tree identifies buses by a distance between axles 1 and 2 of 18.75 feet, and Scheme F uses 19 feet. However, the S-Plus tree also considers the distance between axles 2 and 3, which Scheme F does not. Only vehicles with an axle 2 to 3 spacing less than 5.8 feet are put in Class 4, while all others are combined with Class 3.

The criteria for the two classification methods with regard to 4-axle vehicles are entirely different. The S-Plus tree only puts 4-axle vehicles into two different classes, Classes 3 and 8, whereas Scheme F also distinguishes Classes 2 and 7 among 4-axle vehicles. The criteria are likewise very different in the way the two methods classify 5-axle vehicles. 6-axle vehicles in both the S-Plus and Scheme F algorithms are put into two different classes, Class 10 and Class 12. The criteria are similar. For the S-Plus tree, all vehicles with a distance between axles 5 and 6 greater than 12.74 feet are put into Class 10, whereas with Scheme F the criteria is spacing between axles 5 and 6 greater than 10 feet. For both algorithms, all other vehicles fall into Class 12. For 7 or more axle vehicles, the Georgia dataset prompted the S-Plus software to classify all such vehicles as Class 10, whereas Scheme F considers all 7 or more axle vehicles to be Class 13 trucks. This is probably what caused the very high error rate for Scheme F in this category for this analysis.

The best potential for improvement in the sieve-type axle-based classification method is to add additional independent variables to the decision process, or to use a proportional assignment of vehicles to different classes based on historical data. Scheme F can probably be improved upon, slightly, particularly for 3-axle or more vehicles, but not greatly so without these additional steps. This is largely due to the overlaps in vehicle classes that occur when using axle spacing as the only criteria for assigning class. Adding vehicle length, vehicle weight, axle weights, or other available variables would probably reduce the amount of overlap and the number of classification errors. Using a proportional assignment of class within the areas of overlap that occur in axle spacing would also reduce the number of errors, by making adjustments to the classes assigned by the algorithm in recognition that these overlaps will inevitably occur with axle-based classification methods.

Chapter 3

The Truck Index and Trucking Industry Profile Databases and Scheme F

As a further evaluation of the Scheme F algorithm only, queries were performed using Paradox 7.0 on the Trucking Industry Profile (TIP) and Truck Index databases to evaluate the performance of Scheme F against the assigned FHWA vehicle class in the Truck Index for the truck models in both data sources. Registration data in the TIP database was used to determine registered volume, and the specifications and other information from the Truck Index manuals were used to determine the actual vehicle class. First, the criteria for Scheme F were organized as in Table 3.1 (in the equivalent inches to match the measurements in the Truck Index database) so that individual line queries could be made and the results appropriately combined to obtain the totals for each class. Although there were only vehicles for Classes 3, 4, 5, and 6 in the databases, all Scheme F criteria for 2 and 3-axle vehicles were used in order to identify all possible Scheme F-based classification alternatives. The models that fit the criteria for each query in the Truck Index were linked to the number of those particular models that are registered in the TIP, according to the fields of make, model, and year in both databases. The corresponding results in the form of totals for each FHWA Class, as depicted by Scheme F, are in the far right column of Table 3.1. As can be seen there, Scheme F was accurate in not classifying any of the truck models into Class 1 (motorcycles) or Class 8. A small number was incorrectly classified as Class 2. It is known that there are no Class 2 models in the Truck Index.

Table 3.1 Truck Index and the TIP: The Number of Vehicles in Each FHWA Class Based on Scheme F

Class	# Axles	Wheel Base	Axles 1-2	Axles 2-3	Total Registered
1	2	> 0 and < 6			0
2	2	> 6 and < 10			42,547
	3		< 10	> 10 and < 18	
3	2	> 10 and < 15			1,023,020
	3		> 10 and < 15	> 10 and < 18	
4	3		> 19		520,464
	2	> 20			
5	2	> 15 and < 20			999,861
6	3		< = 10	> 0 and < = 10	177,429
	3		> 10 and < 15	> 0 and < = 10	
	3		> = 15 and < = 19	< = 18	
8	3			> 18	0

Source: Truck Index Manuals and the 1996 Trucking Industry Profile database

Some further information is provided from additional queries of the two databases, in the form of ranges for wheelbase, overall length, and GVWR (minimum and maximum gross vehicle weight rating values) for Scheme F-based FHWA Class assignments for Classes 2 through 6 (Table 3.2). In spite of any misclassification, the ranges occur as might be expected, which is that the ranges generally increase for each increase in class. The GVWR values also increase for each consecutive class, and the wheelbase and overall length values increase when moving from Class 2 to Class 3 to Class 5. Class 4 vehicles, buses, have the longest overall length and wheelbase ranges, which also seems appropriate.

Table 3.2 TIP and Truck Index: Class According to Scheme F

Distance (Feet)	2	3	4	5	6	Total
Wheel Base	8.25 to 9.75	10.08 to 14.92	20.06 to 22.92	15.08 to 19.92	11.50 to 20.50	
Overall Length	15.50 to 19.21	13.88 to 30.40	27.50 to 38.49	20.21 to 35.26	19.67 to 34.83	
GVWR	11,050 to 47,000	11,050 to 60,000	16,850 to 48,000	12,300 to 66,000	43,000 to 66,000	
Number Registered	42,547	1,023,020	520,464	999,861	177,429	2,763,321
Percent Registered	2%	37%	19%	36%	6%	100%

Source: Truck Index Manuals and the 1996 Trucking Industry Profile database

Table 3.3 compares the number of models determined according to Scheme F to the number of models in each class as determined by the FHWA vehicle class definitions. Scheme F misclassifies a great number of the records, generally into classes lower than they should be.

Table 3.3 Truck Index: Identification and Count of Actual Class and Scheme F Class for Vehicle Models

Class	FHWA Class - Number of Models	Scheme F - Number of Models
2	0	30
3	79	230
4	43	108
5	415	183
6	62	48
Total	599	599

Source: Truck Index Manuals and the 1996 Trucking Industry Profile database

Table 3.4 shows the Scheme F classification versus the actual class in matrix form. The first section shows the matrix for the linked databases for registered vehicles, both for the number of registered vehicles and by percentage in each respective class. The diagonal bolded print in each matrix represents the vehicles that are classified the same by both actual class and Scheme F designated class. The actual classes are distributed horizontally in the matrix, against the vertical Scheme F designations. There is no row for Class 2, since there are no Class 2 vehicles in the Truck Index or the TIP. There is a 51 percent misclassification rate for FHWA Class 3 trucks, 64 percent for Class 4, 62 percent for Class 5, and 23 percent for Class 6. The model information is portrayed in the bottom two sections of Table 3.4. Here, the misclassification rate for FHWA Class 3 was 58 percent, 67 percent for both Class 4 and Class 5, and 23 percent for Class 6.

Table 3.4 The Performance of Scheme F as a Classification Method for the Truck Index and TIP Databases

Number of Registered Vehicles
Truck Index

Scheme F/ Actual	2	3	4	5	6	Total For Actual Class
3	10,435	**263,691**	19,220	243,210	0	536,556
4	0	75,006	**102,138**	108,551	0	285,695
5	32,112	684,323	346,755	**648,100**	0	1,711,290
6	0	0	52,351	0	**177,429**	229,780
Total for Scheme F	42,547	1,023,020	520,464	999,861	177,429	2,763,321

Percent of Total Registered In Each Class
Truck Index

Scheme F/ Actual	2	3	4	5	6	Total For Actual Class
3	2%	**49%**	4%	45%	0%	100%
4	0%	26%	**36%**	38%	0%	100%
5	2%	40%	20%	**38%**	0%	100%
6	0%	0%	23%	0%	**77%**	100%
Total for Scheme F	2%	37%	19%	36%	6%	100%

Number of Models in Each Class
Truck Index

Scheme F/ Actual	2	3	4	5	6	Total For Actual Class
3	2	**33**	13	31	0	79
4	0	13	**14**	16	0	43
5	28	184	67	**136**	0	415
6	0	0	14	0	**48**	62
Total for Scheme F	30	230	108	183	48	599

Percent of Total Number of Models in Each Class
Truck Index

Scheme F/ Actual	2	3	4	5	6	Total For Actual Class
3	3%	**42%**	16%	39%	0%	100%
4	0%	30%	**33%**	37%	0%	100%
5	7%	44%	16%	**33%**	0%	100%
6	0%	0%	23%	0%	**77%**	100%
Total for Scheme F	5%	38%	18%	31%	8%	100%

Clearly, Scheme F does not perform well on this particular dataset. There are two important extenuating circumstances. The first is that there are a range of vehicle axle spacing options for each model, which means that extreme values are given the same weight as the standard options, thus skewing the data. Secondly, and possibly more importantly, these data represent only a portion of possible single-unit truck data, incorporate no Class 2 or Class 7 or higher vehicles, and do not consider actual vehicle travel or road usage.

Chapter 4

Discriminate Analysis for Determining Vehicle Class

4.1 Introduction

The statistical procedure discriminate analysis is used in this study to explore its potential in accurately classifying vehicles according to axle count and axle spacing. This method departs from the sieve-type approach, and instead identifies the relationship of the distance between the individual axles for each vehicle class for each subset of vehicles with identical axle counts. As with the classification trees described in Chapter 2, the S-Plus software was used to perform a discriminate analysis. This discriminate analysis on the relative distance between consecutive axles on vehicles with 2 axles, 3 axles, 4 axles, 5 axles, 6 axles, and 7 or more axles in the Georgia dataset was done as another possible method for determining vehicle class from axle-based data sources.

The statistical process produced several tables as output. The first table listed the variables, the variable labels, the number of records for each variable (which in all cases was the same for all variables in the set), as well as the mean, standard deviation, minimum, and maximum for each variable. The second table produced was for "Class Level Information," the frequency and proportion in each class for subsets of data (based on number of axles). Since there is only one data source, the proportion of vehicles for each bin is also the "prior probability," which is determined by the ground truth FHWA class for the vehicle records. This is what will be used to determine the accuracy of the class assignments according to the discriminate analysis. The next table was the "Pooled Covariance Matrix Information," which provided the covariance matrix rank, and the natural log of the determinant of the covariance matrix. The fourth table was the "Pairwise Generalized Squared Distances Between Groups," which is the generalized squared distance of each class bin to each of the others. The table "Linear Discriminate Function" provides the constant and coefficient vector for each axle spacing variable, for all relevant class bins. The last table produced was the "Classification Summary for Calibration Data," which provides the number of observations and the percent classified into each class bin for each "ground truth" class. Error count estimates for each class are also provided in this table. In all cases, the dependent variable for this exercise is used to determine vehicle class. For vehicles with only two axles, there is only one independent variable, which is the distance, in feet, from the first axle to the second. In the Georgia dataset, there are 31,226 vehicles with only two axles. The distance between the axles ranges from 4.3 feet to 30.3 feet, with a mean of 9.45 feet. These vehicle could fall within Classes 1 through 5. The majority, 60.5 percent, are Class 2, and most of the remainder, 35.9 percent, are Class 3. Only 3.2 percent are Class 5 trucks, and 0.2 percent, respectively, are Class 1 (motorcycles) and Class 4 (buses). These proportions from the Georgia dataset are considered the "prior probability" for the purpose of determining the accuracy of the ensuing discriminate analysis.

4.2 Discriminate Analysis for 2-Axle Vehicles

Table 4.2.1 is the classification matrix derived from the discriminate analysis for 2-axle vehicles, based on the distance between axles. The top table gives the number of observations from each FHWA class (for Classes 1 through 5) that are assigned to each class bin. The diagonally placed bolded values are the observations that are correctly identified in each FHWA class. For example, for Class 1 vehicles, 48 records are correctly determined to be Class 1 by the discriminate analysis, and five are incorrectly placed in Class 3. These observations are translated into percentage values at the bottom of the table. So in the same example, the 48 observations that are correctly assigned to Class 1 represent 90.57 percent of the total 2-axle, Class 1 vehicles in the dataset, and the five Class 1 vehicles that are misclassified as Class 3 represent 9.43 of 2-axle, Class 1 vehicles.

For 2-axle vehicles, the vast majority of Class 1 and 2 vehicles are classified correctly — more than 90 percent. The process does not perform as well for Classes 3, 4 and 5. For Class 3 vehicles, 47.06 percent are misclassified as Class 2, a significant rate of error, especially since 35.9 percent of the 2-axle vehicles in the data set are Class 3. But the misclassification rate for Class 4 vehicles is even worse, with only 3.08 percent classified correctly, and most being combined with Class 5 (90.77 percent). It is difficult, however, to draw conclusions from this, since only 0.2 percent of the 2-axle observations in the dataset are Class 4. It may be, based on the similar difficulties in distinguishing 2-axle Class 4 using Scheme F and the S-Plus generated algorithms, no axle-based method will be effective in distinguishing 2-axle buses from other vehicle classes. Class 5 trucks have a better chance of being distinguished correctly using the discriminate analysis, with 68.42 percent identified correctly, and most of the remainder being incorrectly classified as Class 3. The proportional distribution into the five classes by this method are in the "total" row of the bottom matrix in Table 4.3.1, and can be directly compared with the "prior probability" (or actual distribution) in the row directly below it. The last line in the table provides the error rate, or the misclassification rate, for each FHWA Class, and the total misclassification rate for 2-axle vehicles. At 22.88 percent, the misclassification rate using the discriminate analysis method, for 2-axle vehicles, is slightly superior to that of Scheme F (misclassification error rate 24.6 percent) and the pruned tree error rate (23.3 percent).

Table 4.2.1 Discriminate Analysis for 2-Axle Vehicles Based on the Georgia Database

Dependent variable - FHWA Class
Independent (predictor) variable - Axle Spacing 1-2

# Vehicles with 2 Axles	31,226
Mean Axle Spacing 1-2 (ft)	9.45
Standard Deviation (ft)	1.78
Minimum (ft)	4.30
Maximum (ft)	30.31

Class	Frequency	Proportion
1	53	0.2%
2	18,881	60.5%
3	11,220	35.9%
4	65	0.2%
5	1,007	3.2%
Total	1,007	100%

Number of Observations in Each Class

From Class	1	2	3	4	5	Total
1	48	0	5	0	0	53
2	0	17,588	1,323	0	0	18,881
3	0	5,280	5,786	0	154	11,220
4	0	0	4	2	59	65
5	0	17	300	1	689	1,007
Total	48	22,855	7,418	3	902	31,226

Percent Classified into Each Class

From Class	1	2	3	4	5	Total
1	90.57	0.00	9.43	0.00	0.00	100
2	0.00	92.99	7.01	0.00	0.00	100
3	0.00	47.06	51.57	0.00	1.37	100
4	0.00	0.00	6.15	3.08	90.77	100
5	0.00	1.69	29.79	0.10	68.42	100
Total	0.15	73.19	23.76	0.01	2.89	
Prior Probability (%)	0.17	60.47	35.93	0.21	3.22	
Error Rate (%)	9.43	7.01	48.43	96.92	31.58	22.88

4.3 Discriminate Analysis for 3-Axle Vehicles

There are 1,301 3-axle vehicles in the Georgia dataset, and there are two independent variables for predicting FHWA Class: the distance between axles 1 and 2, and the distance between axles 2 and 3. The mean axle spacing between axles 1 and 2 is greater than that for 2-axle vehicles at 13.44 feet (compared to 9.45 feet) even though the range is narrower, from 6.96 feet to 25.24 feet. The standard deviation is 3.63. For axles 2 to 3, the distance range is from 2.86 to 40.7 feet, with a mean of 10.16 feet (Table 4.3.1). The FHWA Class distribution is depicted in Table 2.9.5. The majority (52 percent) of 3-axle vehicles are Class 6, followed by 28.5 percent in Class 3, and 9.5 percent in Class 8. A smaller number are also in Classes 2, 4 and 5.

Table 4.3.1 shows the number of observations and the percent allocated to each class. All 43 of the FHWA Class 2 vehicles are classified in this process as Class 3. Most of the FHWA Class 3 and Class 6 vehicles, which together make up more than 80 percent of this data subset, are classified correctly, 97.6 percent and 98.7 percent, respectively. FHWA Class 4 has 69 percent classified correctly, with 29.3 percent designated as Class 6 instead. FHWA Class 8 has 87.8 percent classified correctly, and 11.4 percent misclassified as Class 3. Overall, the error rate for 3-axle vehicles is 8.2 percent, compared to 25.1 percent for Scheme F, 8.5 percent for the best tree error rate, and 10 percent for the pruned tree.

Table 4.3.1 Discriminate Analysis for 3-Axle Vehicles Based on the Georgia Database

	Axles 1-2 (ft)	Axles 2-3 (ft)
Mean Axle Spacing	13.44	10.16
Standard Deviation	3.63	7.61
Minimum	6.96	2.86
Maximum	25.24	40.70

Class-Level Information

Class	Frequency	Proportion
2	43	3.3%
3	371	28.5%
4	58	4.5%
5	24	1.8%
6	682	52.4%
8	123	9.5%
Total	1,301	100.00%

Table 4.3.1 Discriminate Analysis for 3-Axle Vehicles Based on the Georgia Database (continued)

Number of Observations in Each Class

From Class	2	3	4	5	6	8	Total
2	0	0	0	0	0	0	43
3	0	362	0	3	0	6	371
4	0	0	40	1	17	0	58
5	0	8	0	11	0	5	24
6	0	1	6	0	673	2	682
8	0	14	0	0	1	108	123
Total	0	428	46	15	691	121	1,301

Percent Classified into Each Class

From Class	2	3	4	5	6	8	Total
2	0.00	100.00	0.00	0.00	0.00	0.00	100.00
3	0.00	97.57	0.00	0.81	0.00	1.62	100.00
4	0.00	0.00	68.97	1.72	29.31	0.00	100.00
5	0.00	33.33	0.00	45.83	0.00	20.83	100.00
6	0.00	0.15	0.88	0.00	98.68	0.29	100.00
8	0.00	11.38	0.00	0.00	0.81	87.80	100.00
Total	0.00	32.90	3.54	1.15	53.11	9.30	
Prior Probability (%)	3.31	28.52	4.46	1.84	52.42	9.45	
Error Rate (%)	100.00	2.43	31.03	54.17	1.32	12.20	8.22

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

4.4 Discriminate Analysis for 4-Axle Vehicles

There are three predictor variables for 4-axle vehicles, the distance between axles 1 and 2, axles 2 and 3, and axles 3 and 4. There are 896 4-axle vehicles in the Georgia dataset. Of these 896 vehicles, 54.4 percent are Class 8 trucks, 31.9 percent are Class 3, and 11 percent are Class 5, with Classes 2, 6, 7, and 11 also minimally represented (Table 4.4.1). This segment of the analysis performs substantially better than Scheme F overall, with a 16.8 percent error rate, compared to 26.4 percent for Scheme F, but it performs fairly equivalently to the algorithms from the S-Plus generated trees. FHWA Class 8 vehicles, the majority of 4-axle vehicles, are classified correctly 94.3 percent of the time. Class 3, the second most common, is classified correctly at a rate of 86 percent. The worst performance is for Classes 2 and 5.

Table 4.4.1 Discriminate Analysis for 4-Axle Vehicles Based on the Georgia Database

	Axles 1-2 (ft)	Axles 2-3 (ft)	Axles 3-4 (ft)
Mean Axle Spacing	11.98	23.60	4.99
Standard Deviation	2.13	9.03	4.69
Minimum	5.03	3.66	2.21
Maximum	23.63	42.25	37.91

Class-Level Information

Class	Frequency	Proportion
2	14	1.6%
3	286	31.9%
5	99	11.0%
6	4	0.4%
7	3	0.3%
8	487	54.5%
11	3	0.3%
Total	896	100.00%

Number of Observations in Each Class

From Class	2	3	5	6	7	8	11	Total
2	6	8	0	0	0	0	0	14
3	13	246	9	0	0	18	0	286
5	0	65	25	0	0	9	0	99
6	0	0	0	4	0	0	0	4
7	0	0	0	0	3	0	0	3
8	0	17	3	8	0	459	0	487
11	0	0	0	0	0	0	3	3
Total	19	336	37	12	3	486	3	896

Percent Classified into Each Class

From Class	2	3	5	6	7	8	11	Total
2	42.86	57.14	0.00	0.00	0.00	0.00	0.00	100.00
3	4.55	86.01	3.15	0.00	0.00	6.29	0.00	100.00
5	0.00	65.66	25.25	0.00	0.00	9.09	0.00	100.00
6	0.00	0.00	0.00	100.00	0.00	0.00	0.00	100.00
7	0.00	0.00	0.00	0.00	100.00	0.00	0.00	100.00
8	0.00	3.49	0.62	1.64	0.00	94.25	0.00	100.00
11	0.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00
Total	2.13	37.50	4.13	1.34	0.33	54.24	0.33	
Prior Probability (%)	1.56	31.92	11.05	0.45	0.33 2	54.35	0.33	
Error Rate (%)	57.14	13.99	74.75	0.00	0.00	5.75	0.00	16.74

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

4.5 Discriminate Analysis for 5-Axle Vehicles

Most 5-axle vehicles in the Georgia dataset, 96.5 percent (6,839 out of 7,090), are FHWA Class 9. Of these, 99.4 percent of these are classified correctly (Table 4.5.1). There are also Class 3, 4, 5, 6 and 11 vehicles with five axles. The total misclassification rate of only 1 percent for this category is the same as for Scheme F. The best and pruned tree error rates are slightly better for 5-axle trucks, at 0.4 percent and 0.5 percent, respectively.

Table 4.5.1 Discriminate Analysis for 5-Axle Vehicles Based on the Georgia Database

	Axles 1-2 (ft)	Axles 2-3 (ft)	Axles 3-4 (ft)	Axles 4-5 (ft)
Mean Axle Spacing	13.35	4.96	30.83	4.84
Standard Deviation	3.35	3.39	6.35	3.20
Minimum	7.61	3.67	2.43	2.48
Maximum	157.00	48.87	303.00	44.00

Class Level Information

Class	Frequency	Proportion
3	8	0.1%
4	1	0.0%
5	23	0.3%
6	24	0.3%
9	6,839	96.5%
11	195	2.8%
Total	7,090	100.00%

Number of Observations in Each Class

From Class	3	4	5	6	9	11	Total
3	2	0	6	0	0	0	8
4	0	0	0	0	1	0	1
5	2	0	21	0	0	0	23
6	0	0	0	7	17	0	24
9	13	0	1	26	6,797	2	6,839
11	0	0	0	0	1	194	195
Total	17	0	28	33	6,816	196	7,090

Table 4.5.1 Discriminate Analysis for 5-Axle Vehicles Based on the Georgia Database (continued)

Percent Classified into Each Class

From Class	3	4	5	6	9	11	Total
3	25.00	0.00	75.00	0.00	0.00	0.00	100.00
4	0.00	0.00	0.00	0.00	100.00	0.00	100.00
5	8.70	0.00	91.30	0.00	0.00	0.00	100.00
6	0.00	0.00	0.00	29.17	70.83	0.00	100.00
9	0.19	0.00	0.01	0.38	99.39	0.03	100.00
11	0.00	0.00	0.00	0.00	0.51	99.49	100.00
Total	0.00	32.90	3.54	1.15	53.11	9.30	
Prior Probability (%)	0.11	0.01	0.32	0.34	96.46	2.75	
Error Rate (%)	75.00	100.00	8.70	70.83	0.61	0.51	0.97

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

4.6 Discriminate Analysis for 6-Axle Vehicles

There are 120 6-axle vehicles used for this analysis, which represents 0.3 percent of the Georgia data. As shown in Table 4.6.1, the error rate from the discriminate analysis is 8.3 percent, which is worse than the 4.2 percent for all three of the other classification methods examined, Scheme F and the two S-Plus trees. Six-Axle trucks are for the most part split between Class 10 (48.3 percent) and Class 12 (47.5 percent). There are also relatively small numbers of Class 5, 6 and 9 trucks. For Class 10 trucks, 10.3 percent are misclassified as Class 5, but only 1.8 percent of Class 12 trucks are misclassified.

Table 4.6.1 Discriminate Analysis for 6-Axle Vehicles Based on the Georgia Database

	Axles 1-2 (ft)	Axles 2-3 (ft)	Axles 3-4 (ft)	Axles 4-5 (ft)	Axles 5-6 (ft)
Mean Axle Spacing	12.06	6.86	20.26	8.11	12.78
Standard Deviation	2.87	9.53	7.67	6.22	9.04
Minimum	4.05	3.91	2.54	0.00	2.36
Maximum	19.37	54.29	38.86	41.85	23.31

Class Level Information

Class	Frequency	Proportion
5	1	0.8%
6	2	1.7%
9	2	1.7%
10	58	48.3%
12	57	47.5%
Total	120	100.0%

Table 4.6.1 Discriminate Analysis for 6-Axle Vehicles Based on the Georgia Database (continued)

Number of Observations in Each Class

From Class	5	6	9	10	12	Total
5	1	0	0	0	0	1
6	0	0	0	1	1	2
9	0	1	1	0	0	2
10	6	0	0	52	0	58
12	0	1	0	0	56	57
Total	7	2	1	53	57	120

Percent Classified into Each Class

From Class	5	6	9	10	12	Total
5	100.00	0.00	0.00	0.00	0.00	100.00
6	0.00	0.00	0.00	50.00	50.00	100.00
9	0.00	50.00	50.00	0.00	0.00	100.00
10	10.34	0.00	0.00	89.66	0.00	100.00
12	0.00	1.75	0.00	0.00	98.25	100.00
Total	5.83	1.67	0.83	44.17	47.50	100.00
Prior Probability (%)	0.83	1.67	1.67	48.33	47.50	
Error Rate (%)	0.00	100.00	50.00	10.34	1.76	8.33

Source: Accuracy of Traffic Monitoring Equipment,Georgia DOT

4.7 Discriminate Analysis for 7 or More Axle Vehicles

There are only two classes represented among the observations with 7 or more axles, Classes 10 and 13, and the misclassification error rate for these vehicles using the discriminate analysis is zero. There are only 22 vehicles in this subset, and there are eight independent variables, which are the distances between each of the consecutive individual axles.

Table 4.7.1 Discriminate Analysis for 7 or More Axle Vehicles Based on the Georgia Database

	Axles 1-2 (ft)	Axles 2-3 (ft)	Axles 3-4 (ft)	Axles 4-5 (ft)	Axles 5-6 (ft)	Axles 6-7 (ft)	Axles 7-8 (ft)	Axles 8-9 (ft)
Mean Axle Spacing	12.04	4.20	10.28	17.56	6.48	5.05	1.74	1.34
Standard Deviation	2.57	0.30	10.87	12.97	7.18	2.87	2.14	2.00
Minimum	8.37	3.77	4.13	3.39	3.41	3.85	0.00	0.00
Maximum	16.17	4.74	33.07	34.31	29.39	17.75	4.77	4.27

Table 4.7.1 Discriminate Analysis for 7 or More Axle Vehicles Based on the Georgia Database (continued)

Class Level Information

Class	Frequency	Proportion
10	21	95.5%
13	1	4.5%
Total	22	100.0%

Number of Observations in Each Class

From Class	10	13	Total
10	21	0	21
13	0	1	1
Total	2148	1	22

Percent Classified into Each Class

From Class	5	6	Total
10	100.00	0.00	100.00
13	0.00	100.00	100.00
Total	94.45	4.55	100.00
Prior Probability (%)	95.45	4.55	
Error Rate (%)	0.00	0.00	0.00

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

4.8 Summary

In considering the total number of misclassified vehicles using the four different algorithms discussed, the discriminate analysis has a slightly lower number of erroneous assignments than any of the other methods. Table 4.8.1 compares the error rates for each method in total and by the groupings by number of axles. It is possible that by adding more independent variables to the analysis, such as total vehicle length, wheelbase, and front and rear overhang, even greater accuracy could be achieved with this method. It may also be possible to predict other variables, such as body type, using this method. The discriminate analysis method performs best overall, with an 18.4 percent error rate, compared to 18.5 percent for the best tree, 18.7 percent for the pruned tree, and 20.6 percent for Scheme F. The discriminate analysis was outperformed by the best tree for vehicles with 4, 5, and 6 axles, but had the lowest misclassification rate for 2, 3, and 7-or-more axle vehicles. This method shows tremendous potential and versatility, since independent additional variables can be easily added, and the method could also be adapted to make predictions about other physical characteristics of trucks, such as body type and cargo carried. This preliminary test of the use of discriminate analysis and its superior performance compared to the sieve-type classification method suggests that it warrants further exploration.

Table 4.8.1 Comparison of Different Classification Systems in Correctly Identifying Vehicle Class

Classification of Vehicles in the Georgia Database Using the Scheme F Algorithm

Number of Axles	Number of Observations	Percent of Total Observations	Number of Vehicles Classified Correctly	Percent of Vehicles Classified Correctly	Number of Vehicles Classified Incorrectly	Percent of Vehicles Classified Incorrectly	Weighted Errors
2	31,227	76.8%	23,533	75.4%	7,694	24.6%	18.9%
3	1,302	3.2%	975	74.9%	327	25.1%	0.8%
4	897	2.2%	660	73.6%	237	26.4%	0.6%
5	7,090	17.4%	7,017	99.0%	73	1.0%	0.2%
6	120	0.3%	115	95.8%	5	4.2%	0.0%
7 or More	22	0.1%	1	4.5%	21	95.5%	0.1%
Total/Average	40,658	100.0%	32,301	79.4%	8,357	20.6%	20.6%

Classification of Vehicles in the Georgia Database Using the S-Plus Decision Tree: "Best" Tree

Number of Axles	Number of Observations	Percent of Total Observations	Number of Vehicles Classified Correctly	Percent of Vehicles Classified Correctly	Number of Vehicles Classified Incorrectly	Percent of Vehicles Classified Incorrectly	Weighted Errors
2	31,227	76.8%	23,992	76.8%	7,235	23.2%	17.8%
3	1,302	3.2%	1,191	91.5%	111	8.5%	0.3%
4	897	2.2%	766	85.4%	131	14.6%	0.3%
5	7,090	17.4%	7,063	99.6%	27	0.4%	0.1%
6	120	0.3%	115	95.8%	5	4.2%	0.0%
7 or More	22	0.1%	21	95.5%	1	4.5%	0.0%
Total/Average	40,658	100.0%	33,148	81.5%	7,510	18.5%	18.5%

Classification of Vehicles in the Georgia Database Using the S-Plus Decision Tree: "Pruned" Tree

Number of Axles	Number of Observations	Percent of Total Observations	Number of Vehicles Classified Correctly	Percent of Vehicles Classified Correctly	Number of Vehicles Classified Incorrectly	Percent of Vehicles Classified Incorrectly	Weighted Errors
2	31,227	76.8%	23,943	76.7%	7,284	23.3%	17.9%
3	1,302	3.2%	1,172	90.0%	130	10.0%	0.3%
4	897	2.2%	739	82.4%	158	17.6%	0.4%
5	7,090	17.4%	7,058	99.5%	32	0.5%	0.1%
6	120	0.3%	115	95.8%	5	4.2%	0.0%
7 or More							
Total/Average	40,636	99.9%	33,027	81.3%	7,609	18.7%	18.7%

Classification of Vehicles in the Georgia Database Using the Axle-Based Discriminate Analysis

Number of Axles	Number of Observations	Percent of Total Observations	Number of Vehicles Classified Correctly	Percent of Vehicles Classified Correctly	Number of Vehicles Classified Incorrectly	Percent of Vehicles Classified Incorrectly	Weighted Errors
2	31,227	76.8%	24,083	77.1%	7,144	22.9%	17.6%
3	1,302	3.2%	1,194	91.7%	108	8.3%	0.3%
4	897	2.2%	746	83.2%	151	16.8%	0.4%
5	7,090	17.4%	7,021	99.0%	69	1.0%	0.2%
6	120	0.3%	110	91.7%	10	8.3%	0.0%
7 or More	22	0.1%	22	100.0%	—	0.0%	0.0%
Total/Average	40,658	100.0%	33,176	81.6%	7,482	18.4%	18.4%

Comparison of Error Rates for Different Classification Methods

Number of Axles	Scheme F Error Rates	"Best" Tree Error Rates	"Pruned" Tree Error Rates	Discriminate Analysis Rates
2	24.6%	23.2%	23.3%	22.9%
3	25.1%	8.5%	10.0%	8.3%
4	26.4%	14.6%	17.6%	16.8%
5	1.0%	0.4%	0.5%	1.0%
6	4.2%	4.2%	4.2%	8.3%
7 or More	95.5%	4.5%		0.0%
Total/Average	20.6%	18.5%	18.7%	18.4%

Chapter 5

Data Editing

The "Traffic Data Quality Procedures Pooled Fund Study Expert Knowledge Base" [6] prepared for the Minnesota DOT established a knowledge base of traffic data screening techniques. The project produced a set of state-of-the-practice rules for traffic data screening of traffic volume, classification data, and weight data for anomalies and defects. The purpose of these data editing rules is to identify anomalies and errors and their causes. The majority of these rules provide reference values and general default values, and all rules relate to one of three topical categories: traffic volume, vehicle class, or vehicle weight. For each category, there are checks of the data for validity, realistic values, equipment malfunction, equipment calibration, and expected (site-specific) values. The rules fall into two categories, either per-record rules or aggregate rules, that are concerned with data patterns. There are also certain defined characteristics that help characterize each rule, beyond the topical categories of volume, class, or weight analysis and the nature of the analysis process that is being applied. These categories are integrity, realistic values, equipment malfunction, calibration, and expected data.

5.1 Volume-Based Traffic Data Editing

The focus for this project is a record-level analysis of extreme axle spacing values within the classification data, since this issue is closely related to the types of analysis performed on the Georgia and Truck Index databases. However, one proposal for volume-based traffic data, a way for identifying errors and anomalies in data for a specific site over time that may in particular be related to equipment malfunction or drifting calibration is described in the following process:

1. Determine the frequency distribution and error rates for a given population.
2. Introduce a series of errors of known amounts to the data.
3. Examine changes in the distribution that correspond to each known rate of error.
4. Determine acceptable/unacceptable thresholds of error, and the change in the distribution associated with that error rate.
5. Monitor continuous output from the site for changes in patterns of data.
6. Flag when the data patterns change beyond the pre-determined threshold.
7. Determine cause of data anomalies.

The above process would require ongoing testing of data and comparison of traffic volumes and classification output, but would provide a means for identifying calibration errors or equipment malfunction quickly with a systematic, well-defined testing methodology.

5.2 Record-Level Data Editing Rules

There are several ways that appropriate rules and limits for data values can be examined using output from this study. The example values from the pooled fund report can be compared to values from the Georgia DOT study vehicle records and the Truck Index data, particularly from the discriminate analysis and the production of the S-Plus classification trees. There were also Scatter Plots, Box, and Whisker charts prepared from the Georgia dataset that clearly demonstrate areas of concentration of data and outliers. These charts, shown in Appendix B, can be extremely relevant and useful for setting editing criteria when produced from regional areas of data collections based on ground truth data. Using the Georgia dataset to evaluate rule values from the pooled fund study is more of an example exercise in evaluating data editing criteria. It would be advisable to have access to a greater number of data sources with accurate measures for the vehicle records before assigning specific values from the analyses in this report as recommended or default values for data editing rules.

The tables from the previous section of the report (discriminate analysis as a means for determining vehicle class) provide information from the Georgia dataset that can be useful in examining some of the currently accepted and/or proposed criteria for traffic data editing. These tables provide the axle spacing ranges (minimum and maximum values) and the average axle spacing for 2, 3, 4, 5, 6, and 7 or more axle vehicle records from the Georgia DOT study data source of more than 40,000 vehicles.

An example of how the output of the discriminate analysis study can be used to refine or suggest values for the per-vehicle data editing criteria is described here as relates to Rule C26 from the Pooled Fund Expert Knowledge Base [6], which suggests that records with at least one axle spacing greater than 40 feet be flagged for further review. Failure of this test suggests a failure to detect other intermediate axles or that a sequence of separate vehicles are being detected as one due to high loop sensitivity. From the discriminate analysis section of this report, the following extreme values for vehicles of any number of axles are listed in Table 5.2.1.

Table 5.2.1 Axle Spacing Extreme Values from the Georgia Dataset

Axle Pair	Min (ft)	95th Percentile (ft)	99th Percentile (ft)	Max (ft)
1-2	4.05	12.90	16.31	157.00
2-3	2.86	26.24	35.67	62.63
3-4	1.86	35.73	36.94	303.00
4-5	2.30	10.15	22.44	44.00
5-6	2.36	22.79	27.86	29.39
6-7	3.85	5.11	15.10	17.75
7-8	3.89	4.76	4.77	4.77
8-9	4.08	4.27	4.27	4.27

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

These minimum and maximum axle spacing values can be seen in graphical form in Appendix B, the Box and Whisker plots of axle spacing for class and axle combinations. All of these plots are on the same scale, 0 to 50 feet, except for some additional plots for the 5-axle, FHWA Class 9 vehicles, and the 6-axle FHWA Class 10 vehicles, which are given additional plots with extended scales to show some extreme outliers in those classes.

An additional extrapolation of the extreme axle spacing test might be to apply the rule to each class assigned, by number of axles, which has separate box and whisker plots for subsets of the records based on the number of axles for each FHWA class. Although specific values are not given, general ranges and outlier points for the subsets can be approximated based on the plots. On each one, the entire axle spacing measurement is given for each of the axle pairs in the category, represented by the range between the minimum at the lowest data point on the vertical plot, and the maximum distance for that data subset at the top of the plot. The rectangular box in the center indicates the center of the distribution wherein 50 percent of the data points fall. The horizontal line in the middle of the box indicates the median value. The vertical lines that extend above and below the box, known as "whiskers," indicate the upper and lower range of the data lying outside the box. With the data used for this analysis, there are also frequent "outlier" data points, which are shown by plus signs (+) at either end of the whiskers.

By breaking the editing criteria into subsets based on either number of axles for the vehicle, vehicle class, or both, greater accuracy and relevance can be provided to the "per vehicle" data editing criteria. Providing only single, generalized test value that is applied across-the-board to all vehicles can result in either a great number of missed anomalies, or too great a number of unnecessary flags. Moreover, with computerized processing of the data, the addition of further criteria and the creation of temporary subsets for processing does not greatly complicate it, nor add much additional time or expense. The goal should be to create as great an accuracy as possible with the initial pass, where records are flagged or eliminated, in order to reduce the burden of the later steps required for review and revisions, as well as to improve the overall outcome.

Even a brief glance at the series of boxplots produced makes it quite evident that there are wide variations in the axle spacing ranges, both in the range width and in terms of the minimum and maximum values, depending on the FHWA Class, on which consecutive axles are being examined, and the total number of axles on the vehicle. In setting a single rule for minimum or maximum axle spacing distance, this makes it very difficult to set anything but a very extreme value for the test of minimum and maximum distances between axles or axle groups. It is important tonote that all example values in the Task A3 report of the Pooled Fund Study are user-adjustable values, and are included in the report primarily as an illustration of the rules and concepts. Software is being developed as a continuing part of that study that will allow the user to set minimum and maximum values for axle spacing tolerances that are also "class specifiic;" that is, distinct tolerances can be assigned for each class. The rulebase being developed is also quite varied, doing much more than checking for outlying axle spacings, and applies the most detailed level of data discrimination that the incoming data stream can provide to the highest level of vehicle stratification.

Since FHWA Class is assigned from WIM and AVC data according to axle spacing, utilizing extreme axle spacing as a data editing criteria within specific classes creates some circular logic since any extreme spacing will sometimes be weeded out through the assignment logic. Therefore, the information from Table 5.2.2, Maximum Axle Spacing Values (based on the box and whisker plots in Appendix B) can be summarized without the class distinctions, by using only number of axles as the criteria for minimum and maximum axle spacing between each pair of consecutive axles. This gives the results in Table 5.2.3, which sorts the minimum and maximum axle spacing (in feet) from Table 5.2.2, by number of axles. Although vehicle class is not identified for each row value, all class possibilities are shown for each axle category so that the values can be compared. There are often similarities among the different vehicle classes for the extreme data points between given axle pairs.

Table 5.2.2 Approximated Extreme Axle Spacing Values From the Georgia Dataset Boxplots

FHWA Class	Number of Axles	Axles 1-2 (ft)	Axles 2-3 (ft)	Axles 3-4 (ft)	Axles 4-5 (ft)	Axles 5-6 (ft)	Axles 6-7 (ft)	Axles 7-8 (ft)	Axles 8-9 (ft)
1	2 Axles	6							
2	2 Axles	11							
	3 Axles	11	22						
	4 Axles	11	17	12					
3	2 Axles	17							
	3 Axles	14	23						
	4 Axles	17	25	12					
	5 Axles	14	28	3.5	3				
4	2 Axles	25							
	3 Axles	25	5						
5	2 Axles	25							
	3 Axles	20	26						
	4 Axles	20	29	12					
	5 Axles	18	28	3.5	3.5				
6	3 Axles	22	5						
	4 Axles	24	5	30					
	5 Axles	19	5	38	13				
7	4 Axles	12	22	13					
8	3 Axles	19	41						
	4 Axles	18	42	38					
9	5 Axles	22	50	52	12				
10	6 Axles	20	55	40	41	7			
	7 Axles	17	5	34	35	6	5		
	9 Axles	10	5	5	14	30	6	5	5
11	5 Axles	17	23	21	24				
12	6 Axles	18	5	22	16	24			

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

Table 5.2.3 Extreme Axle Spacing Values Without FHWA Class Distinctions

Number of Axles	Axles 1-2 (ft)	Axles 2-3 (ft)	Axles 3-4 (ft)	Axles 4-5 (ft)	Axles 5-6 (ft)	Axles 6-7 (ft)	Axles 7-8 (ft)	Axles 8-9 (ft)
2 Axles	6 11 17 25 25							
3 Axles	11 14 25 20 22 19	22 23 5 26 5 41						
4 Axles	11 17 20 24 12 18	17 25 29 5 22 42	12 12 12 30 13 38					
5 Axles	14 18 19 22 17	28 28 5 50 23	3.5 3.5 38 52 21	3 3.5 13 12 24				
6 Axles	20 18	55 5	40 22	41 16	7 24			
7 Axles	17	5	34	35	6	5		
9 Axles	10	5	5	14	30	6	5	5

Table 5.2.4 condenses the information even further by taking the lowest minimum value and the highest maximum value for each set of records with identical numbers of axles. Compared to the pooled fund study's suggested maximum extreme axle spacing of 40 feet, many axle spacing pairs have a highest value that is substantially lower than that, although rarely are there values that are higher. Vehicles with 3, 4, 5, and 6 axles have some occurrences of axle spacing greater than 40 feet between axles 2 and 3, and 5-axle vehicles have some occurrences of axle spacing greater than 40 feet between axles 3 and 4. However, between axles 1-2, axles 5-6, axles 6-7, and axles 7-8, the maximum values are much lower, so according to the source data the likelihood of catching errors and anomalies for the distance between those axle pairs would be much better if the test values were set accordingly. Table 5.2.5 summarizes the extreme values by axle pair across all records, based on the box and whisker plots produced from the Georgia study dataset.

Table 5.2.4 Summary Extreme Axle Spacing Values Without FHWA Class Distinctions

Number of Axles	Axles 1-2 (ft)	Axles 2-3 (ft)	Axles 3-4 (ft)	Axles 4-5 (ft)	Axles 5-6 (ft)	Axles 6-7 (ft)	Axles 7-8 (ft)	Axles 8-9 (ft)
2 Axles	25							
3 Axles	25	41						
4 Axles	24	42	38					
5 Axles	22	50	52	24				
6 Axles	20	55	40	41	24			
7 Axles	17	5	34	35	6	5		
9 Axles	10	5	5	14	30	6	5	5

Table 5.2.5 Summary Extreme Axle Spacing Values Based on Axle Pair

Axles 1-2 (ft)	Axles 2-3 (ft)	Axles 3-4 (ft)	Axles 4-5 (ft)	Axles 5-6 (ft)	Axles 6-7 (ft)	Axles 7-8 (ft)	Axles 8-9 (ft)
25	55	52	41	30	6	5	5

The next two data editing rules from the Pooled Fund Expert Knowledge Base [6] are also tests of axle spacing. Rule C27, Minimum First Axle Space, refers to the distance between axles 1 and 2 for any vehicle. Failure of this test suggests an invalid record or an unusual vehicle. Rule C28, Minimum Subsequent Axle Space, is a test of all subsequent axle spacings. The minimum first axle space rule suggests 3.5 feet minimum, but is a user-settable value. Table 5.2.6 shows the minimum axle spacing distance between axles 1 and 2.

Table 5.2.6 Minimum Axle Spacing Distance Between Axles 1 and 2

Number of Axles	Axle Spacing Distance Axles 1 and 2 (ft)
2 axles	4.30
3 axles	6.96
4 axles	5.03
5 axles	7.61
6 axles	4.05
7 or more axles	8.37

Source: Accuracy of Traffic Monitoring Equipment, Georgia DOT

For Rule C28, which applies to the axle spacing for all subsequent axle pairs, the pooled fund study suggests another user-settable value—recommending a minimum spacing of 2.8 feet. There are some cases of vehicles in the Georgia data that violate this rule. Other potentially useful rules similar to the axle spacing rules, which are not currently recommended in the Expert Knowledge Base Task A3 report, are front and rear overhang distances, overall vehicle length, and wheelbase distance. These possible test values, like the axle spacing rules, might be more effective if determined and applied on a per class basis or by number of axles on the vehicle.

5.3 Summary

In summary, statistical analysis of ground truth data that is considered representative of a given vehicle population and data collection site is an invaluable method for determining traffic data editing rules. Logical testing values and extreme data values can be determined with minimal analysis of appropriate data sources. Effectiveness of the per-vehicle data editing rules can be increased if the values are set and records tested on the basis of distinctive subsets of the populations, such as by vehicle class and/or number of axles on the vehicles. A suggestion for a test of equipment malfunction or drifting calibration also requires periodic testing of data at a specific or representative site, and involves regular review of the frequency distribution of the various vehicle classes in comparison to the distribution of the test population or the historical distribution.

References

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Appendix A

1992 Truck Inventory and Use Survey — Truck Body Types

Body Type Descriptions from the 1992 Truck Inventory and Use Survey Form (Item 9)

PLATFORM TYPES

Low Boy Platform (gooseneck) - platform with depressed center
Basic Platform (including flatbed, stake, etc.)
Platform with Devices permanently mounted on bed of truck, such as high lift, lift gate, hoist, etc.

VAN TYPES

Multi-Stop or Step Van (including hi-cube or cutaway)
Basic Enclosed Van (dry cargo)
Drop Frame Van (including furniture van, etc.)
Insulated, Nonrefrigerated Van
Insulated, Refrigerated Van
Open Top Van (including fruit)

SPECIALIZED USE TRUCKS

Automobile Transport
Beverage Truck
Concrete Mixer
Dump Truck (including belly or bottom dump)
Grain Bodies (including low-side grain and hoppers, etc.)
Garbage Truck
Livestock Truck (including livestock drop frame)
Oil Field Truck - service equipment permanently mounted on vehicle
Pole, Logging, Pulpwood, or Pipe Truck
Service Truck or "craftsman's vehicle" - body equipped for mobile repair and service
Dry Bulk Tank Truck
Liquid or Gas Tank Truck
Utility Truck - used in public utility operations (telephone line truck, etc.), body equipped for major repair (may have aerial lift, derrick, etc.)
Winch or Crane Truck - lifting equipment (including roll on, roll off) permanently mounted on vehicle
Wrecker - for motor vehicle towing or lifting
Yard Tractor - cab and chassis only, used to spot trailers

1992 Truck Inventory and Use Survey — Truck Body Types

Body Type by Number of Axles - Row Totals

	Naxles				
	Two Axles, Four Tires	Two Axles, Six Tires	Three Axles	Four or More Axles	
Body Type	1	2	3	4	Total for Body Type
Multi-Stop or Step Van	54.1%	45.9%	0.0%	0.0%	100%
Platform with Devices	11.3%	68.4%	18.8%	1.5%	100%
Low Boy Platform	8.3%	27.6%	61.6%	2.5%	100%
Basic Platform	29.2%	56.1%	14.1%	0.6%	100%
Livestock Truck	30.8%	45.2%	24.0%	0.0%	100%
Insulated, Non-Refrigerated Van	3.3%	52.1%	44.6%	0.0%	100%
Insulated, Refrigerated Van	24.7%	19.0%	54.6%	1.7%	100%
Drop Frame Van	16.6%	38.5%	44.9%	0.0%	100%
Open Top Van	0.0%	15.4%	81.7%	2.9%	100%
Basic Enclosed Van (Dry)	17.5%	51.5%	30.3%	0.6%	100%
Beverage Truck	23.8%	71.5%	4.7%	0.0%	100%
Utility Truck	31.5%	62.3%	5.2%	1.1%	100%
Winch or Crane Truck	12.1%	57.2%	29.3%	1.4%	100%
Wrecker	32.3%	64.9%	2.8%	0.0%	100%
Pole, Logging, Pipe Trucks	0.7%	12.8%	55.1%	31.4%	100%
Automobile Transport	0.9%	20.7%	78.4%	0.0%	100%
Service Truck	28.9%	70.4%	0.6%	0.0%	100%
Yard Tractor	18.2%	27.0%	54.8%	0.0%	100%
Oilfield Truck	5.7%	56.7%	37.6%	0.0%	100%
Grain Bodies	13.3%	54.3%	29.9%	2.5%	100%
Garbage Truck	0.0%	33.3%	58.2%	8.5%	100%
Dump Truck	11.6%	45.4%	32.3%	10.7%	100%
Liquid or Gas Tank Truck	8.6%	36.6%	52.0%	2.8%	100%
Dry Bulk Tank Truck	0.0%	40.7%	59.3%	0.0%	100%
Concrete Mixer	6.3%	4.4%	47.0%	42.4%	100%
Other	2.0%	62.3%	35.6%	0.0%	100%
Total for Naxles	22.0%	49.7%	25.3%	2.9%	100%

Body Type by Number of Axles - Column Totals

Body Type	Naxles: Two Axles, Four Tires 1	Two Axles, Six Tires 2	Three Axles 3	Four or More Axles 4	Total for Body Type
Multi-Stop or Step Van	19.8%	7.4%	0.0%	0.0%	8.1%
Platform with Devices	2.3%	6.1%	3.3%	2.2%	4.4%
Low Boy Platform	0.8%	1.2%	5.2%	1.8%	2.1%
Basic Platform	31.3%	26.6%	13.1%	4.5%	23.6%
Livestock Truck	1.5%	1.0%	1.0%	0.0%	1.1%
Insulated, Non-Refrigerated Van	0.1%	0.6%	1.0%	0.0%	0.6%
Insulated, Refrigerated Van	4.7%	1.6%	9.0%	2.4%	4.2%
Drop Frame Van	0.7%	0.7%	1.6%	0.0%	0.9%
Open Top Van	0.0%	0.1%	1.1%	0.3%	0.3%
Basic Enclosed Van (Dry)	13.3%	17.3%	20.0%	3.5%	16.7%
Beverage Truck	1.4%	1.8%	0.2%	0.0%	1.3%
Utility Truck	5.1%	4.5%	0.7%	1.3%	3.6%
Winch or Crane Truck	0.7%	1.4%	1.4%	0.6%	1.2%
Wrecker	2.6%	2.3%	0.2%	0.0%	1.8%
Pole, Logging, Pipe Trucks	0.0%	0.2%	2.1%	10.2%	1.0%
Automobile Transport	0.0%	0.1%	0.9%	0.0%	0.3%
Service Truck	3.0%	3.2%	0.1%	0.0%	2.3%
Yard Tractor	0.1%	0.1%	0.2%	0.0%	0.1%
Oilfield Truck	0.2%	0.9%	1.2%	0.0%	0.8%
Grain Bodies	4.2%	7.6%	8.2%	5.9%	7.0%
Garbage Truck	0.0%	0.5%	1.6%	2.0%	0.7%
Dump Truck	6.0%	10.5%	14.6%	41.8%	11.5%
Liquid or Gas Tank Truck	1.7%	3.3%	9.2%	4.3%	4.5%
Dry Bulk Tank Truck	0.0%	0.4%	1.0%	0.0%	0.4%
Concrete Mixer	0.4%	0.1%	2.5%	19.1%	1.3%
Other	0.0%	0.4%	0.5%	0.0%	0.3%
Total for Naxles	100.0%	100.0%	100.0%	100.0%	100.0%

Body Type by Number of Lift Axles - Row Totals

Body Type	Lift Axles One Lift Axle 1	 Two Lift Axles 2	 Three Lift Axles 3	Total for Body Type
Multi-Stop or Step Van	65.1%	34.9%	0.0%	100%
Platform with Devices	100.0%	0.0%	0.0%	100%
Low Boy Platform	90.5%	0.0%	9.5%	100%
Basic Platform	6.0%	94.0%	0.0%	100%
Livestock Truck	0.0%	0.0%	0.0%	100%
Insulated, Non-Refrigerated Van	100.0%	0.0%	0.0%	100%
Insulated, Refrigerated Van	66.0%	34.0%	0.0%	100%
Drop Frame Van	0.0%	0.0%	100.0%	100%
Open Top Van	100.0%	0.0%	0.0%	100%
Basic Enclosed Van (Dry)	59.5%	17.2%	23.3%	100%
Beverage Truck	0.0%	0.0%	0.0%	100%
Utility Truck	100.0%	0.0%	0.0%	100%
Winch or Crane Truck	100.0%	0.0%	0.0%	100%
Wrecker	100.0%	0.0%	0.0%	100%
Pole, Logging, Pipe Trucks	97.5%	2.5%	0.0%	100%
Automobile Transport	100.0%	0.0%	0.0%	100%
Service Truck	0.0%	100.0%	0.0%	100%
Yard Tractor	0.0%	0.0%	0.0%	100%
Oilfield Truck	0.0%	0.0%	0.0%	100%
Grain Bodies	94.8%	5.2%	0.0%	100%
Garbage Truck	100.0%	0.0%	0.0%	100%
Dump Truck	88.5%	11.5%	0.0%	100%
Liquid or Gas Tank Truck	83.6%	0.0%	16.4%	100%
Dry Bulk Tank Truck	100.0%	0.0%	0.0%	100%
Concrete Mixer	71.8%	27.0%	1.1%	100%
Other	0.0%	0.0%	0.0%	100%
Total for Lift Axles	64.4%	34.0%	1.6%	100%

Body Type by Number of Lift Axles — Column Totals

Body Type	Lift Axles: One Lift Axle 1	Two Lift Axles 2	Three Lift Axles 3	Total for Body Type
Multi-Stop or Step Van	3.8%	3.9%	0.0%	3.8%
Platform with Devices	2.3%	0.0%	0.0%	1.5%
Low Boy Platform	4.2%	0.0%	17.6%	3.0%
Basic Platform	2.5%	74.9%	0.0%	27.1%
Livestock Truck	0.0%	0.0%	0.0%	0.0%
Insulated, Non-Refrigerated Van	2.2%	0.0%	0.0%	1.4%
Insulated, Refrigerated Van	0.7%	0.7%	0.0%	0.7%
Drop Frame Van	0.0%	0.0%	27.3%	0.4%
Open Top Van	0.4%	0.0%	0.0%	0.2%
Basic Enclosed Van (Dry)	1.9%	1.0%	29.8%	2.1%
Beverage Truck	0.0%	0.0%	0.0%	0.0%
Utility Truck	3.4%	0.0%	0.0%	2.2%
Winch or Crane Truck	0.7%	0.0%	0.0%	0.4%
Wrecker	9.2%	0.0%	0.0%	5.9%
Pole, Logging, Pipe Trucks	10.2%	0.5%	0.0%	6.8%
Automobile Transport	0.7%	0.0%	0.0%	0.4%
Service Truck	0.0%	0.5%	0.0%	0.2%
Yard Tractor	0.0%	0.0%	0.0%	0.0%
Oilfield Truck	0.0%	0.0%	0.0%	0.0%
Grain Bodies	8.8%	0.1%	0.0%	6.0%
Garbage Truck	2.9%	0.0%	0.0%	1.9%
Dump Truck	29.1%	7.2%	0.0%	21.2%
Liquid or Gas Tank Truck	2.1%	0.0%	16.3%	1.6%
Dry Bulk Tank Truck	0.4%	0.0%	0.0%	0.2%
Concrete Mixer	14.7%	10.5%	9.0%	13.1%
Other	0.0%	0.00%	0.0%	0.0%
Total for Lift Axles	100.0%	100.0%	100.0%	100.0%

Body Type by Total Length — Row Totals

Body Type	Less than 13.0 Feet	13.0 to 15.9 Feet	16.0 to 19.9 Feet	20.0 to 27.9 Feet	28.0 to 35.9 Feet	36.0 to 40.9 Feet	41.0 to 44.9 Feet	45.0 to 49.9 Feet	50.0 to 54.9 Feet	55.0 to 59.9 Feet	60.0 to 64.9 Feet	65.0 to 69.9 Feet	70.0 to 74.9 Feet	75.0 Feet or More	Total for Body Type
Multi-Stop or Step Van	0.0%	8.9%	61.4%	27.4%	1.4%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Platform with Devices	0.0%	4.0%	26.2%	47.9%	11.1%	3.3%	0.1%	0.1%	2.2%	0.4%	3.2%	0.8%	0.6%	0.0%	100%
Low Boy Platform	0.0%	0.0%	4.2%	0.7%	11.8%	9.1%	2.1%	13.8%	16.4%	7.5%	13.0%	18.4%	2.0%	0.9%	100%
Basic Platform	0.5%	2.3%	43.7%	31.4%	4.3%	2.4%	0.1%	2.4%	1.1%	4.3%	3.8%	2.9%	0.6%	0.2%	100%
Livestock Truck	0.0%	0.0%	8.4%	57.7%	1.9%	0.0%	1.4%	0.0%	3.6%	6.3%	15.7%	4.1%	0.5%	0.5%	100%
Insulated, Non-Refrigerated Van	0.0%	0.0%	0.0%	44.8%	2.7%	0.0%	0.0%	0.6%	10.6%	15.3%	3.7%	22.3%	0.0%	0.0%	100%
Insulated, Refrigerated Van	0.0%	1.9%	8.0%	20.2%	9.3%	1.9%	2.2%	0.7%	1.6%	13.0%	22.0%	12.0%	4.3%	2.8%	100%
Drop Frame Van	0.0%	0.0%	1.0%	19.5%	0.4%	0.0%	0.9%	6.6%	9.2%	18.0%	24.6%	15.5%	0.6%	3.6%	100%
Open Top Van	0.0%	0.0%	0.0%	20.1%	22.6%	2.8%	0.0%	3.7%	9.3%	13.2%	14.3%	10.9%	0.0%	2.9%	100%
Basic Enclosed Van (Dry)	0.0%	1.8%	10.1%	28.1%	11.2%	5.6%	0.3%	1.0%	4.3%	11.6%	10.3%	8.8%	4.6%	2.3%	100%
Beverage Truck	0.0%	0.0%	4.7%	19.4%	25.8%	7.4%	7.9%	10.1%	4.1%	19.2%	1.4%	0.0%	0.0%	0.0%	100%
Utility Truck	0.0%	11.2%	24.5%	26.1%	15.8%	20.7%	1.2%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Winch or Crane Truck	0.0%	6.5%	9.7%	51.1%	27.1%	1.1%	0.3%	1.3%	0.2%	1.4%	0.9%	0.0%	0.0%	0.5%	100%
Wrecker	9.4%	10.1%	29.5%	40.3%	4.2%	1.2%	0.3%	0.0%	4.7%	0.4%	0.0%	0.0%	0.0%	0.0%	100%
Pole, Logging, Pipe Trucks	0.0%	0.9%	0.0%	15.0%	29.0%	1.3%	0.0%	15.0%	17.3%	9.3%	7.3%	3.6%	0.3%	1.0%	100%
Automobile Transport	0.0%	0.0%	0.0%	0.0%	4.9%	0.0%	0.0%	0.0%	0.9%	0.0%	5.3%	51.1%	8.7%	29.1%	100%
Service Truck	1.5%	3.6%	70.1%	18.7%	2.5%	3.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Yard Tractor	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.9%	45.7%	14.5%	33.9%	0.0%	0.0%	0.0%	100%
Oilfield Truck	0.0%	0.0%	34.6%	30.4%	26.8%	1.1%	0.0%	1.8%	0.0%	2.7%	2.3%	0.3%	0.0%	0.0%	100%
Grain Bodies	0.0%	0.8%	12.8%	61.3%	15.2%	0.0%	0.2%	0.6%	2.7%	3.3%	2.6%	0.2%	0.0%	0.4%	100%
Garbage Truck	0.0%	0.0%	3.5%	31.9%	56.2%	1.5%	0.0%	0.0%	0.6%	2.1%	4.2%	0.0%	0.0%	0.0%	100%
Dump Truck	0.4%	3.8%	30.4%	35.2%	6.2%	4.6%	3.4%	2.7%	7.1%	4.5%	1.1%	0.3%	0.0%	0.4%	100%
Liquid or Gas Tank Truck	1.4%	0.2%	2.2%	45.6%	9.2%	1.2%	1.3%	2.4%	8.2%	18.2%	7.5%	1.5%	0.4%	0.6%	100%
Dry Bulk Tank Truck	0.0%	0.0%	16.7%	21.2%	3.9%	0.0%	0.0%	8.7%	6.4%	13.6%	13.2%	4.1%	3.2%	9.0%	100%
Concrete Mixer	0.0%	0.0%	14.1%	15.8%	45.1%	24.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Other	0.0%	0.0%	19.2%	2.9%	10.7%	0.0%	0.0%	0.0%	3.3%	3.8%	12.3%	1.9%	3.3%	42.6%	100%
Total for Total Length	0.4%	3.1%	26.9%	32.6%	9.3%	3.8%	0.9%	1.9%	3.5%	6.1%	5.4%	3.7%	1.2%	1.0%	100%

Body Type by Total Length — Column Totals

Body Type	Less then 13.0 Feet	13.0 to 15.9 Feet	16.0 to 19.9 Feet	20.0 to 27.9 Feet	28.0 to 35.9 Feet	36.0 to 40.9 Feet	41.0 to 44.9 Feet	45.0 to 49.9 Feet	50.0 to 54.9 Feet	55.0 to 59.9 Feet	60.0 to 64.9 Feet	65.0 to 69.9 Feet	70.0 to 74.9 Feet	75.0 Feet or More	Total for Body Type
Multi-Stop or Step Van	0.0%	23.3%	18.4%	6.8%	1.3%	0.0%	6.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.1%
Platform with Devices	0.0%	5.7%	4.3%	6.5%	5.3%	3.8%	0.5%	0.1%	2.8%	0.3%	2.7%	0.9%	2.2%	0.0%	4.4%
Low Boy Platform	0.0%	0.0%	0.3%	0.0%	2.7%	5.1%	4.9%	15.4%	10.1%	2.7%	5.2%	10.6%	3.4%	1.9%	2.1%
Basic Platform	26.9%	17.8%	38.2%	22.7%	10.8%	14.9%	3.1%	28.8%	7.4%	16.8%	16.8%	18.2%	10.8%	4.9%	23.6%
Livestock Truck	0.0%	0.0%	0.3%	1.9%	0.2%	0.0%	1.6%	0.0%	1.1%	1.1%	3.1%	1.2%	0.4%	0.5%	1.1%
Insulated, Non-Refrigerated Van	0.0%	0.0%	0.0%	0.8%	0.2%	0.0%	0.0%	0.2%	1.7%	1.4%	0.4%	3.3%	0.0%	0.0%	0.6%
Insulated, Refrigerated Van	0.0%	2.6%	1.3%	2.6%	4.2%	2.1%	9.9%	1.5%	1.9%	8.9%	17.2%	13.4%	14.6%	11.7%	4.2%
Drop Frame Van	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.9%	3.2%	2.4%	2.8%	4.3%	3.8%	0.5%	3.4%	0.9%
Open Top Van	0.0%	0.0%	0.0%	0.2%	0.8%	0.2%	0.0%	0.6%	0.9%	0.7%	0.9%	1.0%	0.0%	1.0%	0.3%
Basic Enclosed Van (Dry)	0.0%	10.0%	6.3%	14.4%	20.1%	24.3%	5.9%	8.3%	20.5%	31.7%	31.9%	39.1%	62.1%	39.0%	16.7%
Beverage Truck	0.0%	0.0%	0.2%	0.8%	3.5%	2.5%	10.9%	6.7%	1.5%	4.0%	0.3%	0.0%	0.0%	0.0%	1.3%
Utility Truck	0.0%	13.0%	3.3%	2.9%	6.1%	19.5%	4.7%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	3.6%
Winch or Crane Truck	0.0%	2.6%	0.4%	1.9%	3.5%	0.3%	0.3%	0.8%	0.1%	0.3%	0.2%	0.0%	0.0%	0.6%	1.2%
Wrecker	40.0%	5.8%	1.9%	2.2%	0.8%	0.5%	0.5%	0.0%	2.4%	0.1%	0.0%	0.0%	0.0%	0.0%	1.8%
Pole, Logging, Pipe Trucks	0.0%	0.3%	0.0%	0.4%	3.0%	0.3%	0.0%	7.5%	4.7%	1.5%	1.3%	0.9%	0.2%	1.0%	1.0%
Automobile Transport	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.1%	0.0%	0.3%	4.1%	2.1%	8.7%	0.3%
Service Truck	8.4%	2.7%	6.0%	1.3%	0.6%	2.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.3%
Yard Tractor	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	1.5%	0.3%	0.7%	0.0%	0.0%	0.0%	0.1%
Oilfield Truck	0.0%	0.0%	1.1%	0.8%	2.4%	0.2%	0.0%	0.8%	0.0%	0.4%	0.4%	0.1%	0.0%	0.0%	0.8%
Grain Bodies	0.0%	1.7%	3.3%	13.1%	11.3%	0.0%	1.6%	2.1%	5.4%	3.8%	3.4%	0.3%	0.0%	2.6%	7.0%
Garbage Truck	0.0%	0.0%	0.1%	0.7%	4.2%	0.3%	0.0%	0.0%	0.1%	0.2%	0.5%	0.0%	0.0%	0.0%	0.7%
Dump Truck	9.8%	14.2%	13.0%	12.4%	7.6%	13.6%	42.0%	16.2%	23.2%	8.5%	2.3%	0.8%	0.2%	4.2%	11.5%
Liquid or Gas Tank Truck	15.0%	0.3%	0.4%	6.2%	4.4%	1.4%	6.4%	5.5%	10.5%	13.4%	6.3%	1.8%	1.5%	2.7%	4.5%
Dry Bulk Tank Truck	0.0%	0.0%	0.3%	0.3%	0.2%	0.0%	0.0%	2.0%	0.8%	1.0%	1.1%	0.5%	1.1%	4.0%	0.4%
Concrete	0.0%	0.0%	0.7%	0.6%	6.4%	8.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%

Body Type by Average Gross Vehicle Weight — Row Totals

Body Type	6,000 or Less	6,001 to 10,000	10,001 to 14,000	14,001 to 16,000	16,001 to 19,500	19,501 to 26,000	26,001 to 33,000	33,001 to 40,000	40,001 to 50,000	50,001 to 60,000	60,001 to 80,000	80,001 to 100,000	100,001 to 130,000	130,001 and Over	Total for Body Type
Multi-Stop or Step Van	22.8%	53.1%	17.8%	2.9%	1.7%	1.3%	0.2%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	100%
Platform with Devices	5.1%	18.2%	10.7%	6.9%	8.2%	23.9%	11.5%	4.5%	6.0%	2.2%	2.4%	0.2%	0.1%	0.0%	100%
Low Boy Platform	1.0%	1.8%	3.2%	0.9%	1.8%	8.5%	8.1%	8.8%	11.2%	12.1%	33.5%	6.1%	2.2%	0.8%	100%
Basic Platform	13.3%	27.0%	12.5%	6.8%	5.5%	13.0%	4.5%	2.6%	3.1%	1.6%	9.8%	0.3%	0.1%	0.1%	100%
Livestock Truck	1.9%	14.2%	13.1%	7.2%	4.5%	19.1%	10.7%	2.1%	5.0%	1.5%	19.7%	0.9%	0.1%	0.0%	100%
Insulated, Non-Refrigerated Van	0.0%	8.1%	5.0%	0.8%	4.4%	20.9%	7.7%	2.5%	8.8%	4.5%	36.5%	0.6%	0.2%	0.0%	100%
Insulated, Refrigerated Van	1.5%	5.4%	5.4%	3.1%	5.2%	12.3%	8.2%	4.6%	6.1%	5.1%	42.6%	0.3%	0.1%	0.0%	100%
Drop Frame Van	1.3%	10.8%	8.2%	3.7%	2.2%	16.6%	7.1%	9.7%	13.8%	13.6%	13.0%	0.1%	0.0%	0.0%	100%
Open Top Van	0.9%	6.2%	7.3%	2.4%	0.6%	5.4%	9.1%	7.1%	10.6%	4.9%	37.1%	5.6%	2.5%	0.3%	100%
Basic Enclosed Van (Dry)	2.2%	11.3%	7.6%	4.3%	6.6%	13.3%	6.2%	6.2%	7.8%	7.0%	27.1%	0.2%	0.1%	0.0%	100%
Beverage Truck	0.5%	3.4%	5.3%	1.5%	2.8%	24.0%	32.1%	14.0%	9.9%	4.7%	1.6%	0.1%	0.0%	0.0%	100%
Utility Truck	7.1%	28.0%	12.2%	5.8%	8.1%	20.1%	12.7%	3.9%	1.3%	0.6%	0.2%	0.0%	0.0%	0.0%	100%
Winch or Crane Truck	2.1%	14.2%	12.0%	9.2%	6.7%	16.7%	10.6%	7.6%	10.7%	3.5%	5.3%	0.7%	0.6%	0.1%	100%
Wrecker	10.9%	35.0%	28.6%	8.1%	3.6%	8.4%	2.0%	2.1%	0.7%	0.3%	0.2%	0.0%	0.0%	0.0%	100%
Pole, Logging, Pipe Trucks	1.4%	2.0%	4.0%	3.4%	2.7%	6.1%	5.6%	4.0%	7.3%	4.8%	51.7%	6.2%	0.7%	0.1%	100%
Automobile Transport	0.4%	3.9%	10.8%	3.2%	4.9%	4.8%	1.3%	3.9%	2.8%	3.0%	60.8%	0.1%	0.0%	0.0%	100%
Service Truck	20.9%	45.7%	17.3%	4.1%	3.5%	6.1%	1.6%	0.3%	0.3%	0.1%	0.1%	0.0%	0.0%	0.0%	100%
Yard Tractor	0.4%	8.2%	6.8%	4.3%	4.4%	12.9%	7.8%	15.5%	11.4%	5.8%	20.6%	1.8%	0.0%	0.0%	100%
Oilfield Truck	5.2%	11.9%	8.1%	5.5%	5.7%	16.1%	7.0%	5.5%	11.4%	8.6%	14.4%	0.4%	0.2%	0.0%	100%
Grain Bodies	0.9%	4.6%	5.2%	4.1%	5.5%	29.2%	15.6%	7.0%	12.4%	2.9%	11.5%	0.9%	0.2%	0.0%	100%
Garbage Truck	0.0%	1.8%	3.2%	1.3%	2.8%	10.2%	16.4%	11.1%	23.7%	20.0%	9.1%	0.2%	0.0%	0.1%	100%
Dump Truck	1.9%	11.8%	8.7%	5.9%	5.9%	15.3%	8.6%	5.3%	11.1%	7.1%	16.3%	1.4%	0.4%	0.4%	100%
Liquid or Gas Tank Truck	0.4%	2.1%	4.0%	4.1%	5.7%	22.6%	13.0%	6.3%	7.3%	4.6%	27.0%	1.5%	1.2%	0.1%	100%
Dry Bulk Tank Truck	0.0%	0.0%	0.0%	0.2%	2.0%	15.3%	11.4%	6.3%	7.4%	5.0%	49.2%	1.1%	1.8%	0.2%	100%
Concrete Mixer	0.0%	0.0%	0.0%	0.6%	0.1%	1.9%	3.7%	5.2%	21.6%	33.4%	32.8%	0.6%	0.0%	0.1%	100%
Other	1.7%	7.9%	9.2%	7.9%	3.9%	14.2%	18.9%	10.8%	14.3%	4.4%	6.6%	0.2%	0.0%	0.0%	100%
Total for TIUS GVW	7.1%	18.9%	10.1%	5.0%	5.2%	14.3%	7.6%	4.5%	6.6%	4.4%	15.3%	0.7%	0.2%	0.1%	100%

Body Type by Average Gross Vehicle Weight — Column Totals

Body Type	6,000 or Less	6,001 to 10,000	10,001 to 14,000	14,001 to 16,000	16,001 to 19,500	19,501 to 26,000	26,001 to 33,000	33,001 to 40,000	40,001 to 50,000	50,001 to 60,000	60,001 to 80,000	80,001 to 100,000	100,001 to 130,000	130,001 and Over	Total for Body Type
Multi-Stop or Step Van	25.8%	22.5 %	14.1%	4.6%	2.6%	0.7%	0.2%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	8.0%
Platform with Devices	4.2%	5.6%	6.1%	8.0%	9.1%	9.6%	8.8%	5.8%	5.3%	2.9%	0.9%	1.9%	1.2%	1.6%	5.8%
Low Boy Platform	0.2%	0.2%	0.6%	0.3%	0.6%	1.0%	1.9%	3.4%	3.0%	4.8%	3.8%	16.4%	15.7%	15.7%	1.8%
Basic Platform	43.6%	33.1%	28.6%	31.3%	24.4%	21.0%	13.7%	13.0%	10.8%	8.5%	14.8%	9.9%	11.9%	13.9%	23.1%
Livestock Truck	0.2%	0.7%	1.2%	1.4%	0.8%	1.3%	1.3%	0.4%	0.7%	0.3%	1.2%	1.3%	0.3%	0.0%	0.9%
Insulated, Non-Refrigerated Van	0.0%	0.2%	0.2%	0.1%	0.4%	0.7%	0.5%	0.3%	0.6%	0.5%	1.1%	0.4%	0.5%	0.00%	0.5%
Insulated, Refrigerated Van	0.8%	1.1%	2.2%	2.5%	4.0%	3.4%	4.4%	4.1%	3.7%	4.6%	11.2%	1.9%	1.6%	0.1%	4.0%
Drop Frame Van	0.2%	0.7%	1.0%	0.9%	0.5%	1.4%	1.1%	2.5%	2.4%	3.6%	1.0%	0.3%	0.0%	0.0%	1.2%
Open Top Van	0.0%	0.1%	0.3%	0.2%	0.0%	0.1%	0.5%	0.6%	0.6%	0.4%	1.0%	3.4%	4.1%	1.5%	0.4%
Basic Enclosed Van (Dry)	4.7%	9.2%	11.6%	13.4%	19.4%	14.3%	12.6%	21.1%	18.2%	24.3%	27.3%	5.6%	3.4%	2.5%	15.4%
Beverage Truck	0.1%	0.3%	0.7 %	0.4%	0.8%	2.4%	6.1%	4.4%	2.1%	1.5%	0.2%	0.2%	0.1%	0.6%	1.4%
Utility Truck	3.1%	4.6%	3.7 %	3.5 %	4.7 %	4.3 %	5.1 %	2.6%	0.6 %	0.4%	0.0%	0. 0%	0. 0%	0. 0%	3.1 %
Winch or Crane Truck	0.3%	0.9%	1.4 %	2.1%	1.5%	1.3%	1.6%	1.9%	1.9%	0.9%	0.4%	1.2%	2.9%	0.9%	1.1%
Wrecker	3.1 %	3.8%	5. 8%	3.3 %	1.4 %	1.2%	0. 5%	0.9 %	0.2 %	0.1 %	0.0 %	0.1 %	0.1 %	0.2 %	2.0 %
Pole, Logging, Pipe Trucks	0.2%	0.1%	0.4%	0.7%	0.5%	0.4%	0.8%	0.9%	1.2%	1.1%	3.6%	10.0%	3.2%	1.5%	1.1%
Automobile Transport	0.0%	0.1%	0.5 %	0.3 %	0.4 %	0.1 %	0.1 %	0.4 %	0.2%	0.3 %	1.7%	0.1 %	0. 0%	0. 0%	0.4 %
Service Truck	8.3%	6.8%	4.8 %	2.0%	1.9%	1.2%	0.6%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	2.8%
Yard Tractor	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.5%	0.3%	0.2%	0.2%	0. 4%	0. 0%	0.0 %	0.2 %
Oilfield Truck	0.4%	0.3%	0.4%	0.6%	0.6%	0.6%	0.5%	0.6%	0.9%	1.0%	0.5%	0.3%	0.4%	0.1%	0.5%
Grain Bodies	0.7%	1.5%	3.2%	5.0%	6.4%	12.4%	12.5%	9.3%	11.4%	4.0%	4.6%	8.4%	5.6%	0.0%	6.1%
Garbage Truck	0.0%	0.1%	0.5%	0.4%	0.8%	1.0%	3.1%	3.5%	5.1%	6.4%	0.8%	0.5%	0.0%	2.2%	1.4%
Dump Truck	3.3%	7.5%	10.3%	14.1%	13.5%	12.8%	13.6%	13.8%	20.1%	19.0%	12.8%	25.5%	22.0%	50.4%	12.0%
Liquid or Gas Tank Truck	0.2%	0.5%	1.8%	3.7%	5.0%	7.2%	7.8%	6.3%	5.0%	4.7%	8.0%	10.1%	22.1%	6.2%	4.5%
Dry Bulk Tank Truck	0.0%	0.0%	0.0%	0.0%	0.3%	0.7%	1.0%	0.9%	0.7%	0.7%	2.1%	1.1%	4.9%	1.5%	0.7%
Concrete Mixer	0.0%	0.0%	0.0%	0.1%	0.0%	0.2%	0.6%	1.4%	3.9%	9.0%	2.6%	1.0%	0.0%	0.9%	1.2%
Other	0.1%	0.2%	0.4%	0.7%	0.3%	0.5%	1.2%	1.1%	1.0%	0.5%	0.2%	0.2%	0.1%	0.0%	0.5%
Total for TIUS GVW	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Body Type by Kind of Trailer Pulled by Truck Tractors — Row Totals

Body Type	One Axle on One Semi-Trailer	Two Axles on One Semi-Trailer	Three or More Axles on One Semi-Trailer	Three Axles on Two Trailers	Four Axles on Two Trailers	Five Axles on Two Trailers	Six Axles on Two Trailers	Five Axles on Three Trailers	Total for Body Type
Multi-Stop or Step Van	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Platform with Devices	0.0%	88.6%	11.4%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Low Boy Platform	7.7%	59.7%	31.2%	0.0%	0.7%	0.7%	0.0%	0.0%	100%
Basic Platform	3.9%	78.6%	5.5%	8.6%	0.5%	0.5%	2.4%	0.0%	100%
Livestock Truck	7.1%	92.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Insulated, Non-Refrigerated Van	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Insulated, Refrigerated Van	5.5%	88.5%	1.3%	3.2%	0.2%	0.2%	1.1%	0.0%	100%
Drop Frame Van	7.7%	82.6%	5.1%	3.9%	0.0%	0.0%	0.6%	0.0%	100%
Open Top Van	0.0%	80.9%	10.5%	0.0%	4.3%	4.3%	0.0%	0.0%	100%
Basic Enclosed Van (Dry)	12.5%	69.7%	3.4%	13.9%	0.2%	0.0%	0.2%	0.2%	100%
Beverage Truck	38.2%	61.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Utility Truck	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Winch or Crane Truck	9.7%	66.6%	23.7%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Wrecker	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Pole, Logging, Pipe Trucks	0.0%	95.1%	3.8%	0.0%	0.0%	1.1%	0.0%	0.0%	100%
Automobile Transport	0.9%	99.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Service Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Yard Tractor	20.6%	78.5%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Oilfield Truck	0.0%	94.7%	5.3%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Grain Bodies	4.9%	78.9%	1.5%	10.6%	2.6%	1.5%	0.0%	0.0%	100%
Garbage Truck	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Dump Truck	0.0%	80.8%	9.4%	7.3%	0.3%	0.3%	1.9%	0.0%	100%
Liquid or Gas Tank Truck	0.1%	95.9%	3.0%	0.0%	0.9%	0.1%	0.0%	0.0%	100%
Dry Bulk Tank Truck	0.0%	85.3%	8.8%	2.4%	1.9%	0.0%	1.6%	0.0%	100%
Concrete Mixer	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Other	0.0%	69.0%	31.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Total for Length of First Trailer	7.7%	77.6%	6.1%	7.2%	0.4%	0.3%	0.7%	0.1%	100%

Body Type by Kind of Trailer Pulled by Truck Tractors — Column Totals

Body Type	One Axle on One Semi-Trailer	Two Axles on One Semi-Trailer	Three or More Axles on Two Trailers	Three Axles on Two Trailers	Four Axles on Two Trailers	Five Axles on Two Trailers	Six Axles on Two Trailers	Five Axles on Three Trailers	Total for Body Type
Multi-Stop or Step Van	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
Platform with Devices	0.0%	1.0%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%
Low Boy Platform	7.2%	5.5%	36.6%	0.0%	12.4%	18.8%	0.0%	0.0%	7.2%
Basic Platform	7.1%	14.1%	12.5%	16.8%	16.8%	25.5%	48.4%	0.0%	14.0%
Livestock Truck	1.3%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%
Insulated, Non-Refrigerated Van	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%
Insulated, Refrigerated Van	7.6%	12.2%	2.3%	4.8%	4.8%	7.3%	17.6%	0.0%	10.7%
Drop Frame Van	3.2%	3.3%	2.6%	1.7%	0.0%	0.0%	2.9%	0.0%	3.1%
Open Top Van	0.0%	1.0%	1.6%	0.0%	9.8%	14.9%	0.0%	0.0%	0.9%
Basic Enclosed Van (Dry)	55.1%	30.3%	18.8%	65.1%	13.3%	0.0%	9.1%	100.0%	33.8%
Beverage Truck	14.2%	2.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.8%
Utility Truck	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Winch or Crane Truck	0.3%	0.2%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
Wrecker	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pole, Logging, Pipe Trucks	0.0%	2.5%	1.3%	0.0%	0.0%	7.8%	0.0%	0.0%	2.0%
Automobile Transport	0.1%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%
Service Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Yard Tractor	1.3%	0.5%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
Oilfield Truck	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
Grain Bodies	1.7%	2.8%	0.7%	4.0%	17.1%	14.9%	0.0%	0.0%	2.7%
Garbage Truck	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
Dump Truck	0.0%	7.3%	10.8%	7.2%	5.1%	7.3%	19.4%	0.0%	7.0%
Liquid or Gas Tank Truck	0.1%	9.1%	3.7%	0.0%	15.6%	3.6%	0.0%	0.0%	7.4%
Dry Bulk Tank Truck	0.0%	1.2%	1.6%	0.4%	5.1%	0.0%	2.6%	0.0%	1.1%
Concrete Mixer	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other	0.0%	0.8%	4.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%
Total for Length of First Trailer	100%	100%	100%	100%	100%	100%	100%	100%	100%

Body Type by Kind of Trailer Pulled by Straight Trucks — Row Totals

Body Type	One Axle on Trailer < 20 Feet	Two Axles on Trailer < 20 Feet	Three Axles on Trailer < 20 Feet	Two Axles on Full Trailer or Semi-Trailer	Three Axles on Full Trailer or Semi-Trailer	Four or More Axles on Full Trailer or Semi-Trailer	Total for Body Type
Multi-Stop or Step Van	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Platform with Devices	26.3%	42.5%	0.0%	31.2%	0.0%	0.0%	100%
Low Boy Platform	0.0%	8.1%	0.0%	81.9%	10.0%	0.0%	100%
Basic Platform	16.2%	37.7%	5.0%	40.5%	0.6%	0.0%	100%
Livestock Truck	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100%
Insulated, Non-Refrigerated Van	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Insulated, Refrigerated Van	78.7%	0.0%	0.0%	21.3%	0.0%	0.0%	100%
Drop Frame Van	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Open Top Van	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100%
Basic Enclosed Van (Dry)	6.6%	1.2%	0.0%	92.2%	0.0%	0.0%	100%
Beverage Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Utility Truck	50.3%	35.8%	0.0%	13.9%	0.0%	0.0%	100%
Winch or Crane Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Wrecker	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Pole, Logging, Pipe Trucks	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100%
Automobile Transport	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Service Truck	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100%
Yard Tractor	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Oilfield Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Grain Bodies	23.9%	0.0%	0.0%	70.4%	5.6%	0.0%	100%
Garbage Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Dump Truck	0.0%	45.0%	10.4%	42.6%	2.0%	0.0%	100%
Liquid or Gas Tank Truck	0.0%	0.0%	0.0%	61.1%	28.3%	10.5%	100%
Dry Bulk Tank Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Concrete Mixer	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
Total	19.5%	35.9%	3.7%	39.1%	1.7%	0.1%	100%

Body Type by Kind of Trailer Pulled by Straight Trucks — Column Totals

Body Type	One Axle on Trailer < 20 Feet	Two Axles on Trailer < 20 Feet	Three Axles on Trailer < 20 Feet	Two Axles on Full Trailer or Semi-Trailer	Three Axles on Full Trailer or Semi-Trailer	Four or More Axles on Full Trailer or Semi-Trailer	Total for Body Type
Multi-Stop or Step Van	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
Platform with Devices	8.8%	7.7%	0.0%	5.2%	0.0%	0.0%	6.5%
Low Boy Platform	0.0%	1.7%	0.0%	15.7%	43.8%	0.0%	7.5%
Basic Platform	19.8%	25.0%	32.2%	24.6%	8.3%	0.0%	23.8%
Livestock Truck	0.0%	4.9%	0.0%	0.0%	0.0%	0.0%	1.8%
Insulated, Non-Refrigerated Van	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Insulated, Refrigerated Van	6.4%	0.0%	0.0%	0.9%	0.0%	0.0%	1.6%
Drop Frame Van	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Open Top Van	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	0.5%
Basic Enclosed Van (Dry)	1.5%	0.1%	0.0%	10.5%	0.0%	0.0%	4.5%
Beverage Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Utility Truck	60.0%	23.1%	0.0%	8.2%	0.0%	0.0%	23.2%
Winch or Crane Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Wrecker	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pole, Logging, Pipe Trucks	0.0%	0.0%	0.0%	3.0%	0.0%	0.0%	1.2%
Automobile Transport	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Service Truck	0.0%	7.4%	0.0%	0.0%	0.0%	0.0%	2.7%
Yard Tractor	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Oilfield Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Grain Bodies	2.0%	0.0%	0.0%	3.0%	5.4%	0.0%	1.7%
Garbage Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Dump Truck	0.0%	30.1%	67.8%	26.2%	27.8%	0.0%	24.0%
Liquid or Gas Tank Truck	0.0%	0.0%	0.0%	1.4%	14.7%	100.0%	0.9%
Dry Bulk Tank Truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Concrete Mixer	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100%	100%	100%	100%	100%	100%	100%

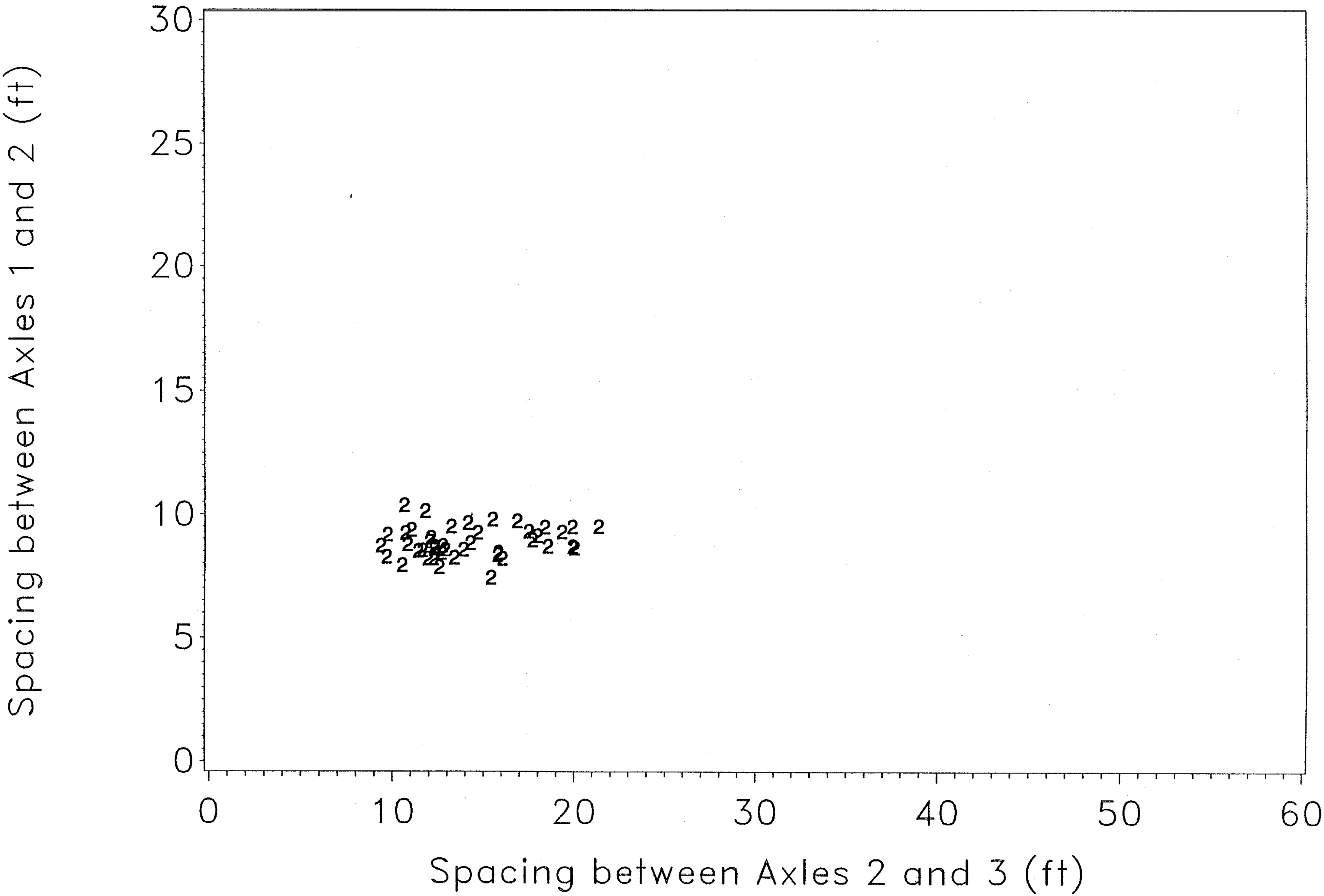
Appendix B

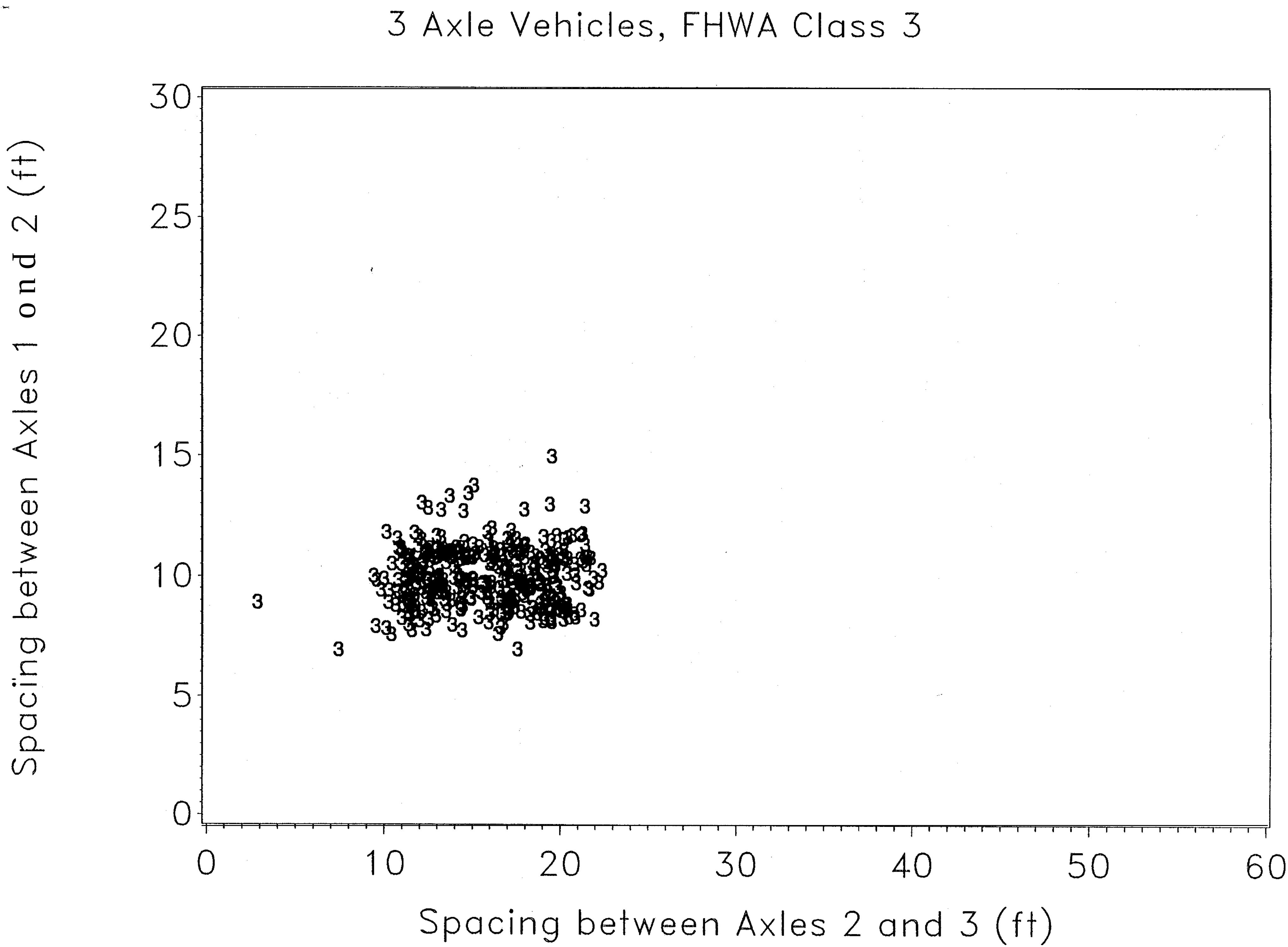
Box and Whisker Plots and Scatter Plots based on the Georgia Dataset

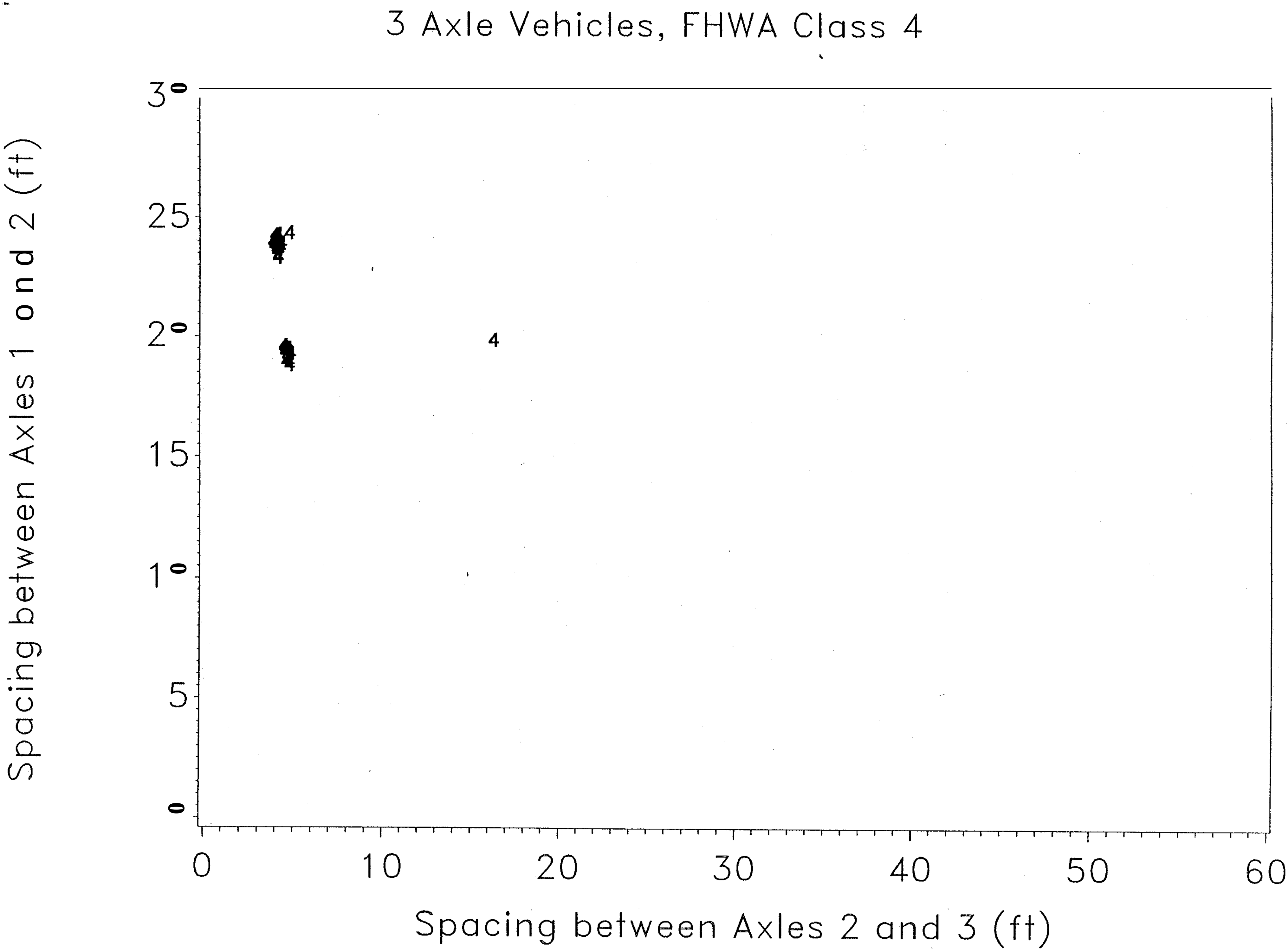
Figure B-1

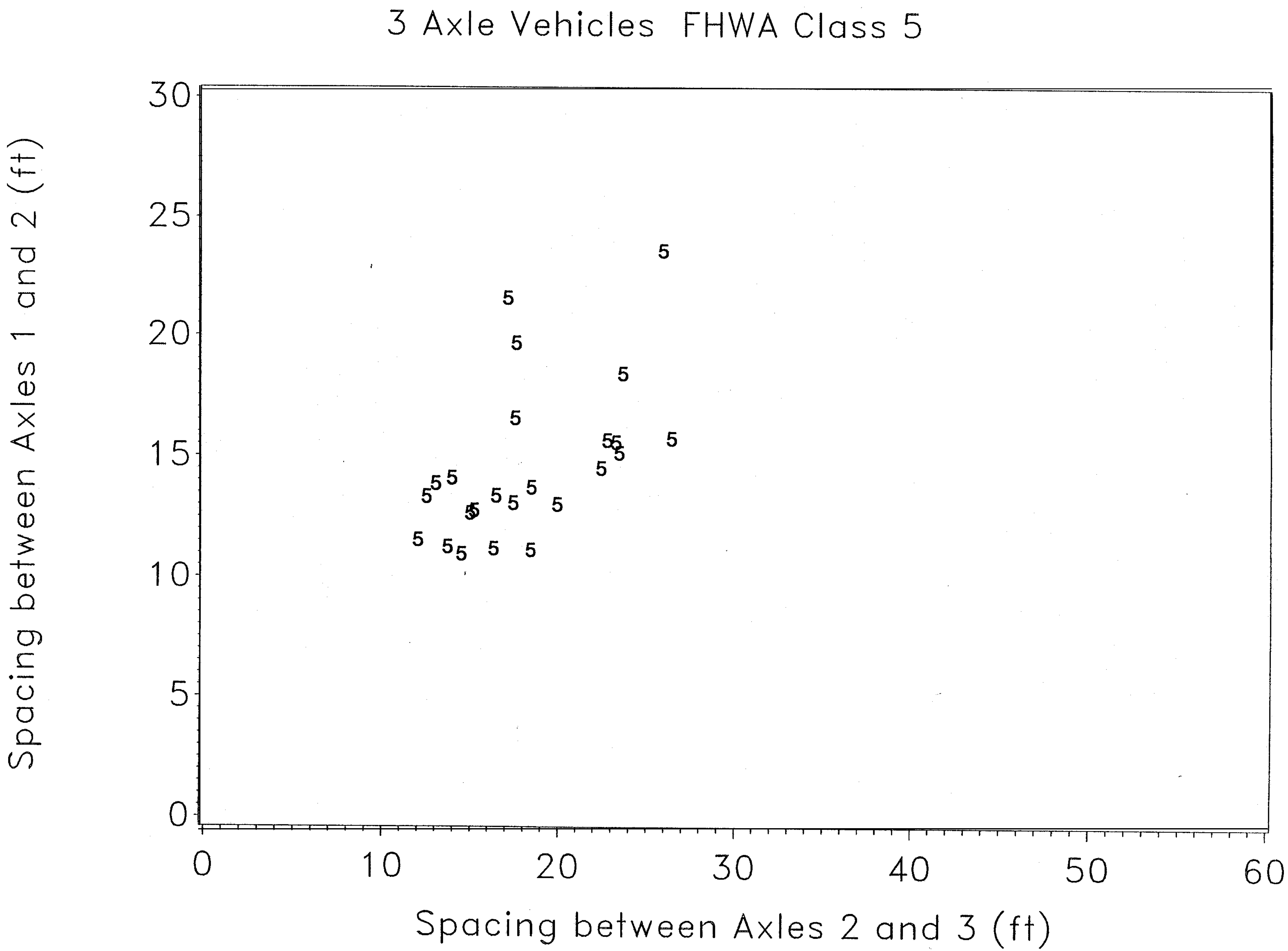
Scatter Plots of Axle Spacing by FHWA Class and Number of Axles

3 Axle Vehicles, FHWA Class 2

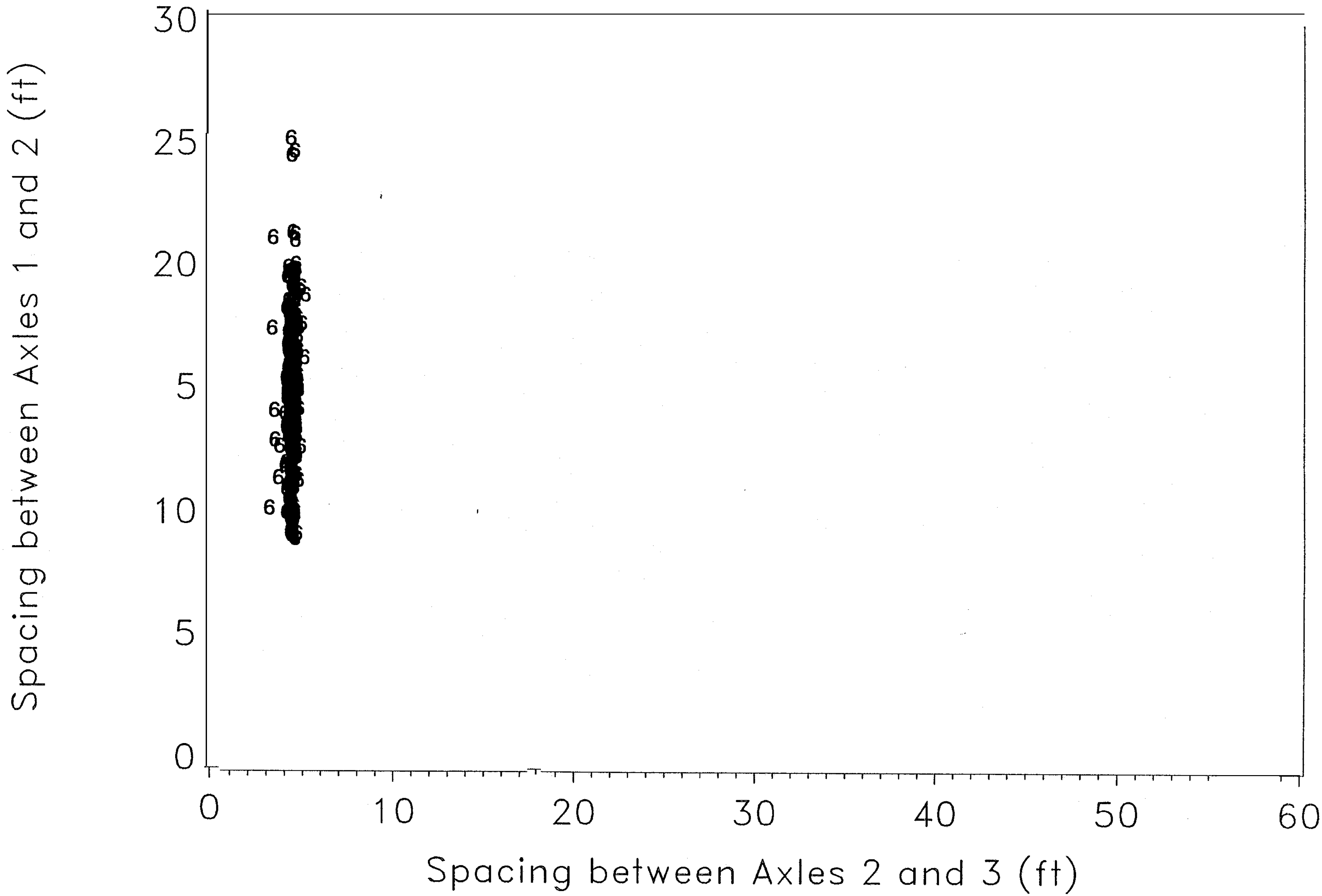


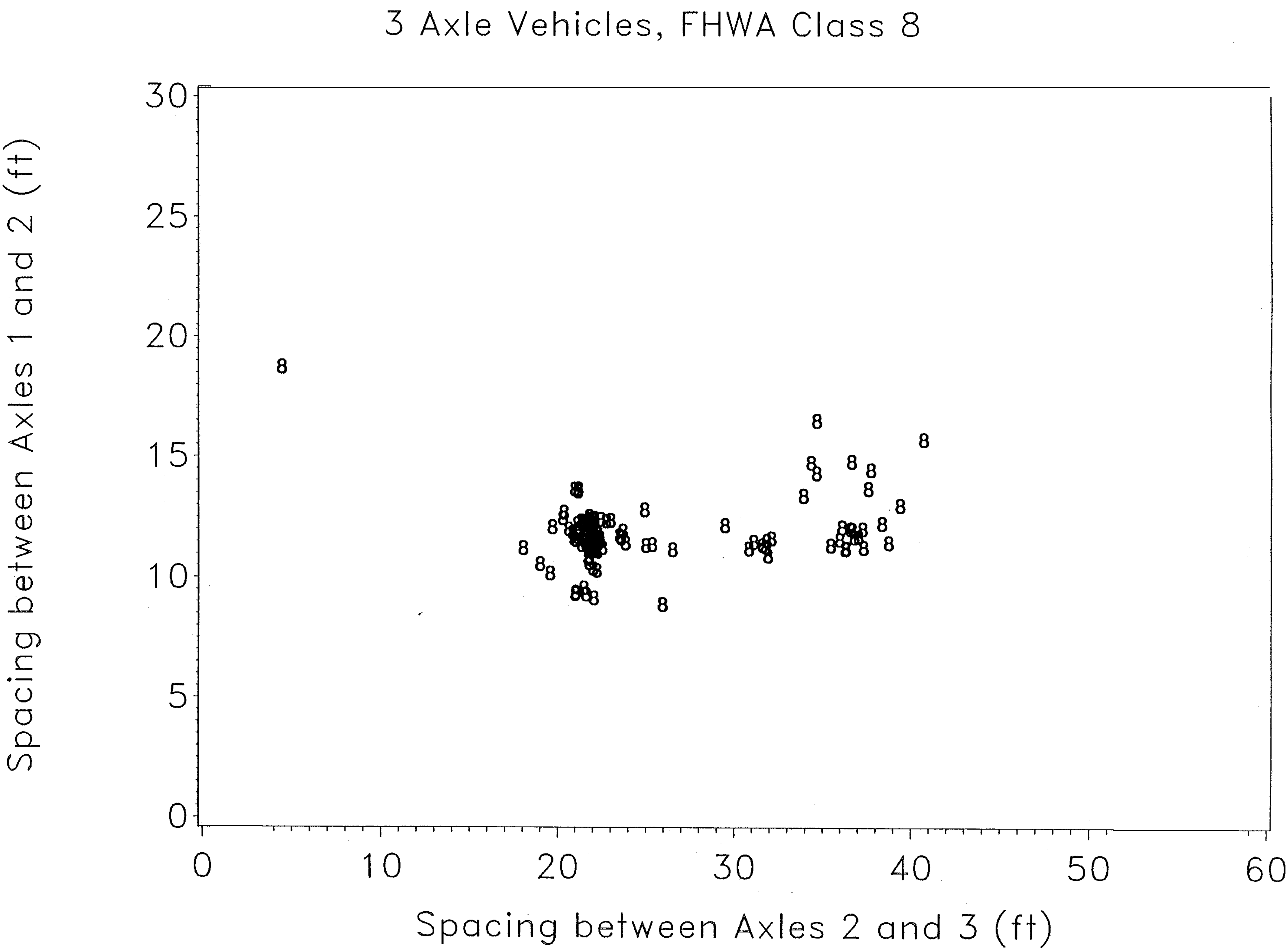

3 Axle Vehicles, FHWA Class 3
Spacing between Axles 1 ond 2 (ft)
Spacing between Axles 2 and 3 (ft)
0
5
10
15
20
25
30
0
10
20
30
40
50
60


3 Axle Vehicles, FHWA Class 4
Spacing between Axles 1 and 2 (ft)
Spacing between Axles 2 and 3 (ft)
0
5
10
15
20
25
30
0
10
20
30
40
50
60
4

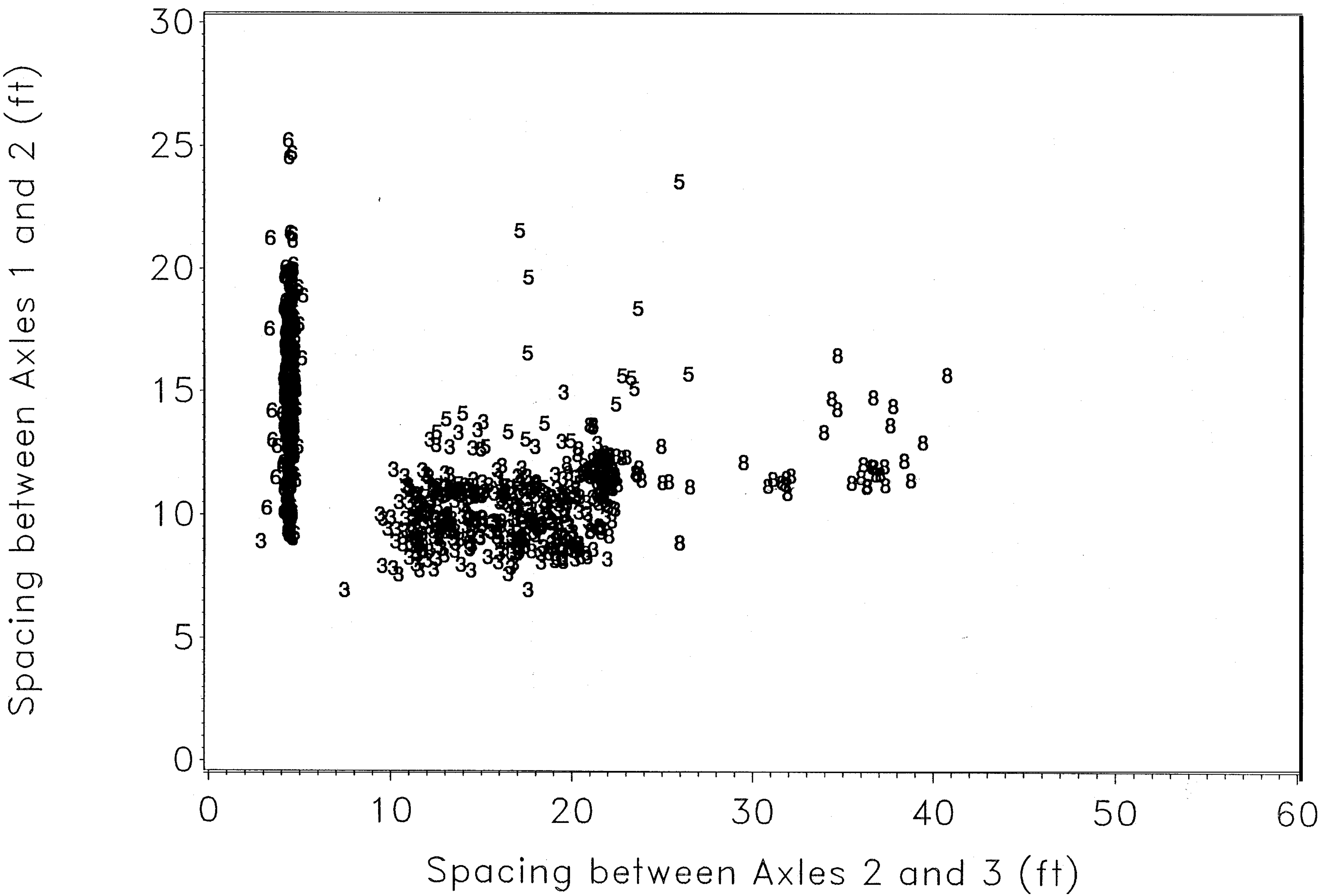

3 Axle Vehicles FHWA Class 5
Spacing between Axles 1 and 2 (ft)
Spacing between Axles 2 and 3 (ft)
0
5
10
15
20
25
30
0
10
20
30
40
50
60

3 Axle Vehicles, FHWA Class 6

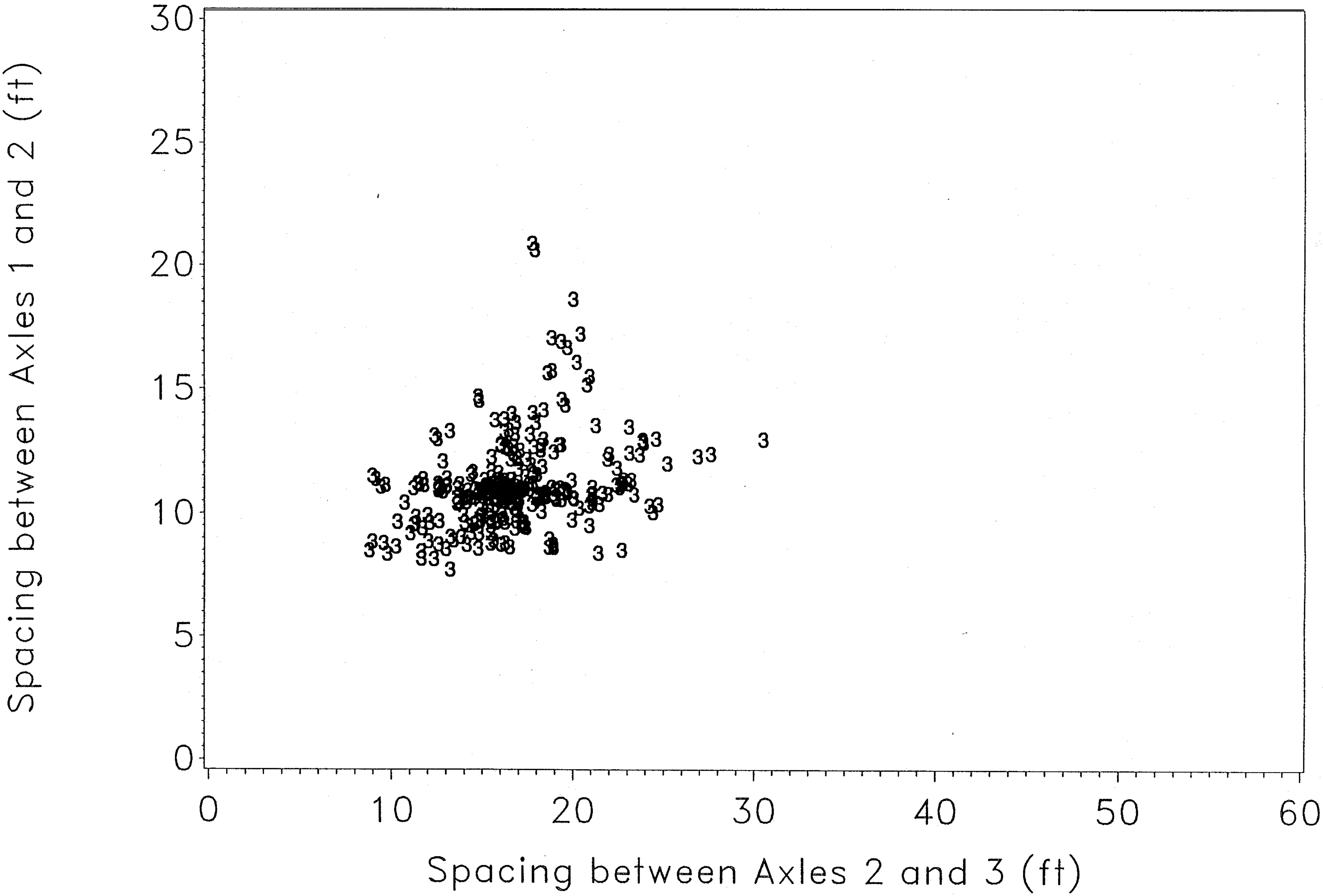



3 Axle Vehicles, FHWA Class 8
Spacing between Axles 1 and 2 (ft)
30
25
20
15
10
5
0
0
10
20
30
40
50
60
Spacing between Axles 2 and 3 (ft)

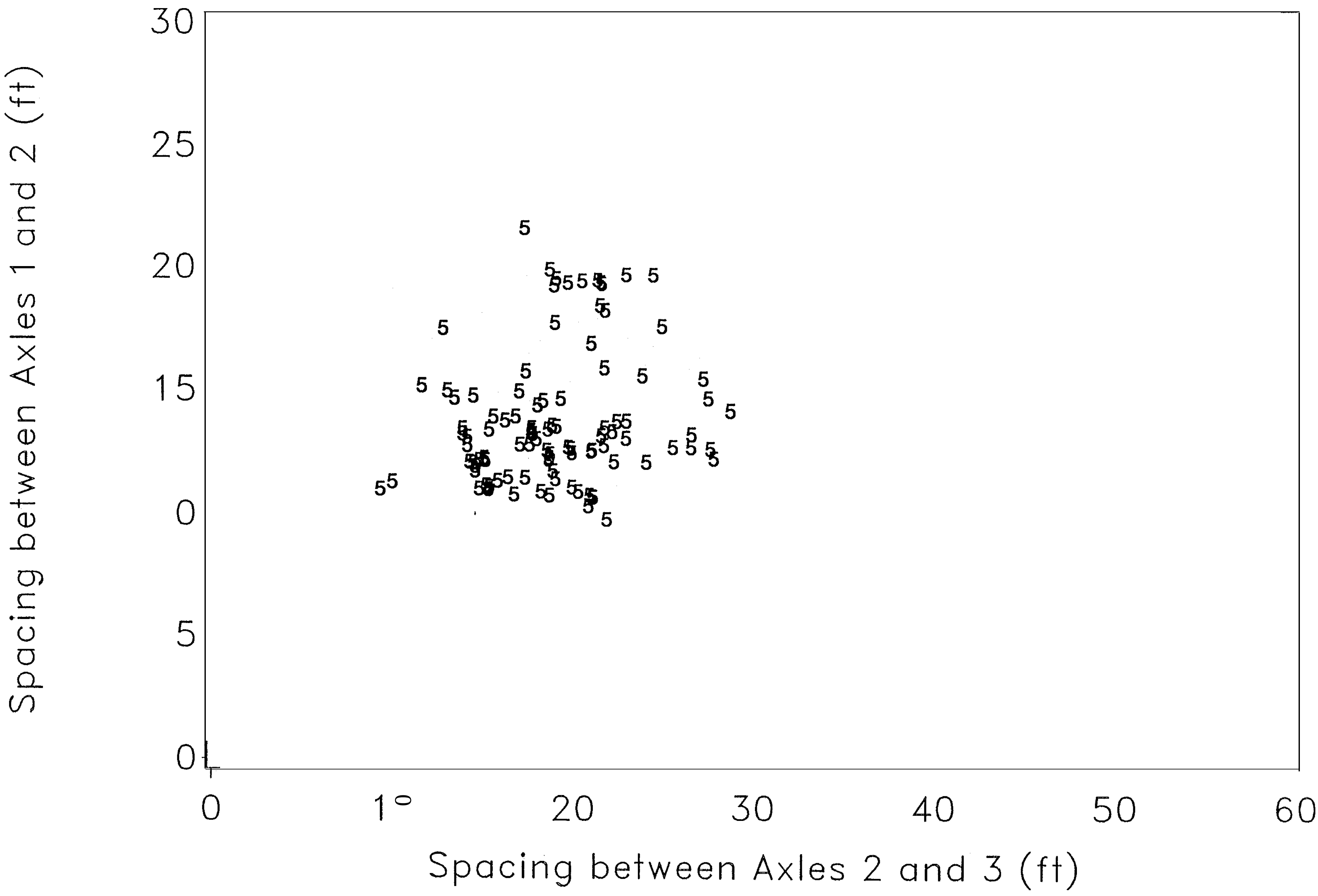
3 Axle Vehicles, FHWA Classes 3, 5, 6, 8

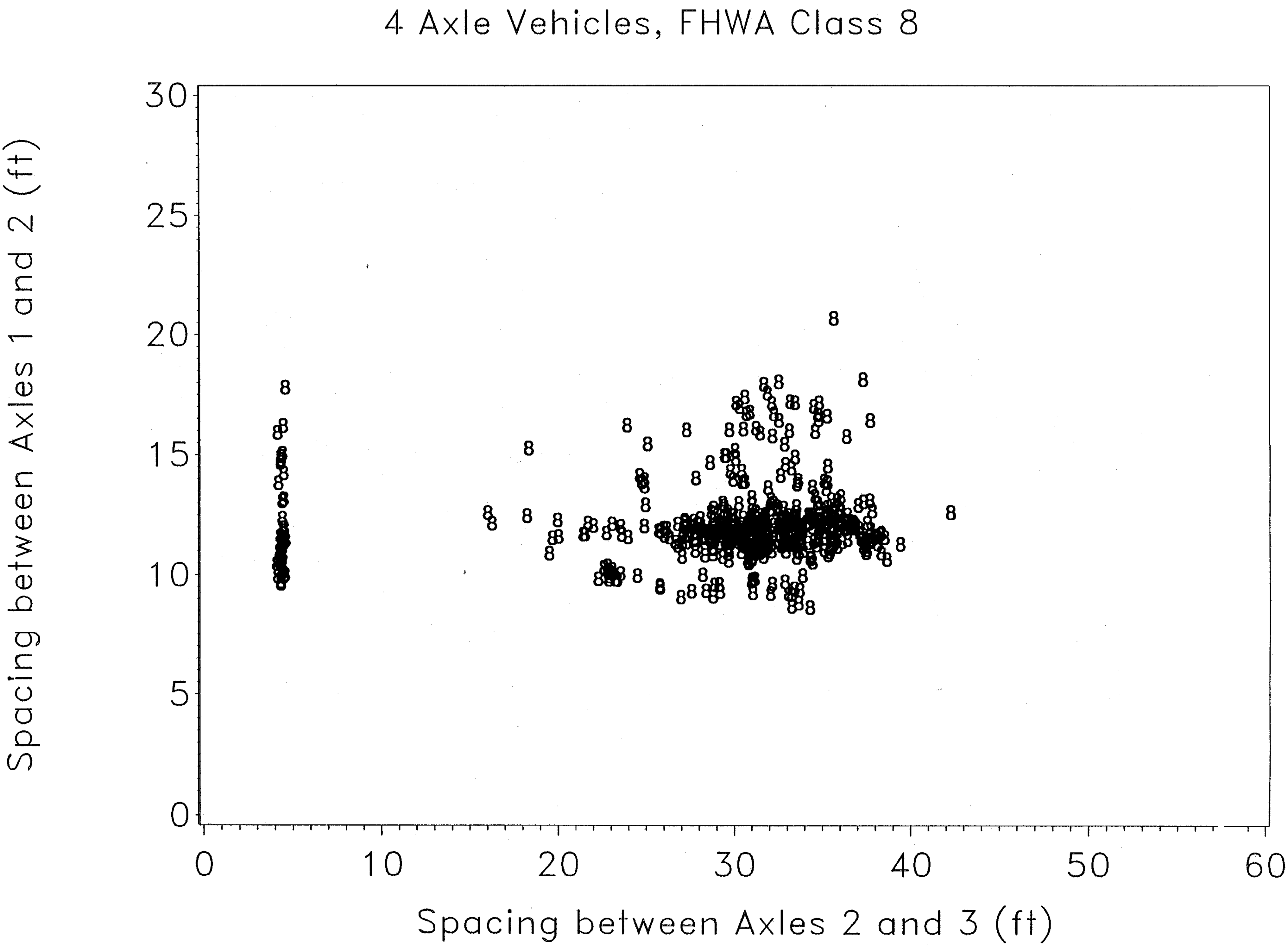


4 Axle Vehicles, FHWA Class 3

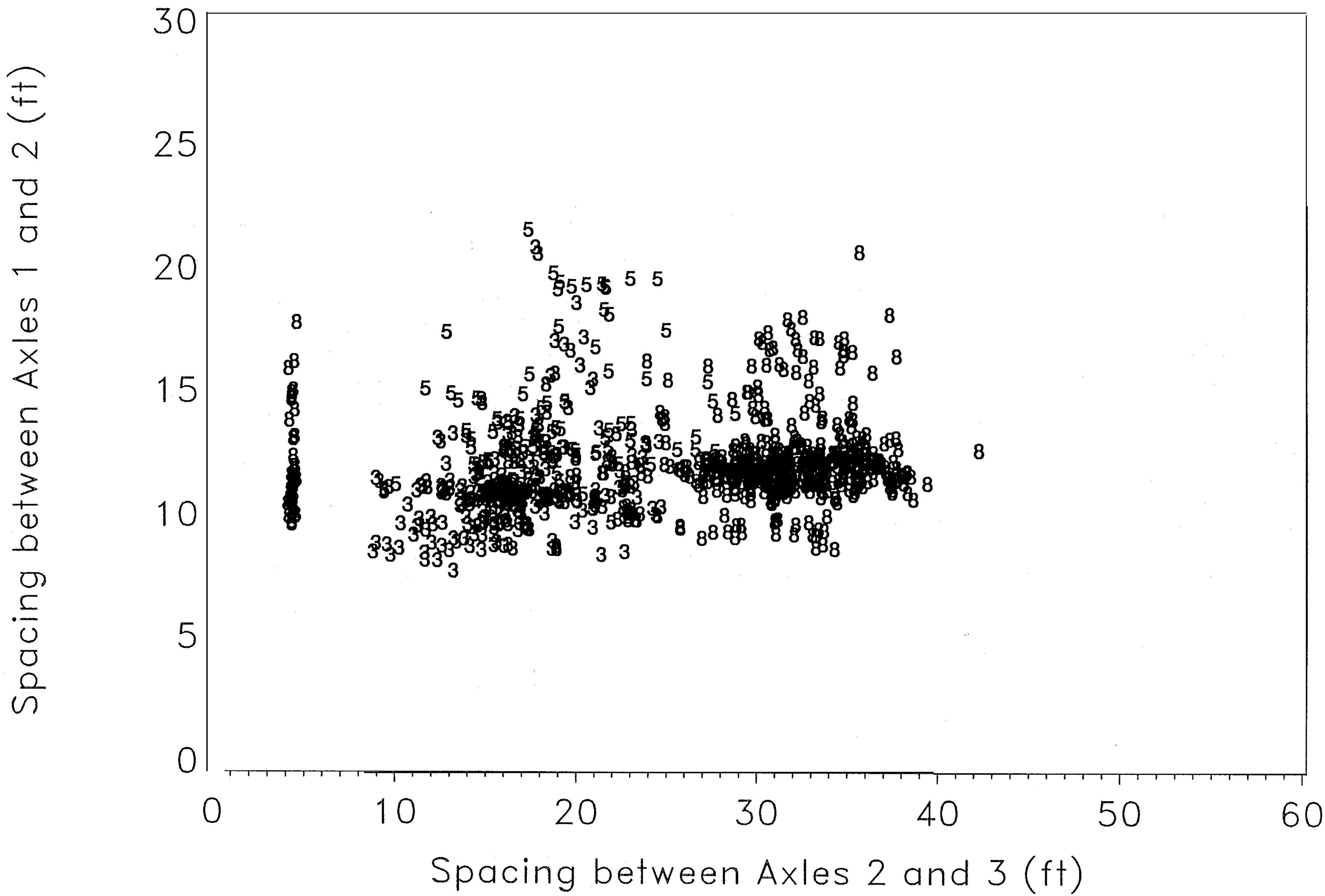


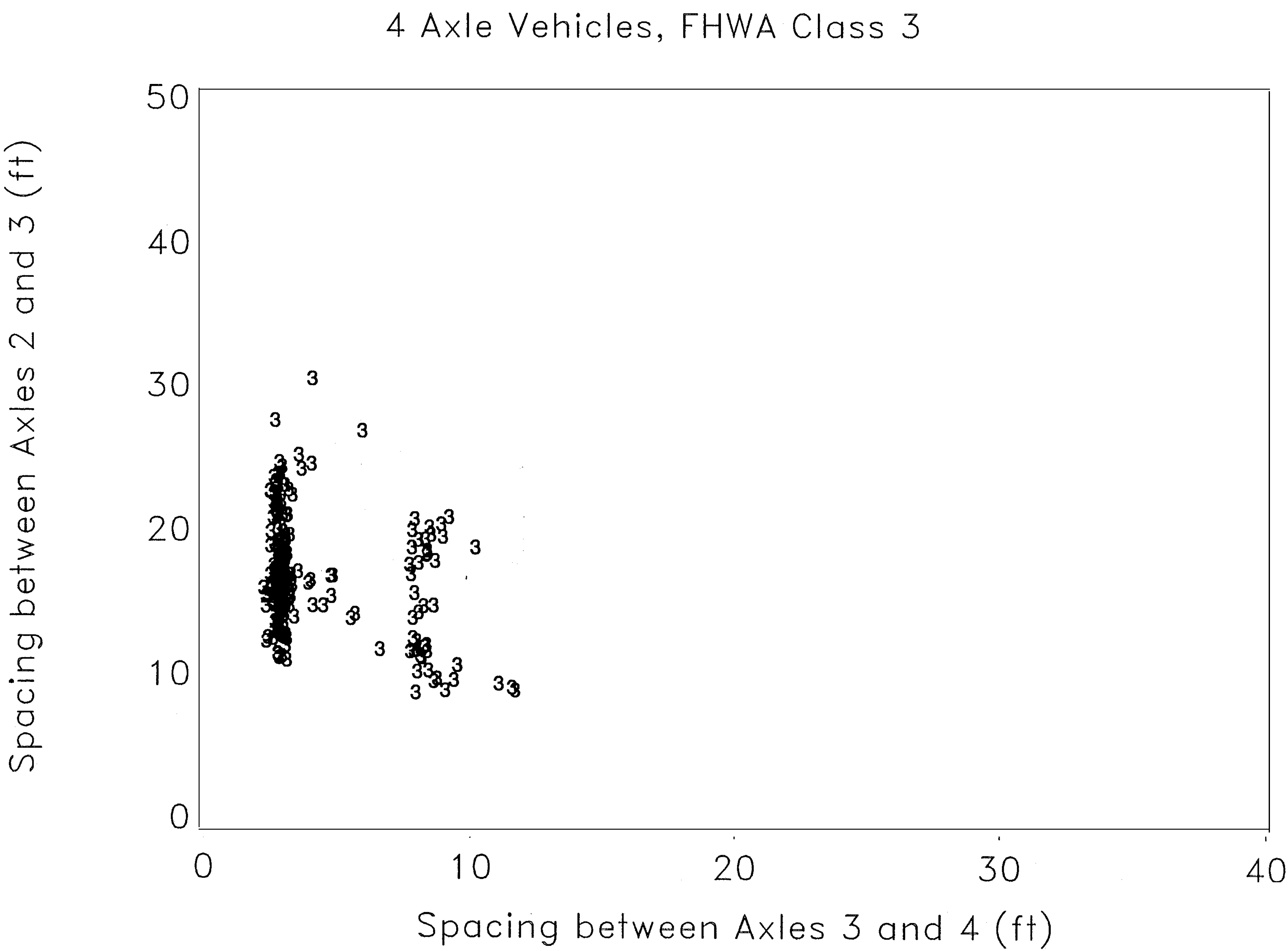
4 Axle Vehicles, FHWA Class 5

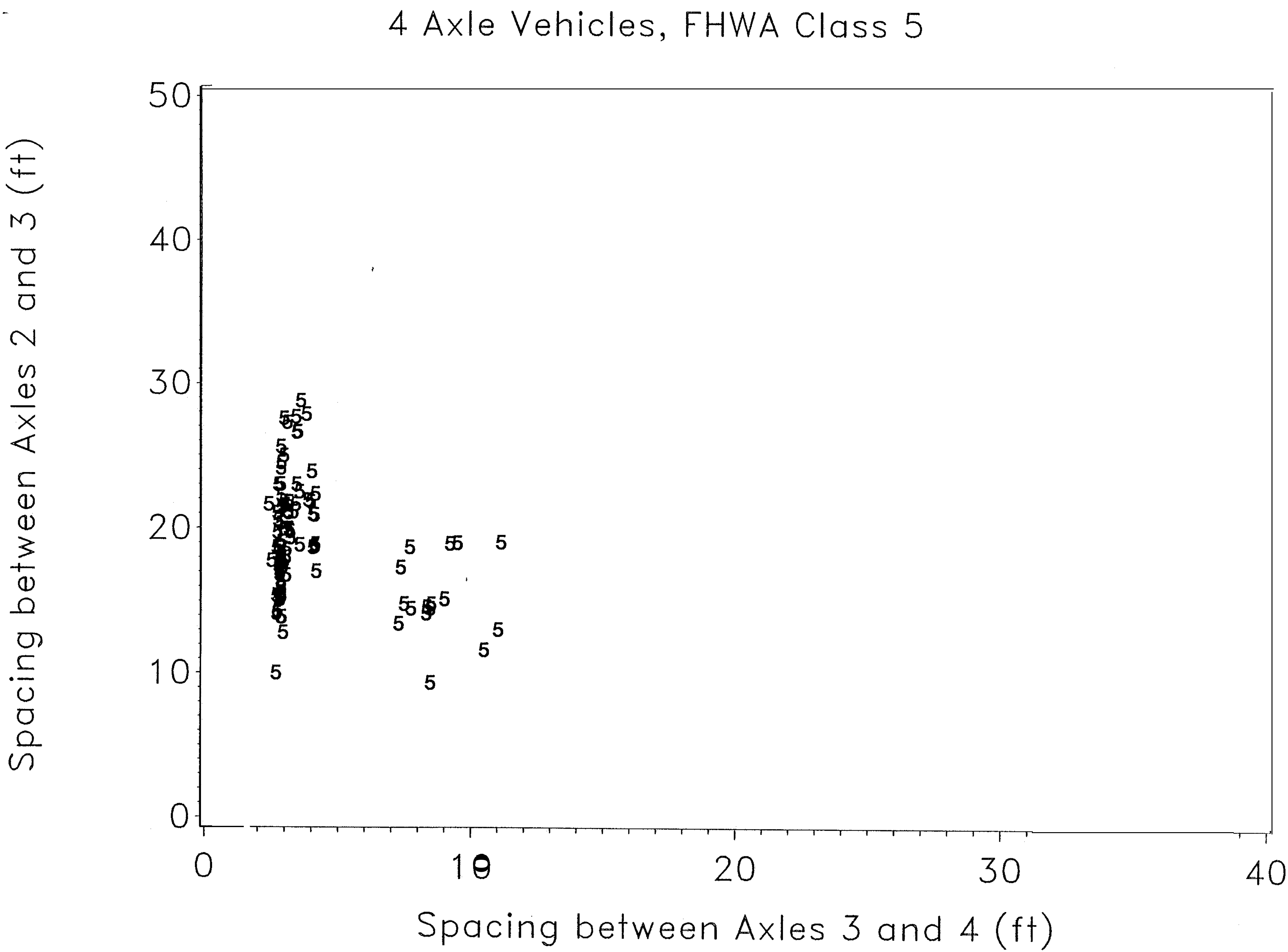



4 Axle Vehicles, FHWA Class 8
Spacing between Axles 1 and 2 (ft)
0
5
10
15
20
25
30
Spacing between Axles 2 and 3 (ft)
0
10
20
30
40
50
60

4 Axle Vehicles, FHWA Classes 3, 5, 8,

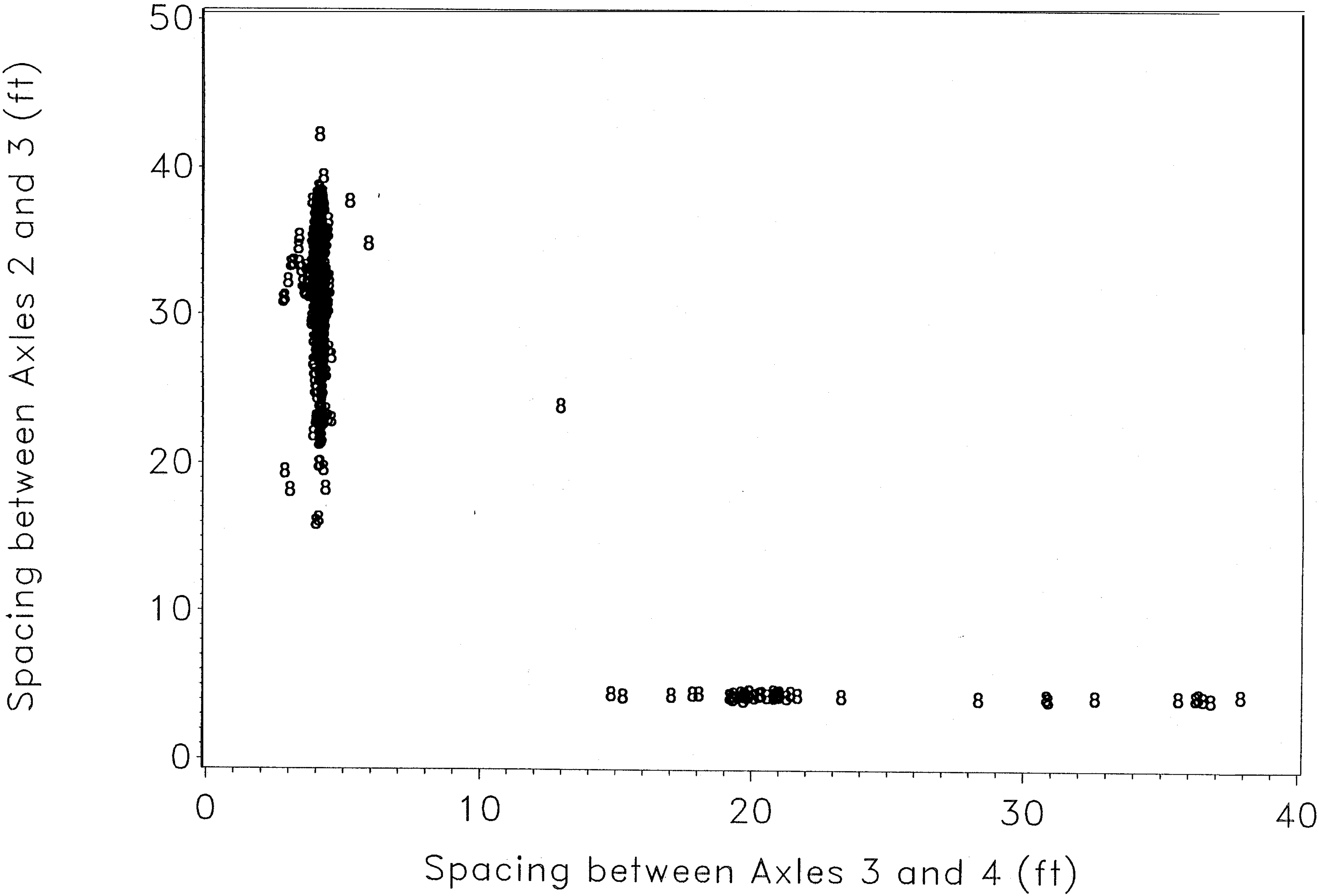


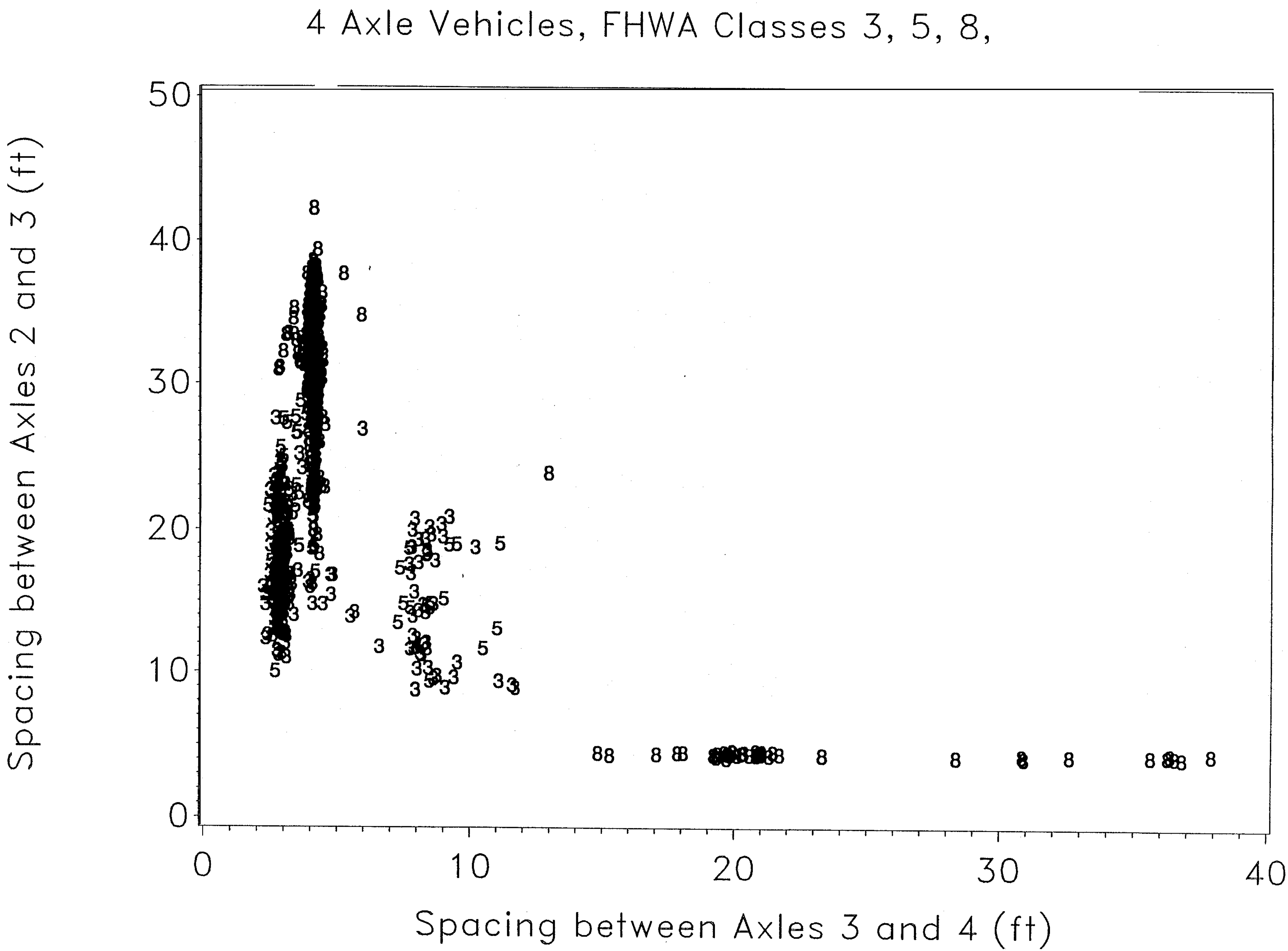

4 Axle Vehicles, FHWA Class 3
Spacing between Axles 2 and 3 (ft)
0
10
20
30
40
50
0
10
20
30
40
Spacing between Axles 3 and 4 (ft)

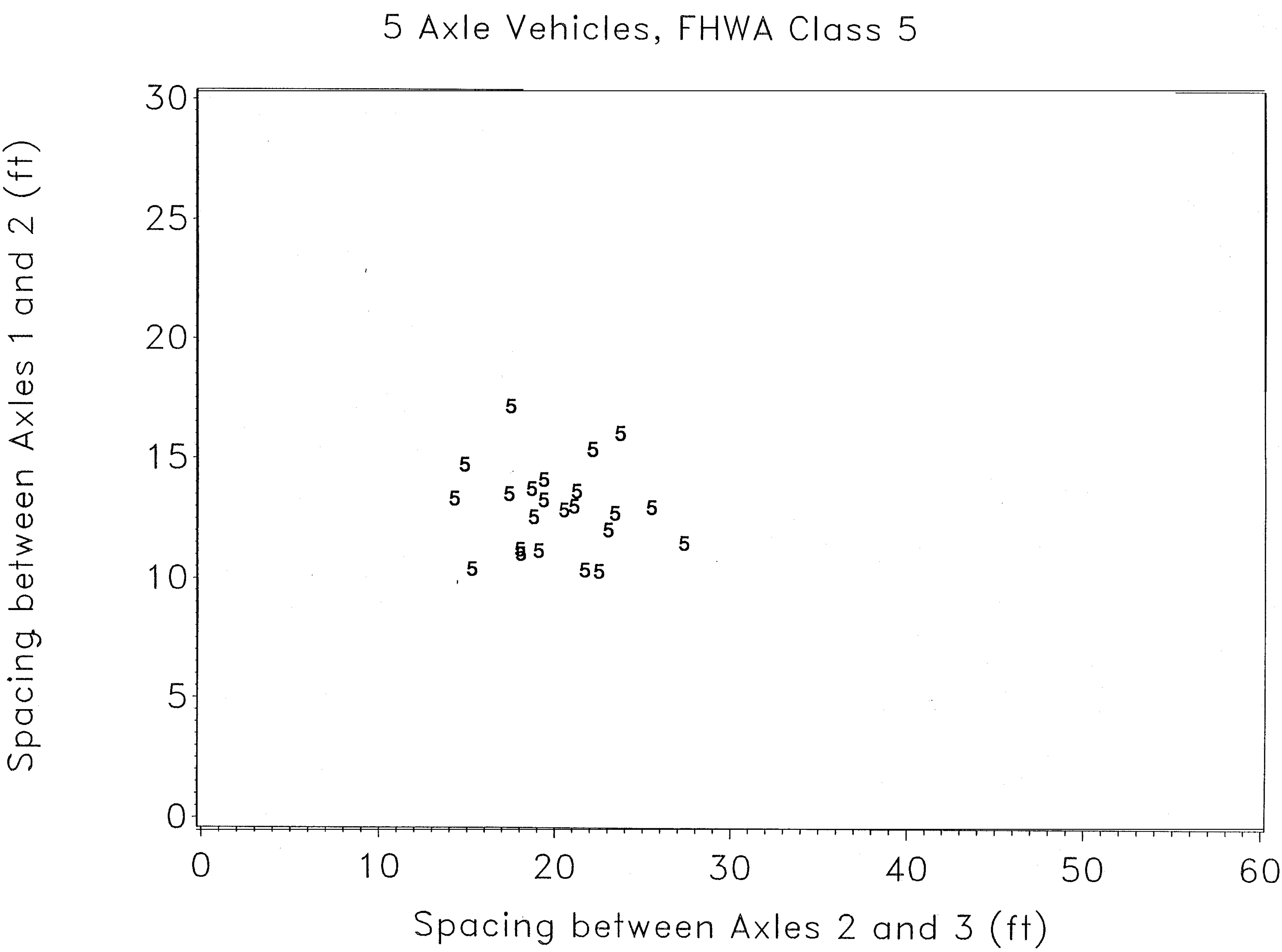


4 Axle Vehicles, FHWA Class 5
Spacing between Axles 2 and 3 (ft)
Spacing between Axles 3 and 4 (ft)
0
10
20
30
40
50

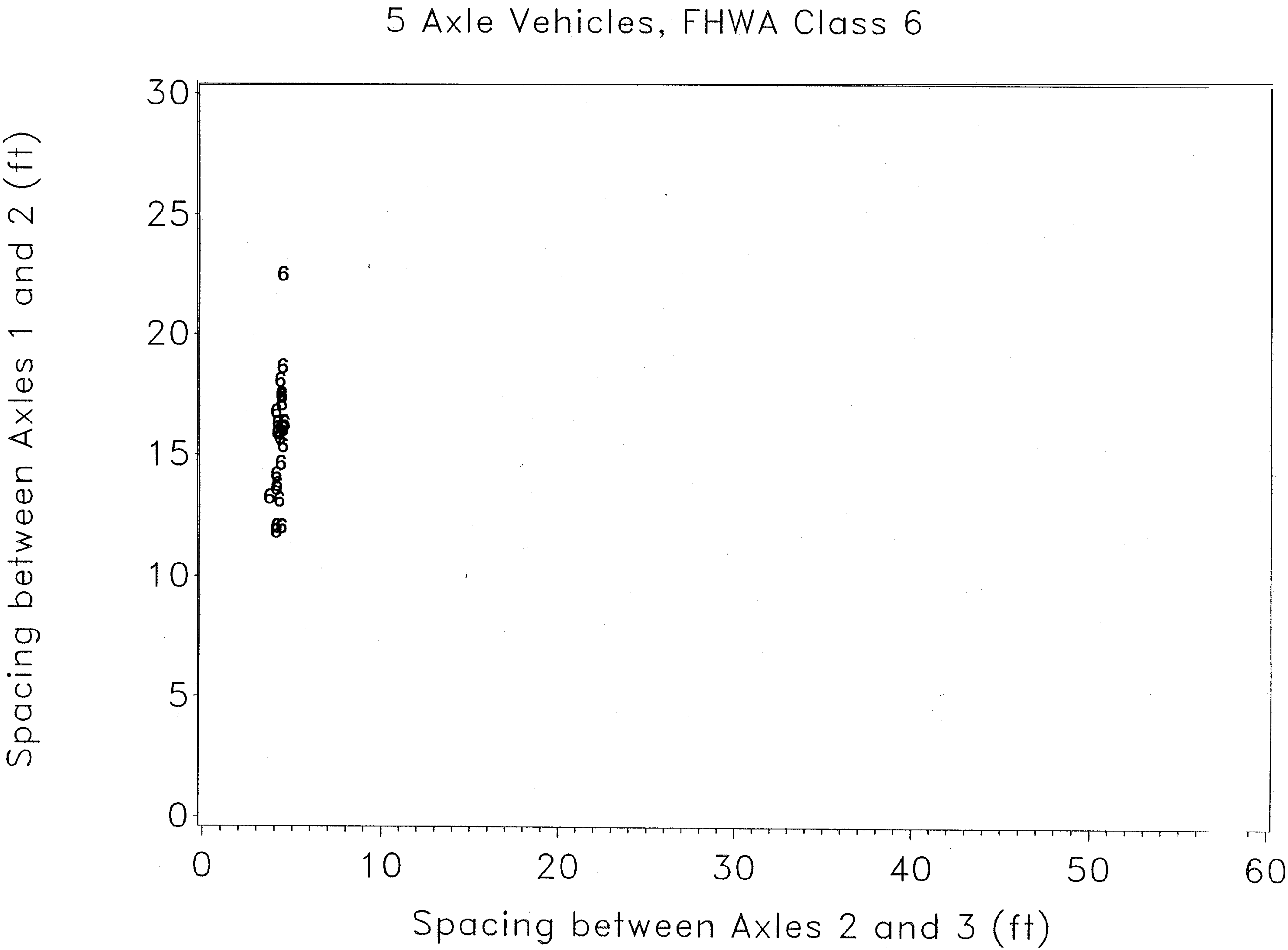
4 Axle Vehic es, FHWA Class 8

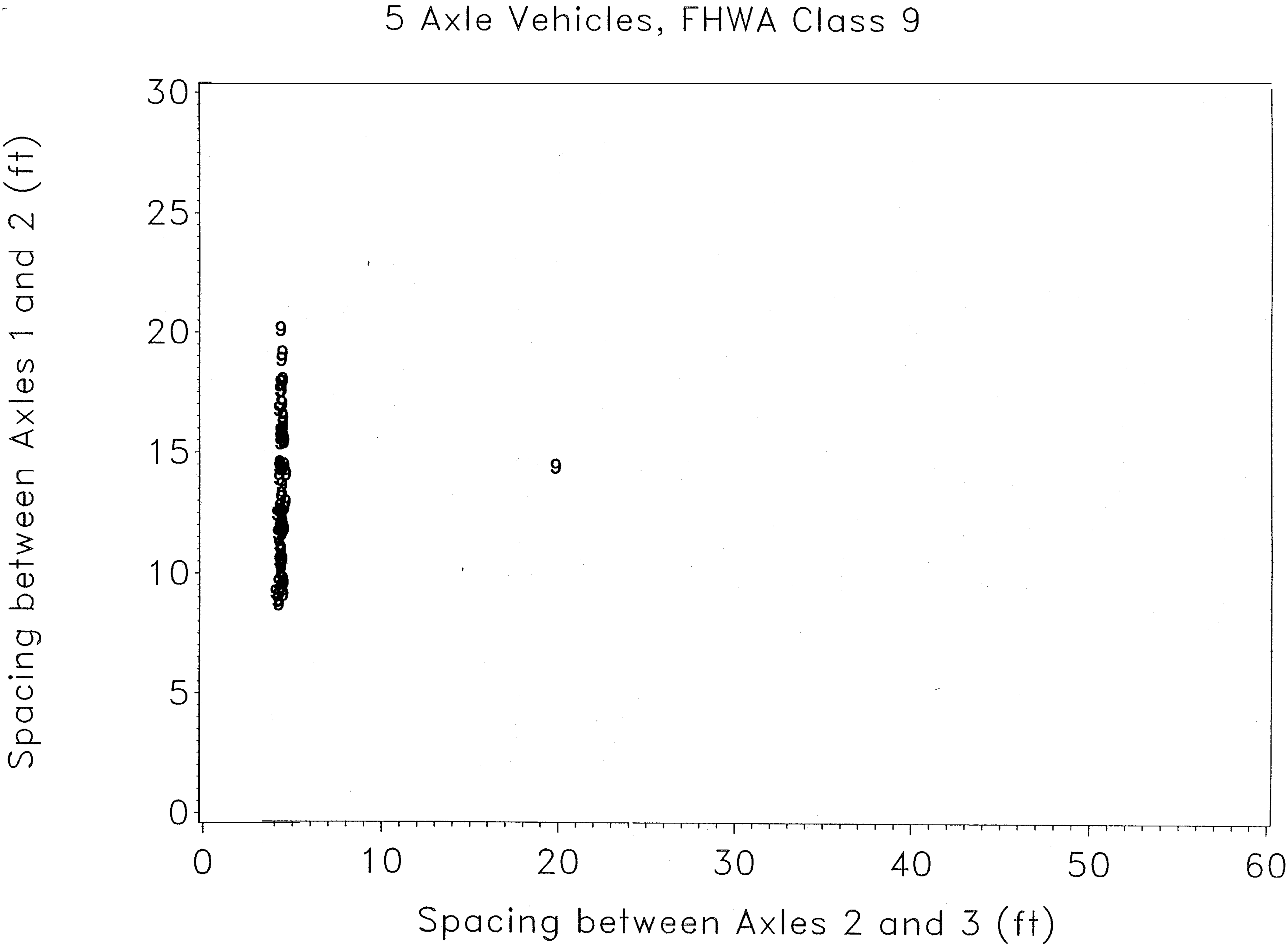



4 Axle Vehicles, FHWA Classes 3, 5, 8,
Spacing between Axles 2 and 3 (ft)
Spacing between Axles 3 and 4 (ft)
0
10
20
30
40
50

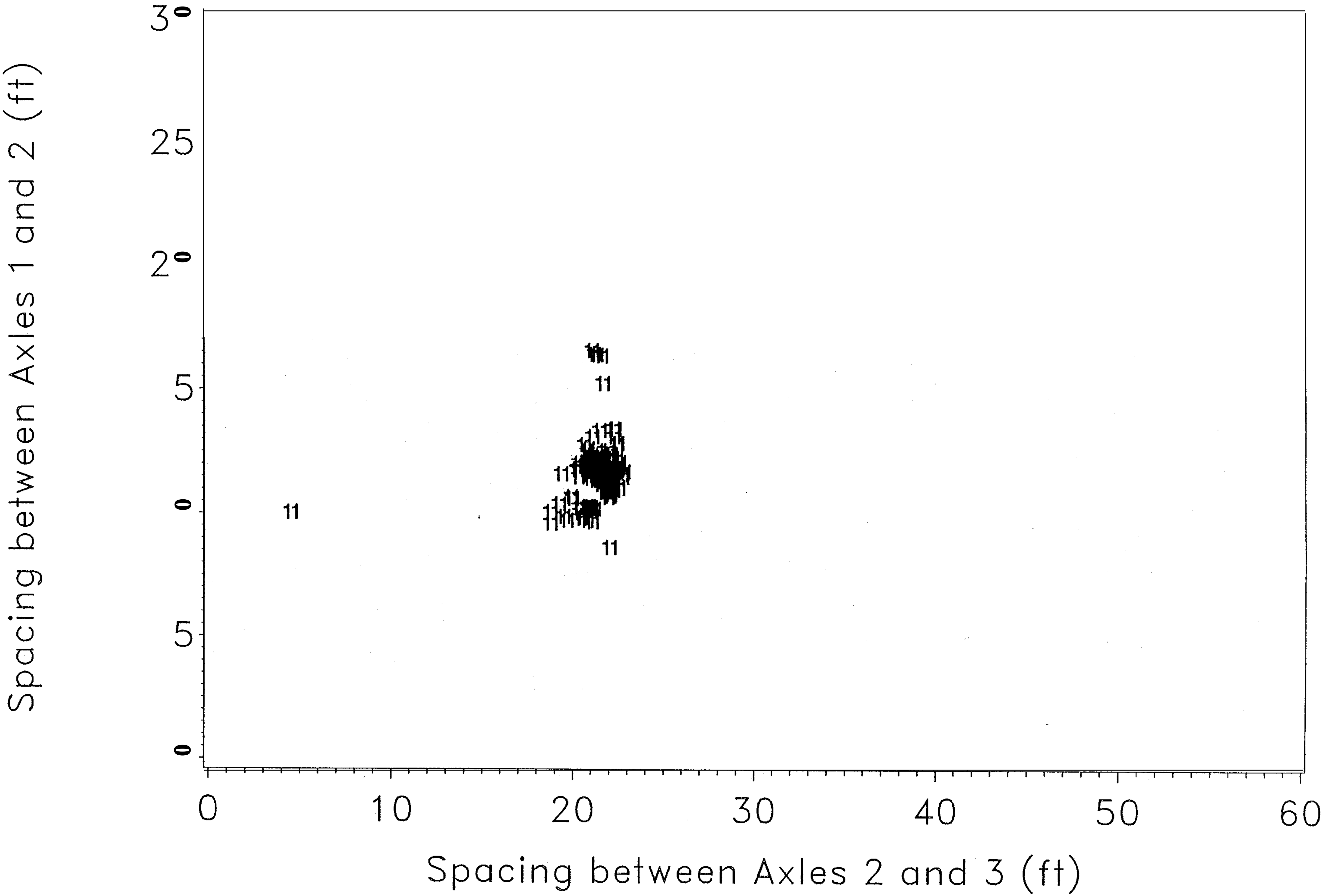


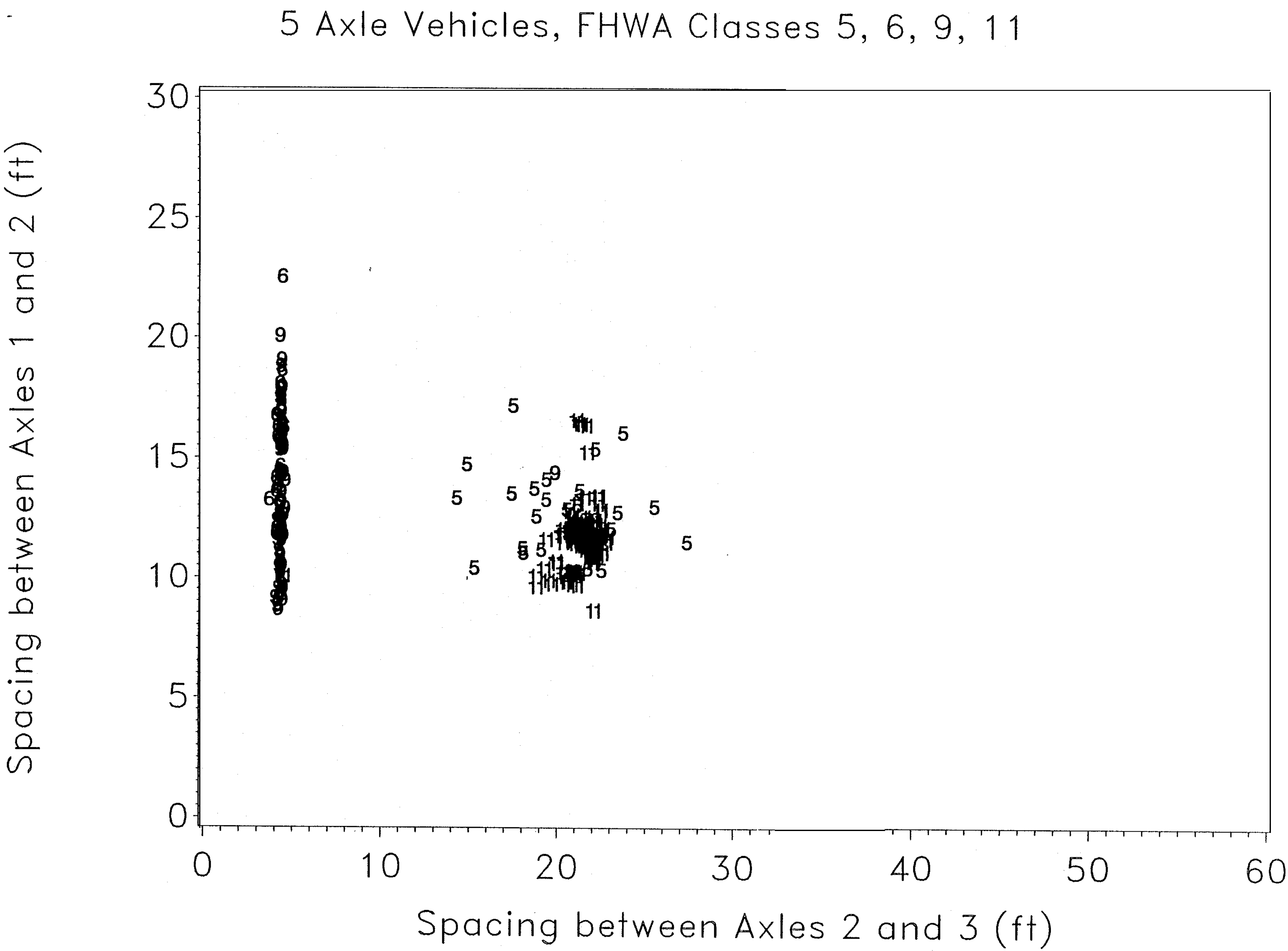
5 Axle Vehicles, FHWA Class 5
Spacing between Axles 1 and 2 (ft)
Spacing between Axles 2 and 3 (ft)
0
5
10
15
20
25
30
0
10
20
30
40
50
60

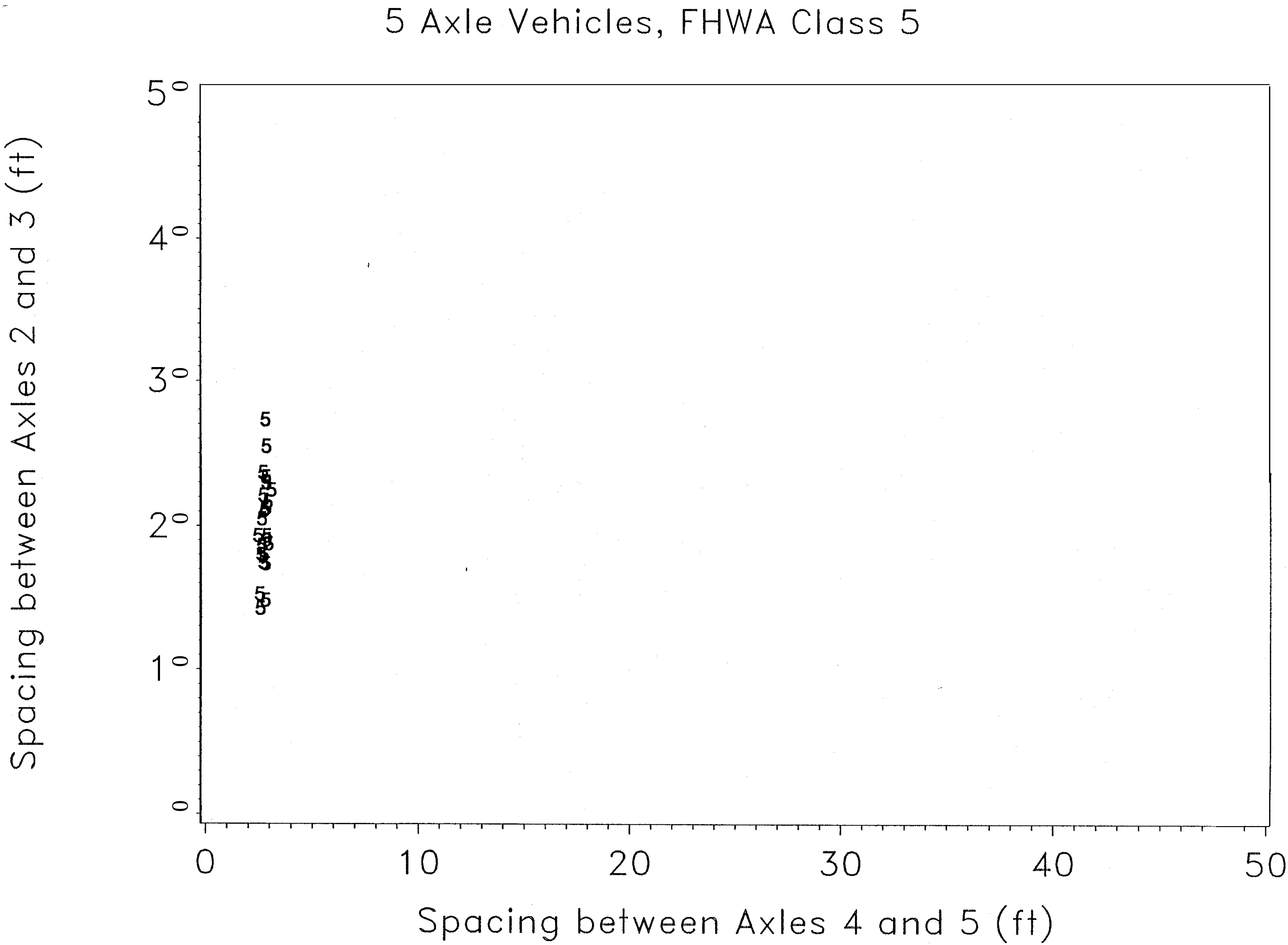

5 Axle Vehicles, FHWA Class 6
Spacing between Axles 1 and 2 (ft)
Spacing between Axles 2 and 3 (ft)
0
5
10
15
20
25
30
0
10
20
30
40
50
60

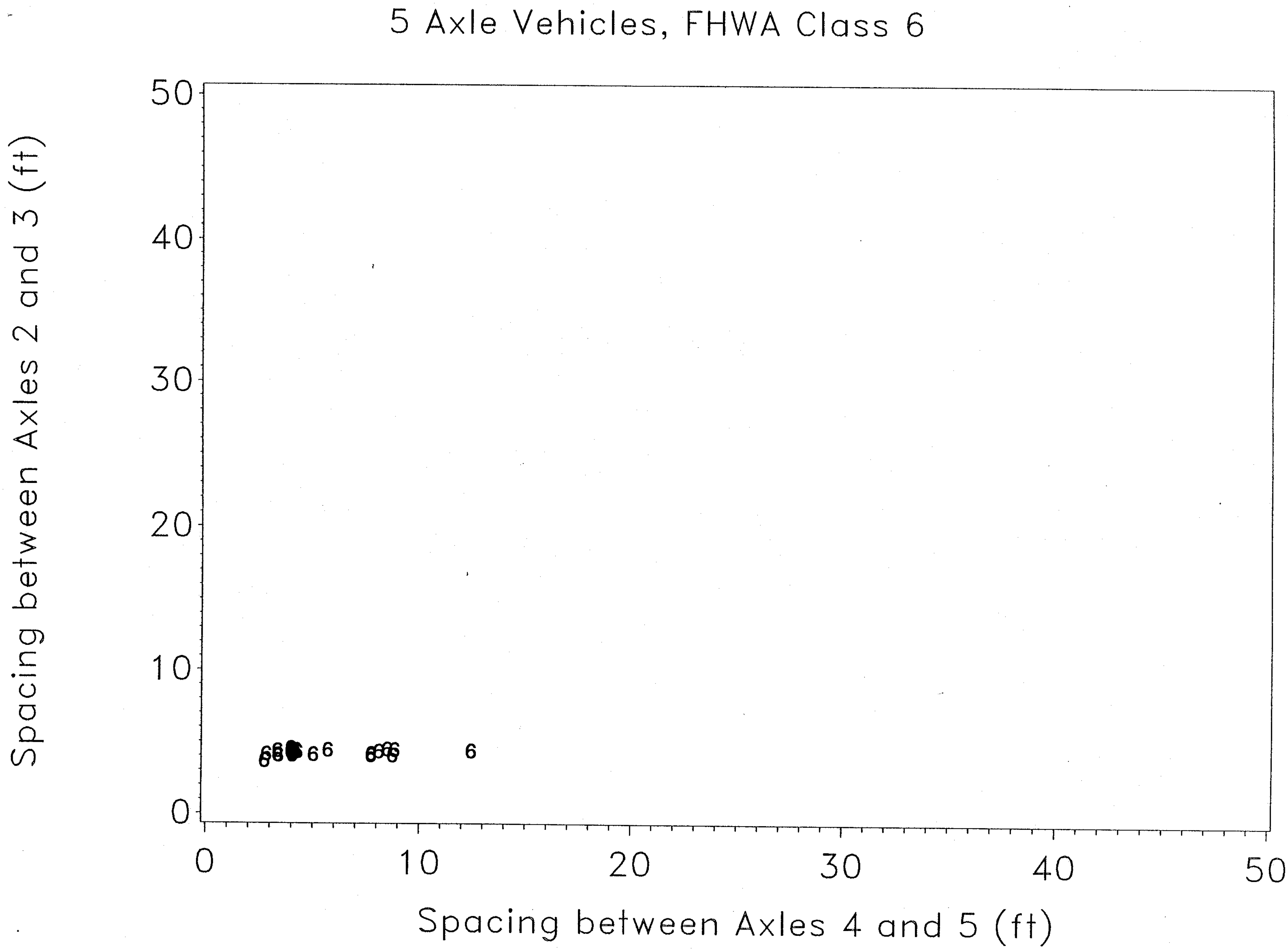

5 Axle Vehicles, FHWA Class 9
Spacing between Axles 1 and 2 (ft)
Spacing between Axles 2 and 3 (ft)
0
5
10
15
20
25
30
0
10
20
30
40
50
60

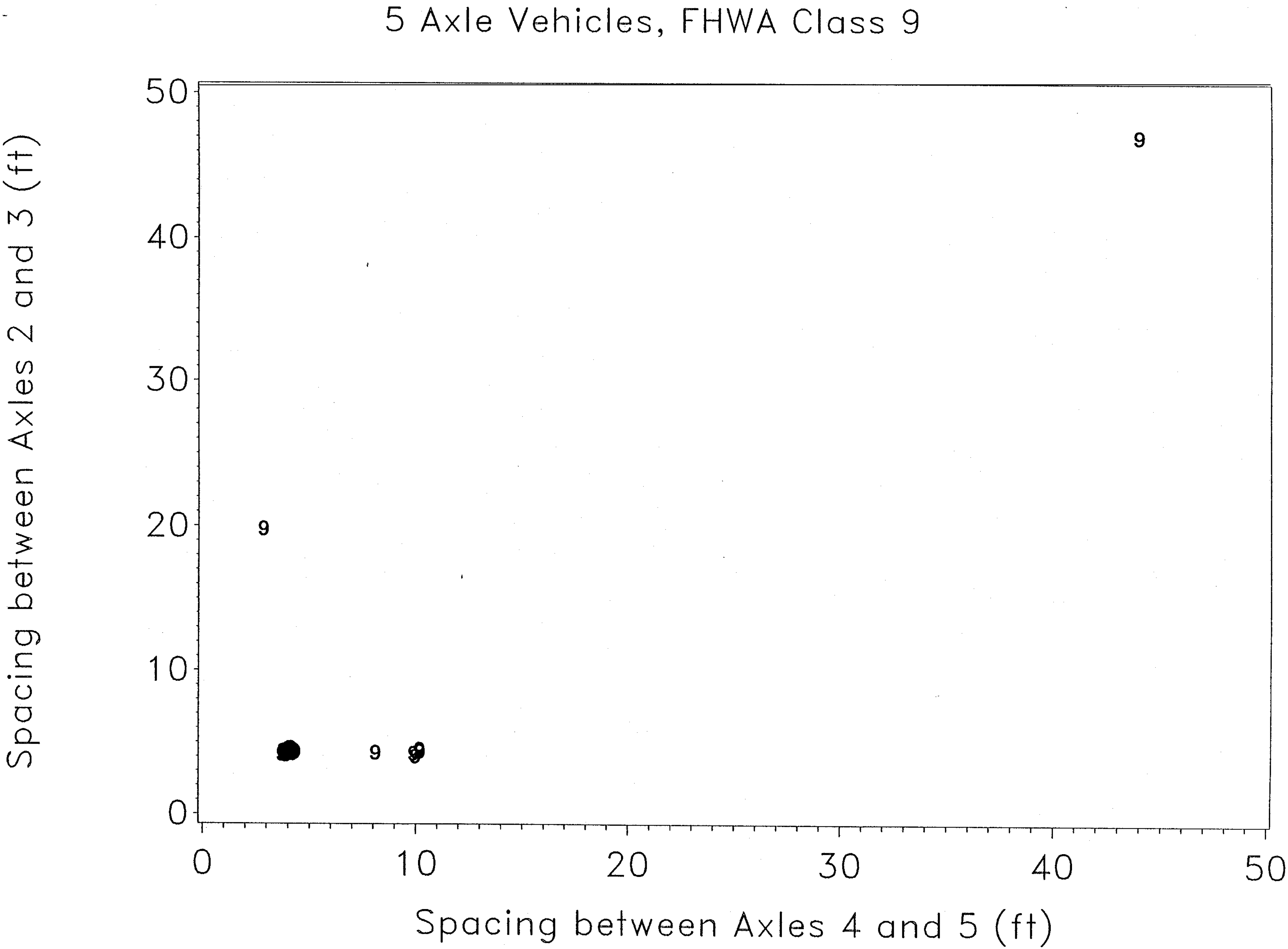
5 Axle Vehicles, FHWA Class 11

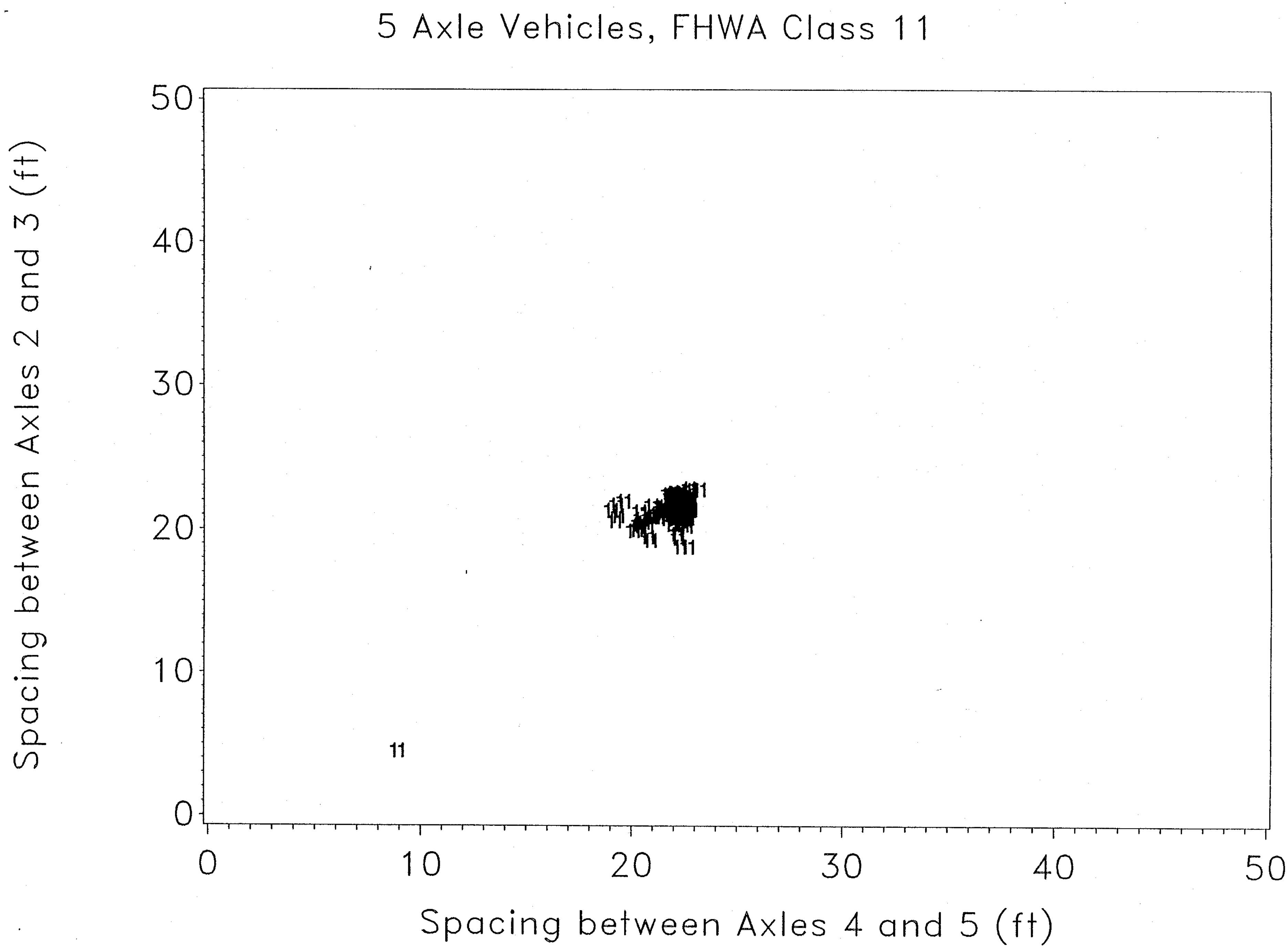


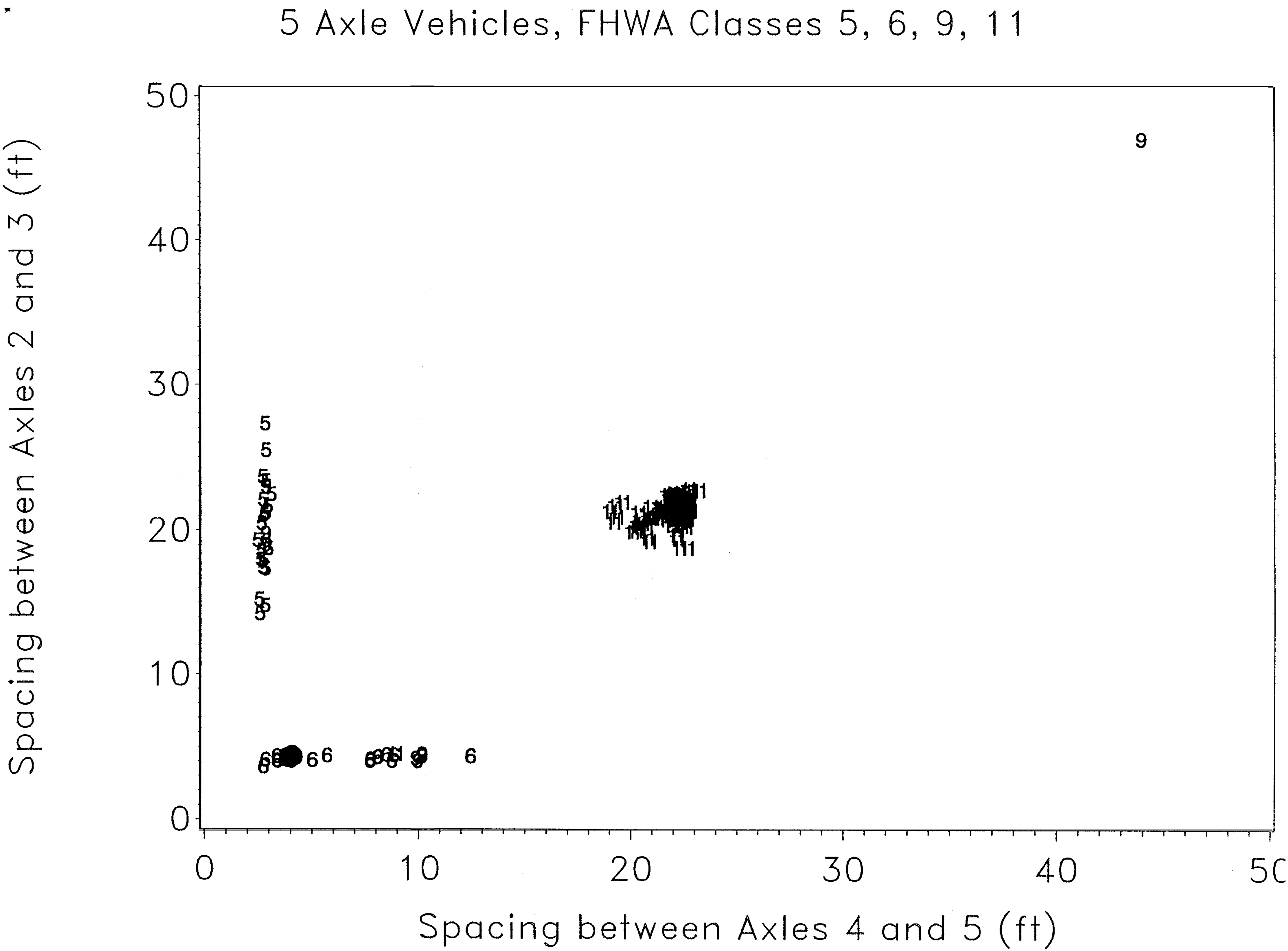



5 Axle Vehicles, FHWA Class 5
Spacing between Axles 2 and 3 (ft)
Spacing between Axles 4 and 5 (ft)
0
10
20
30
40
50

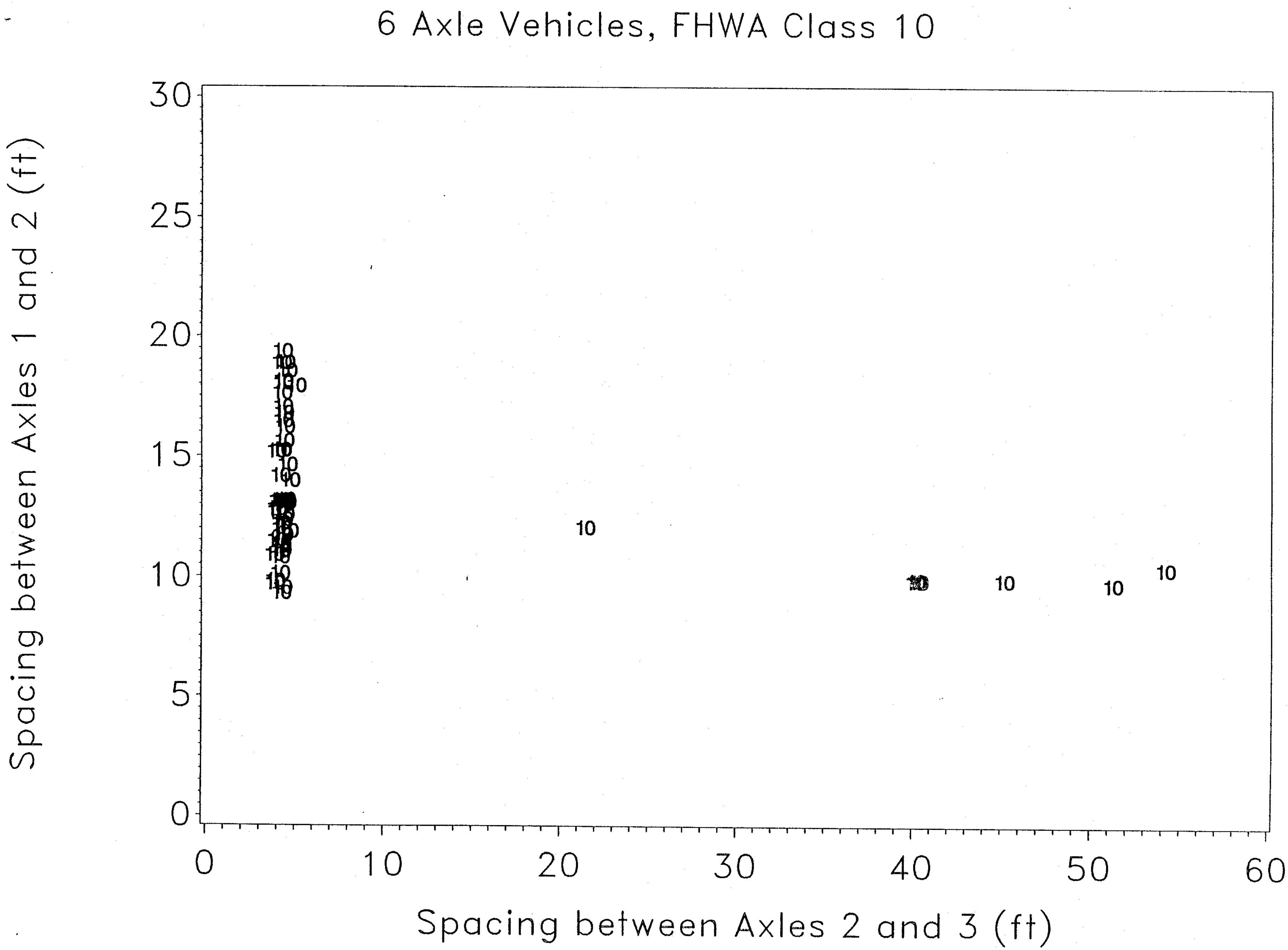

5 Axle Vehicles, FHWA Class 6
Spacing between Axles 2 and 3 (ft)
Spacing between Axles 4 and 5 (ft)
0
10
20
30
40
50

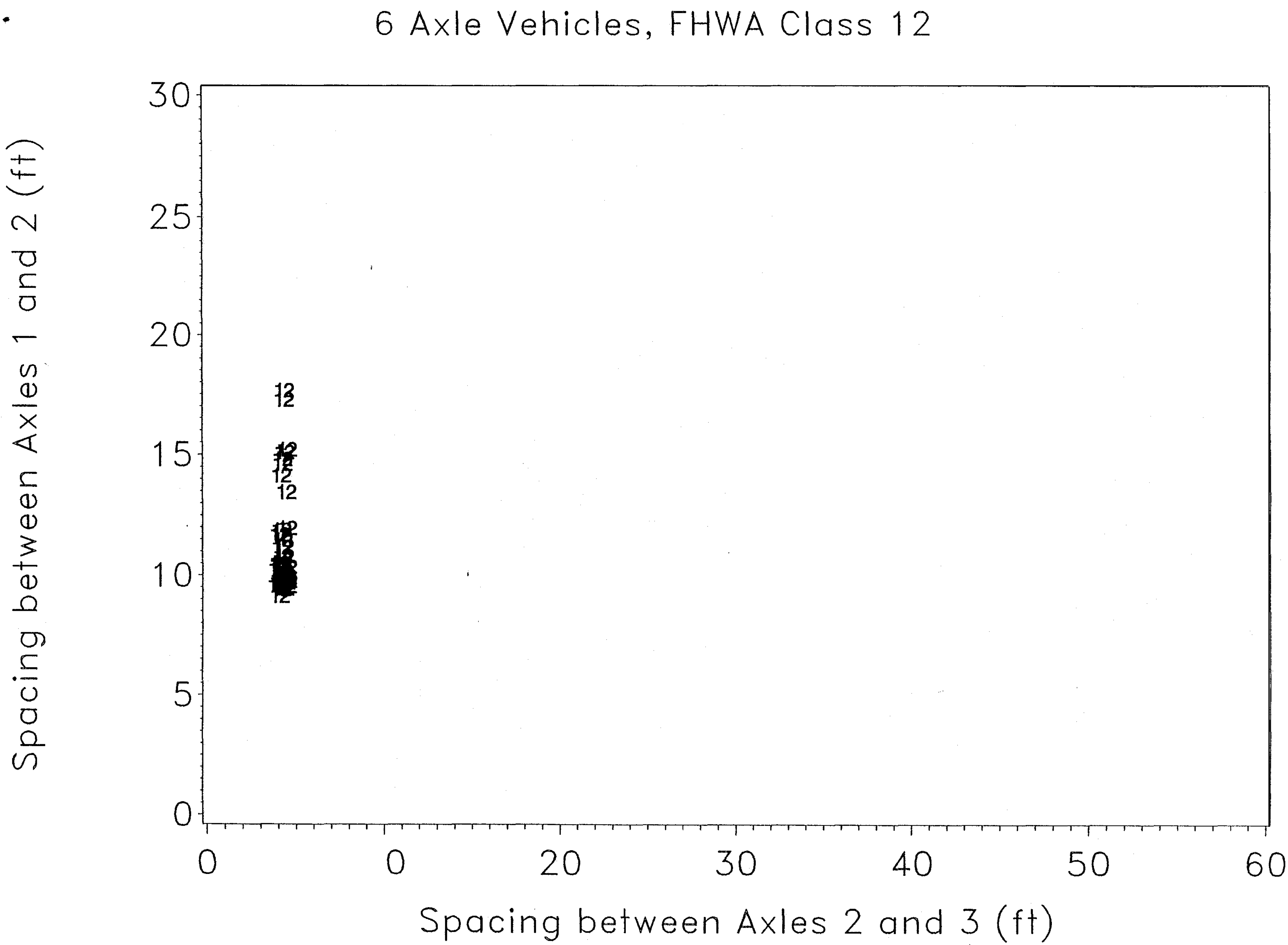

5 Axle Vehicles, FHWA Class 9
Spacing between Axles 2 and 3 (ft)
Spacing between Axles 4 and 5 (ft)
0
10
20
30
40
50
9


5 Axle Vehicles, FHWA Class 11
Spacing between Axles 2 and 3 (ft)
Spacing between Axles 4 and 5 (ft)
0
10
20
30
40
50
11



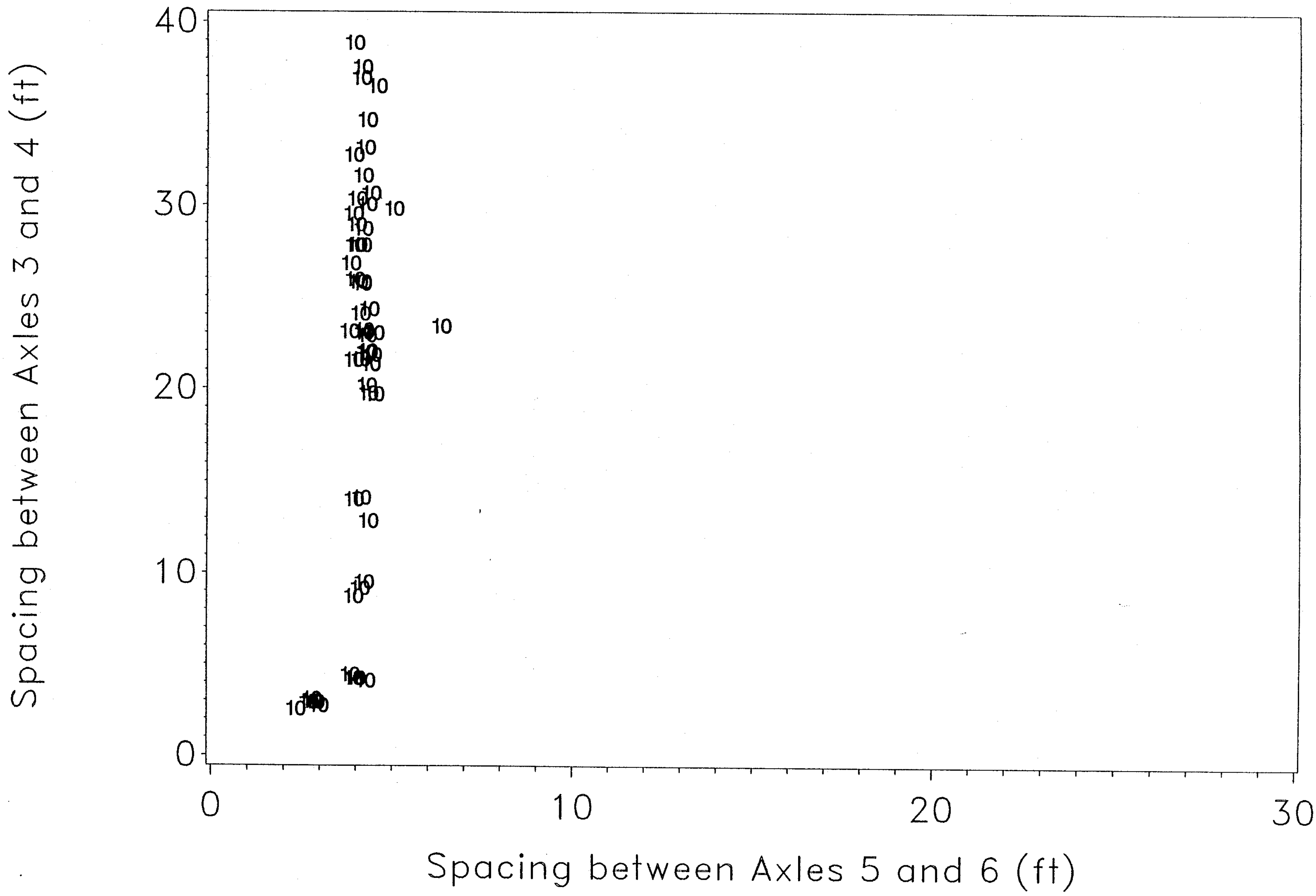
5 Axle Vehicles, FHWA Classes 5, 6, 9, 11
Spacing between Axles 2 and 3 (ft)
Spacing between Axles 4 and 5 (ft)
0
10
20
30
40
50


6 Axle Vehicles, FHWA Class 10
Spacing between Axles 1 and 2 (ft)
Spacing between Axles 2 and 3 (ft)
0
5
10
15
20
25
30
0
10
20
30
40
50
60



6 Axle Vehicles, FHWA Class 12
Spacing between Axles 1 and 2 (ft)
Spacing between Axles 2 and 3 (ft)
0
5
10
15
20
25
30
0
0
20
30
40
50
60

6 Axle Vehicles, FHWA Class 10



6 Axle Vehicles, FHWA Class 12

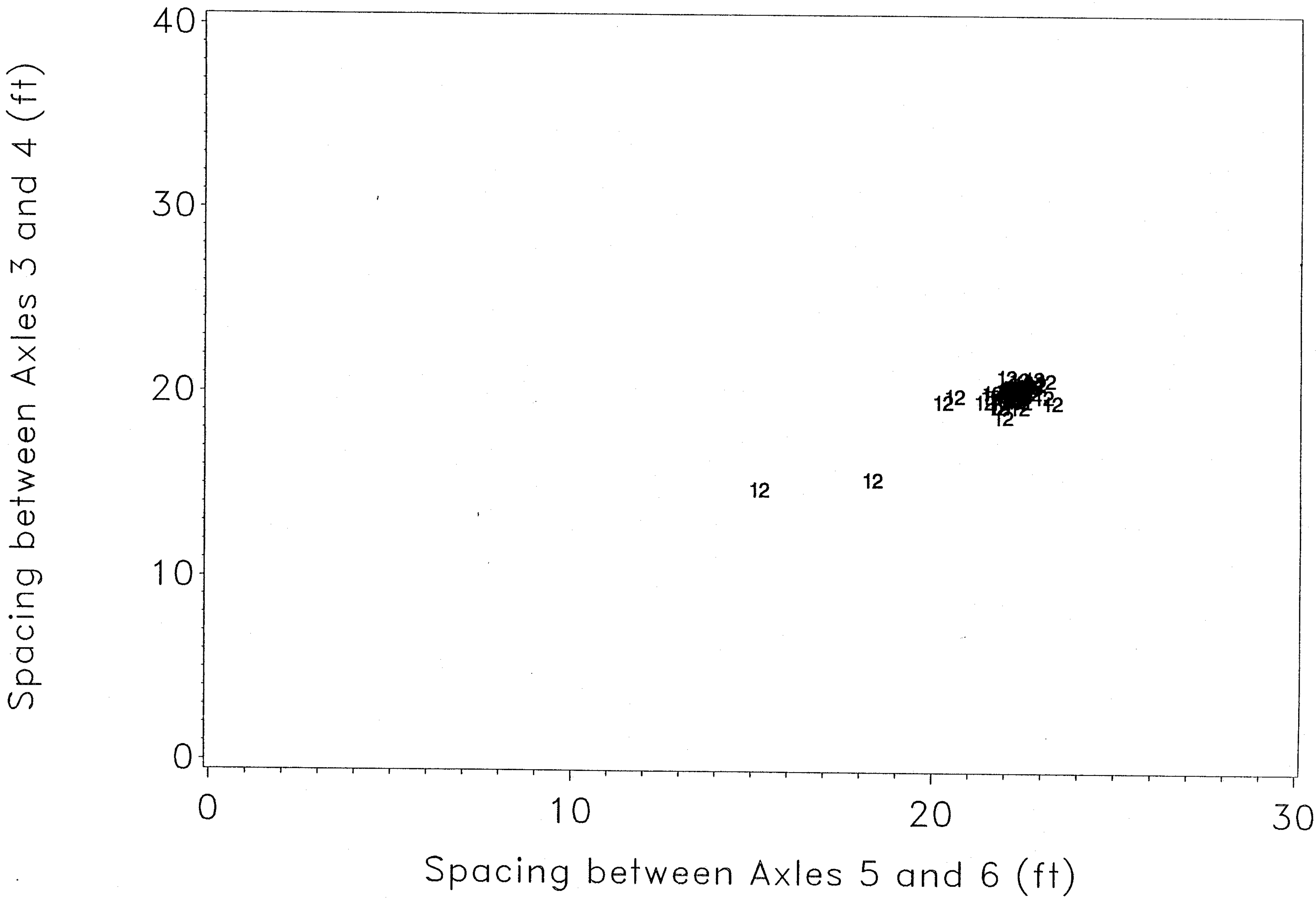


Figure B-2

Box and Whisker Plots of Axle Spacing by FHWA Class for 2-Axle Vehicles

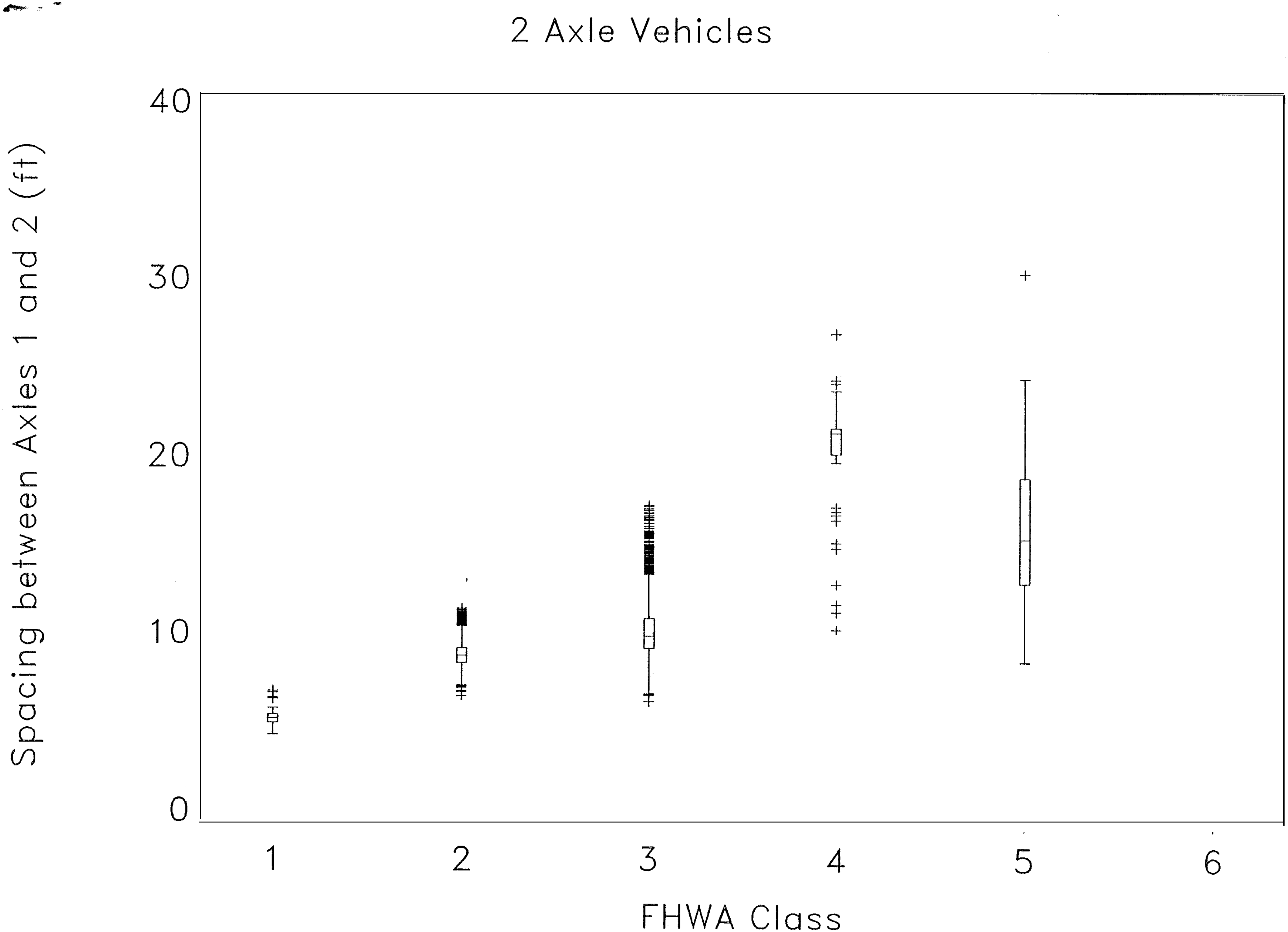
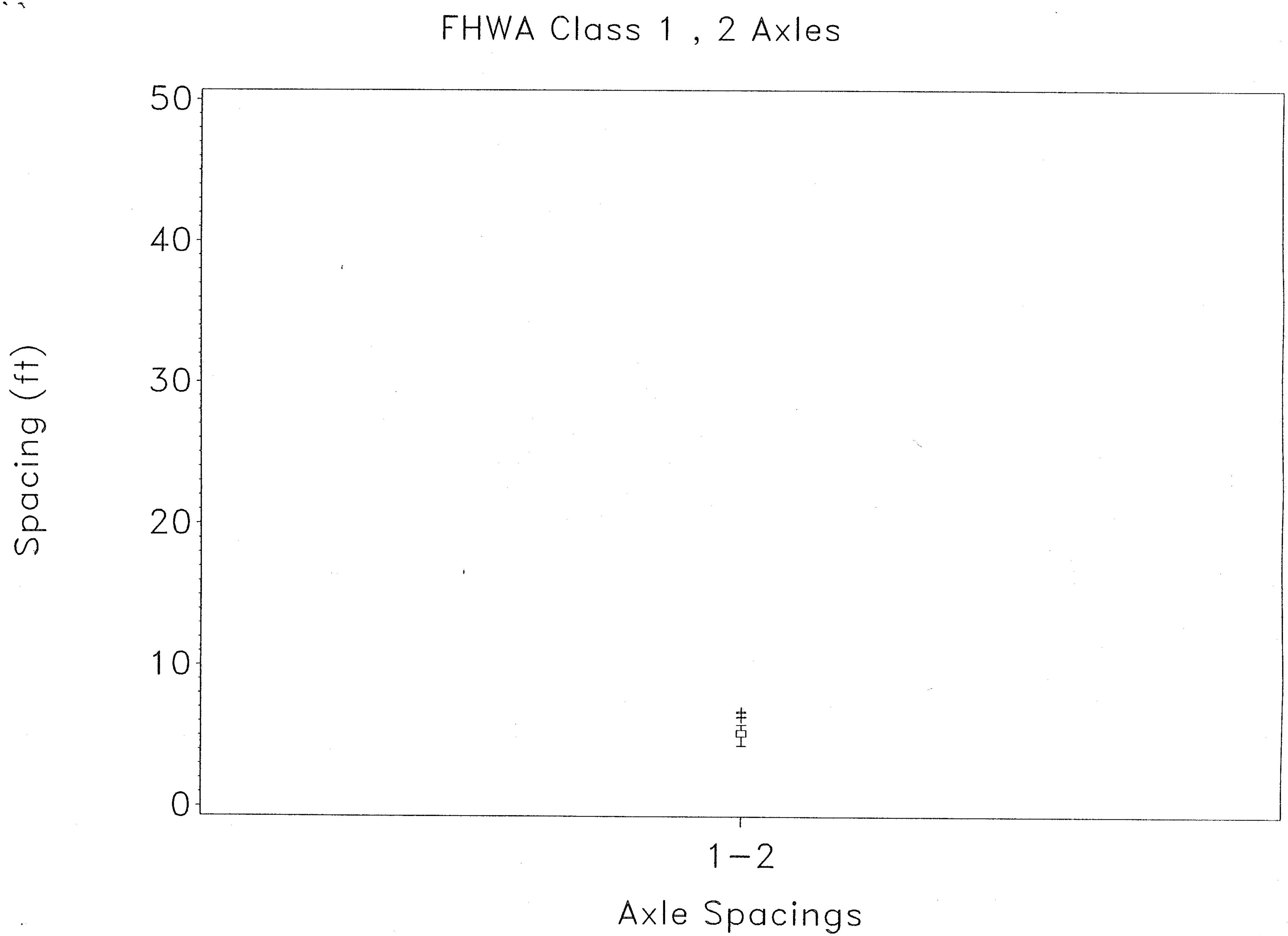
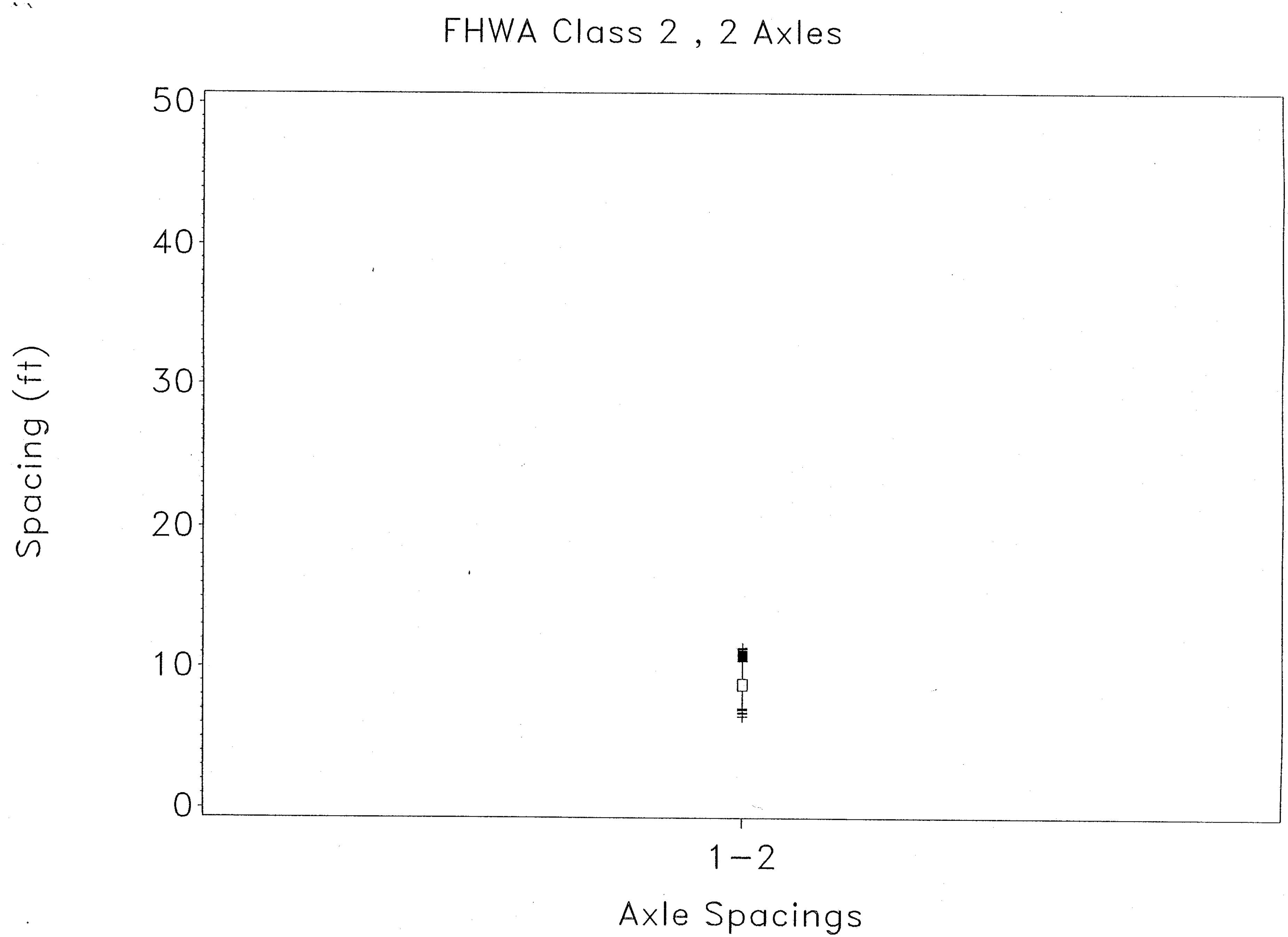
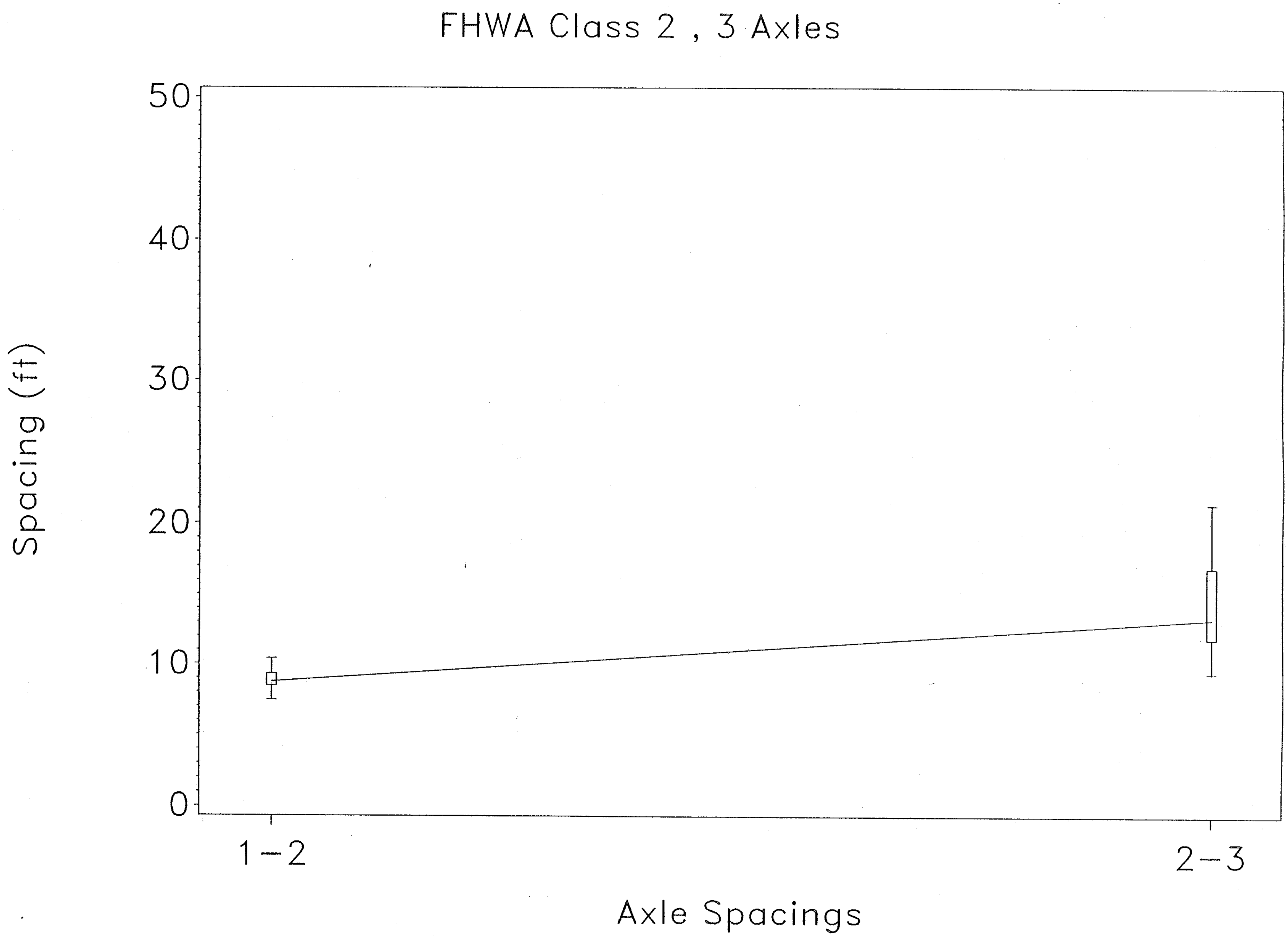

2 Axle Vehicles
Spacing between Axles 1 and 2 (ft)
40
30
20
10
0
1
2
3
4
5
6
FHWA Class

Figure B-3

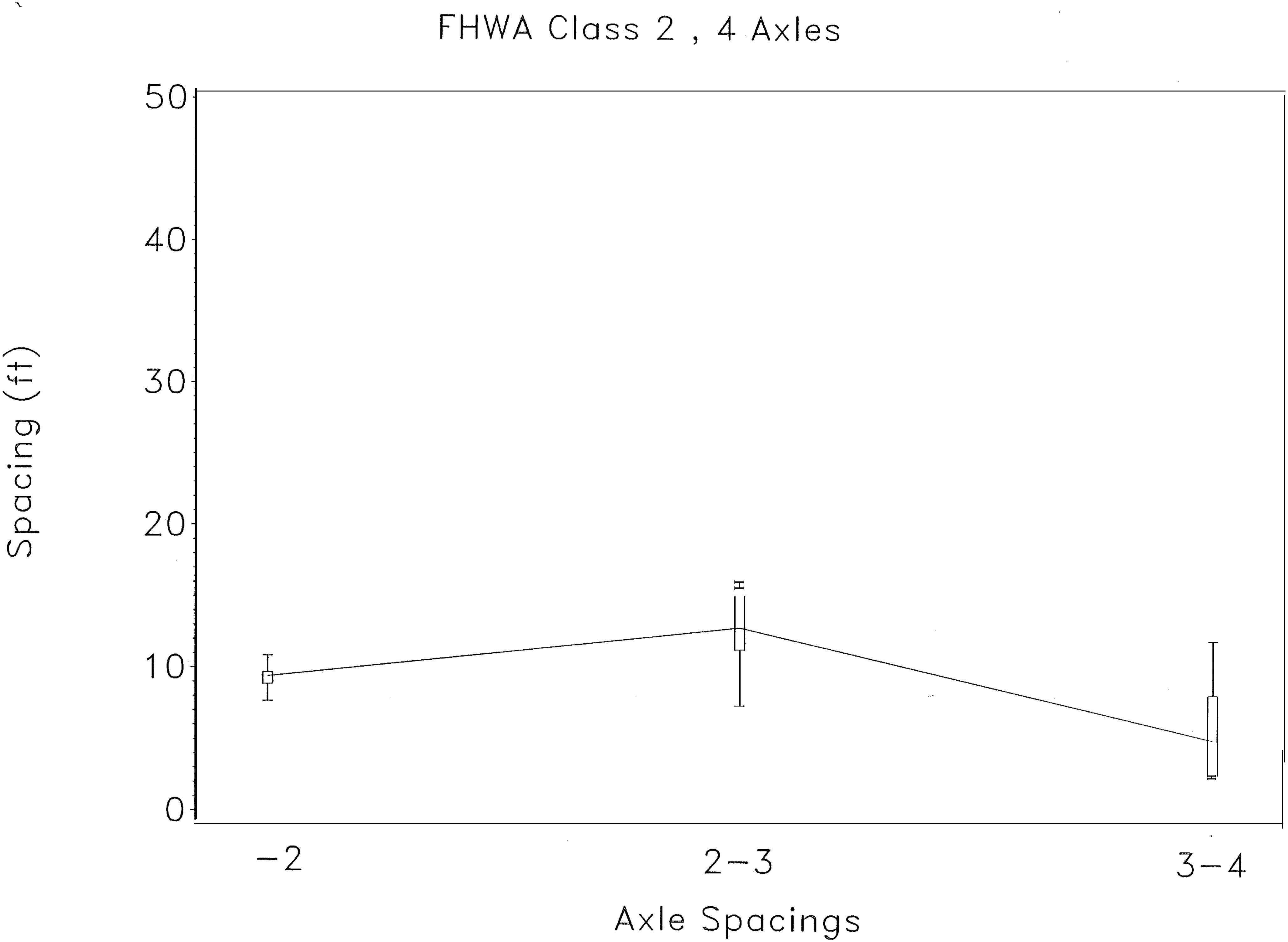
Box and Whisker Plots of Axle Spacing by Number of Axles and FHWA Class

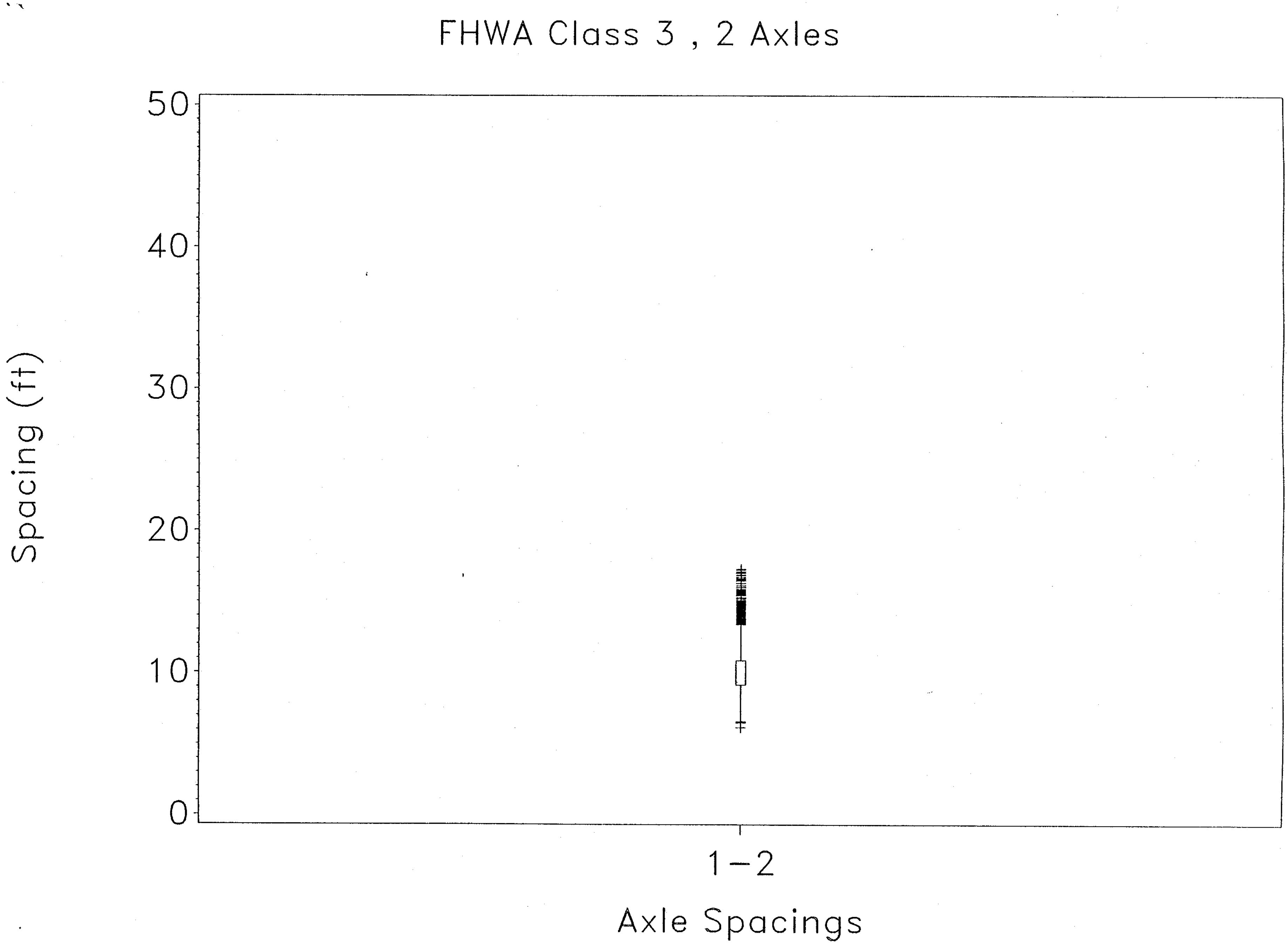

FHWA Class 1 , 2 Axles
Spacing (ft)
50
40
30
20
10
0
1–2
Axle Spacings

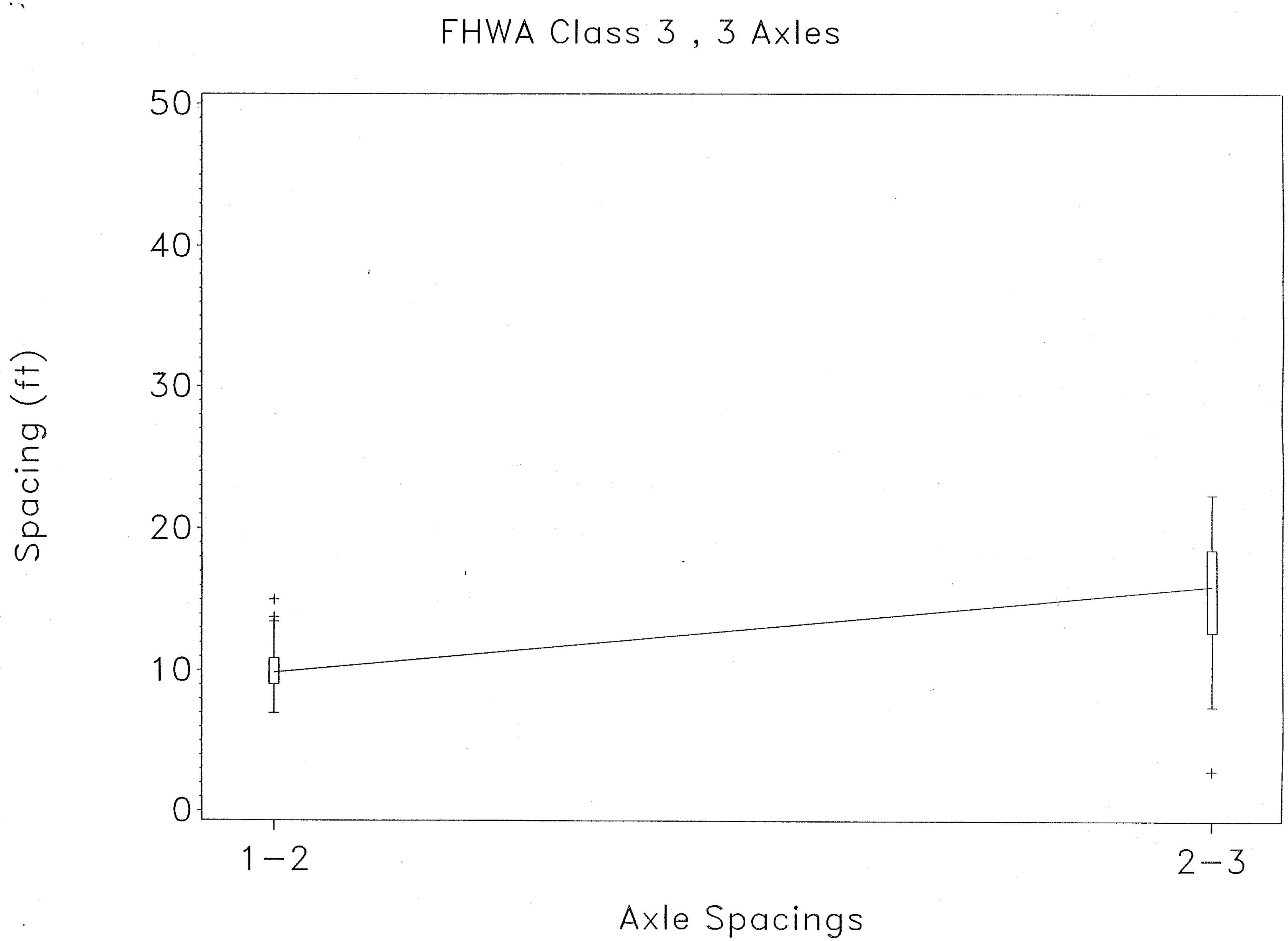

FHWA Class 2 , 2 Axles
Spacing (ft)
0
10
20
30
40
50
1-2
Axle Spacings



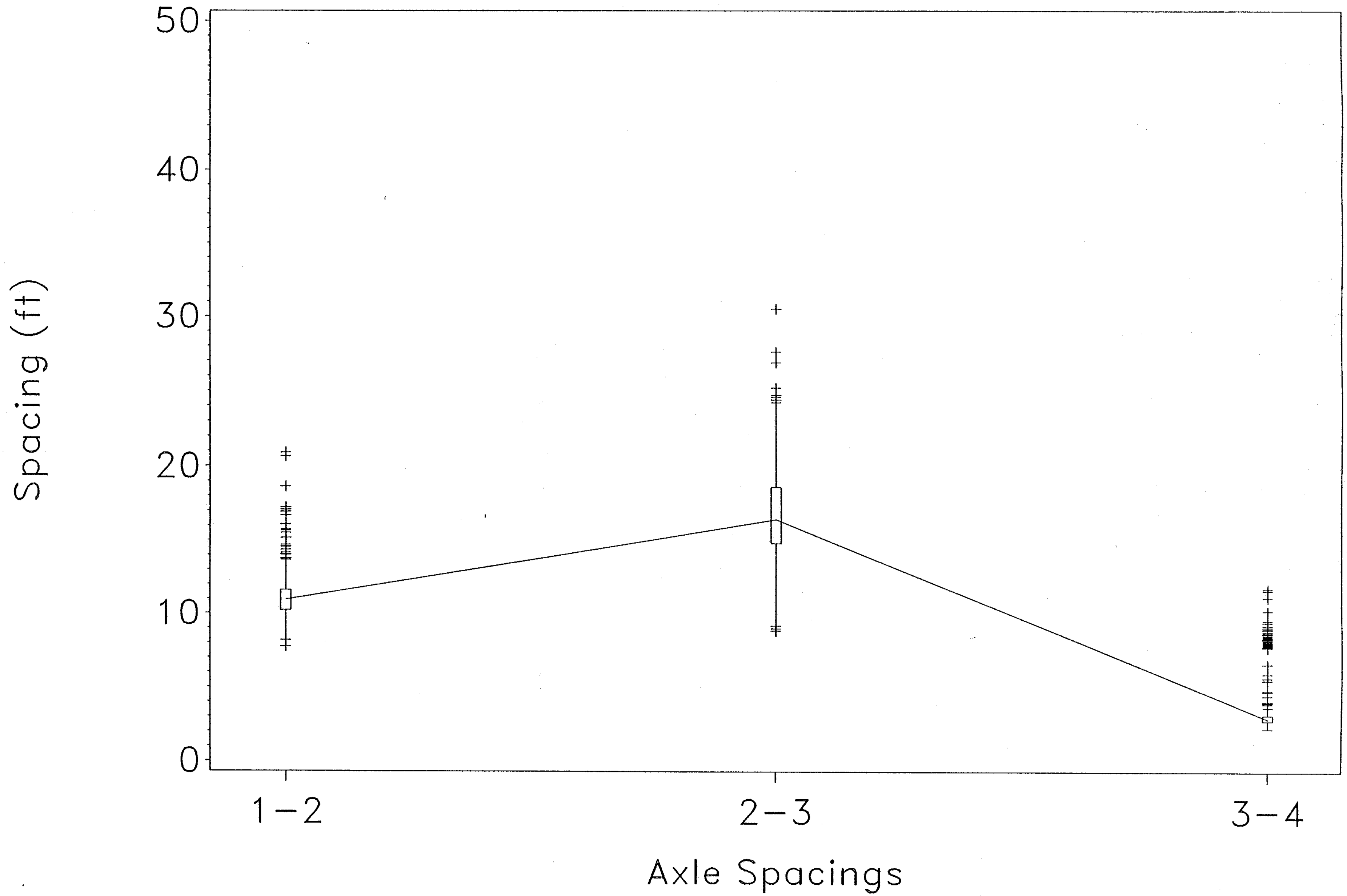
FHWA Class 2 , 3 Axles
Spacing (ft)
50
40
30
20
10
0
1-2
2-3
Axle Spacings

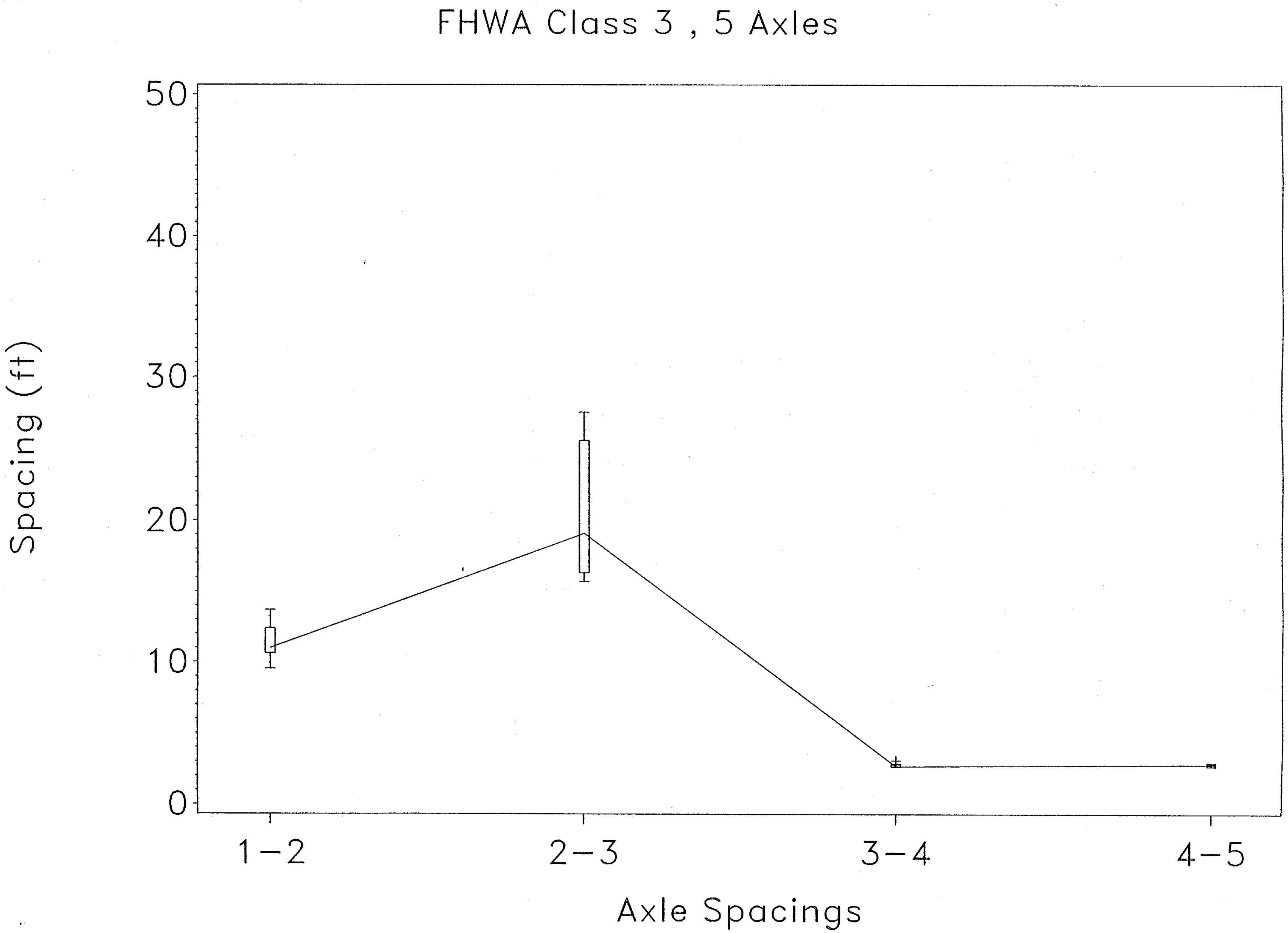

FHWA Class 2 , 4 Axles
Spacing (ft)
0
10
20
30
40
50
-2
2-3
3-4
Axle Spacings

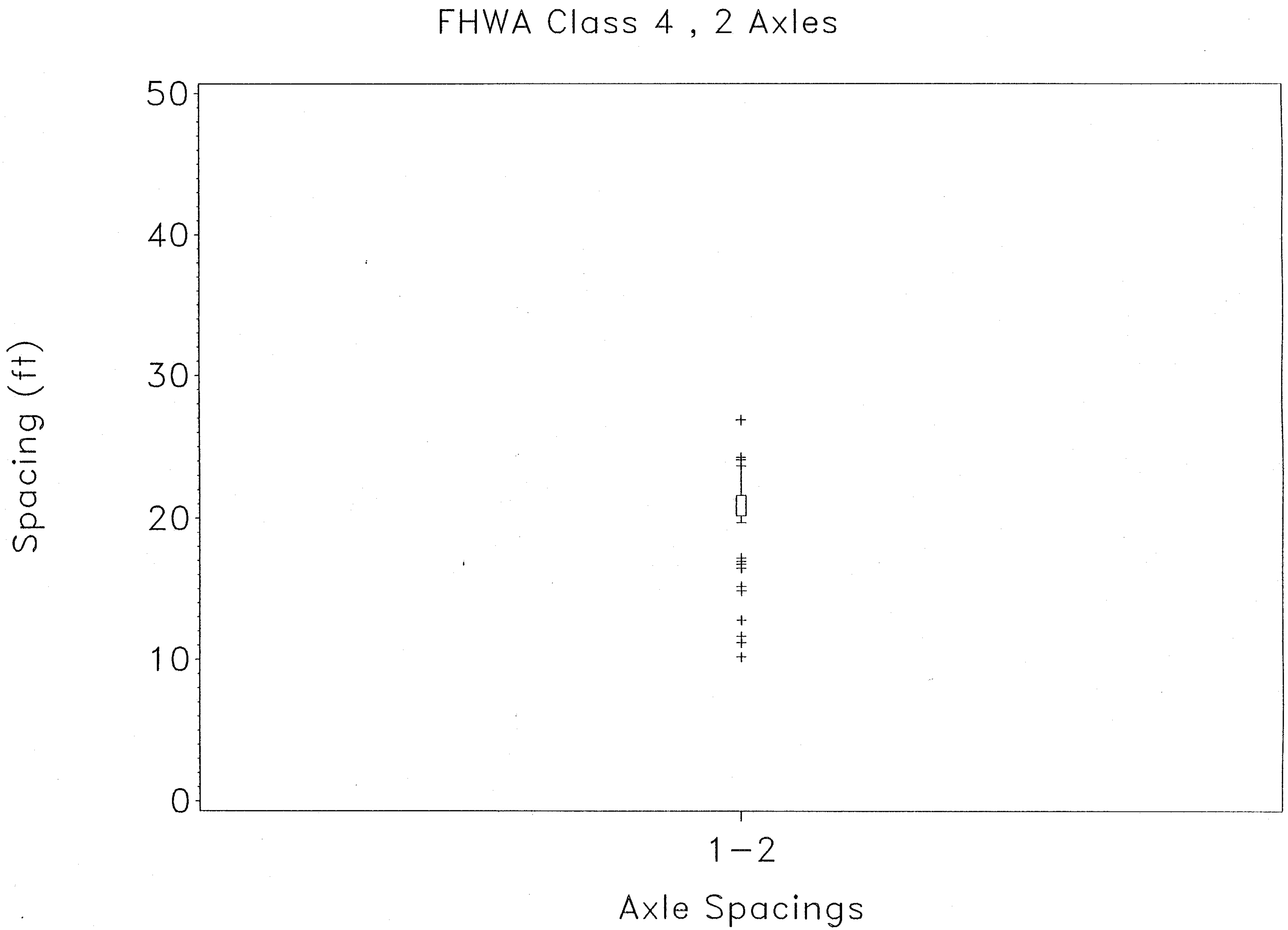

FHWA Class 3 , 2 Axles
50
40
30
20
10
0
Spacing (ft)
1-2
Axle Spacings

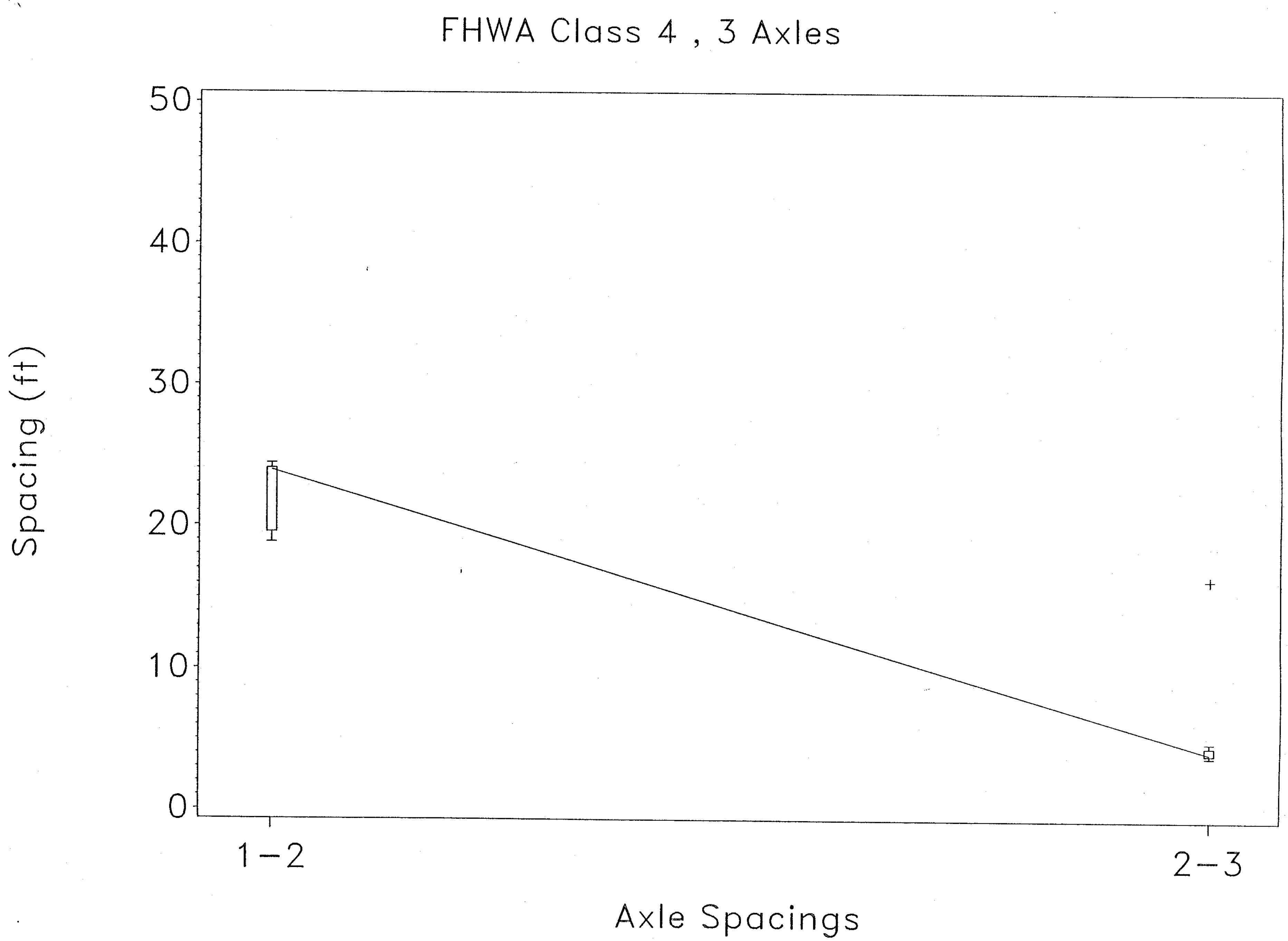

FHWA Class 3 , 3 Axles
50
40
30
20
10
0
Spacing (ft)
1-2
2-3
Axle Spacings

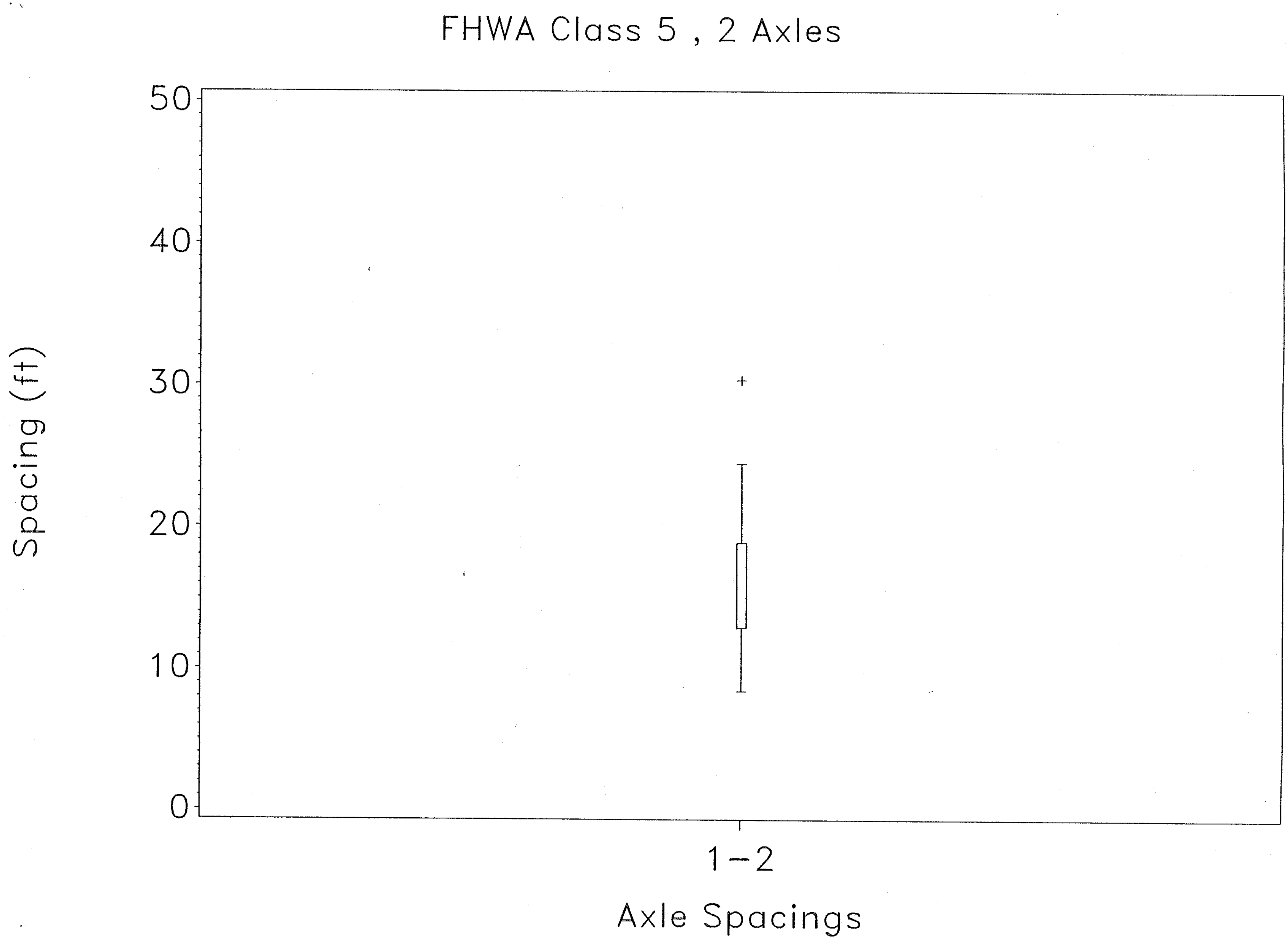
FHWA Class 3 , 4 Axles

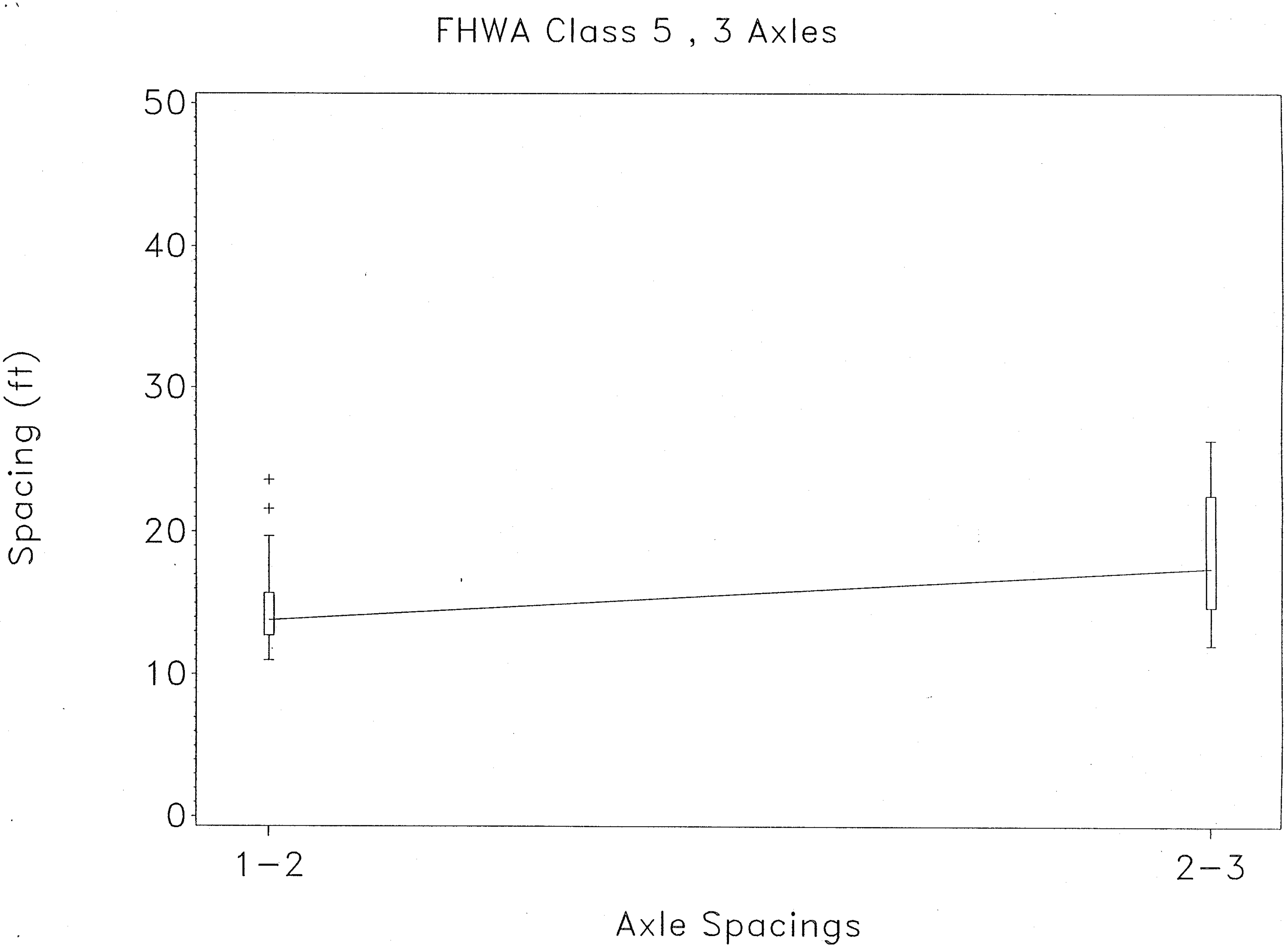


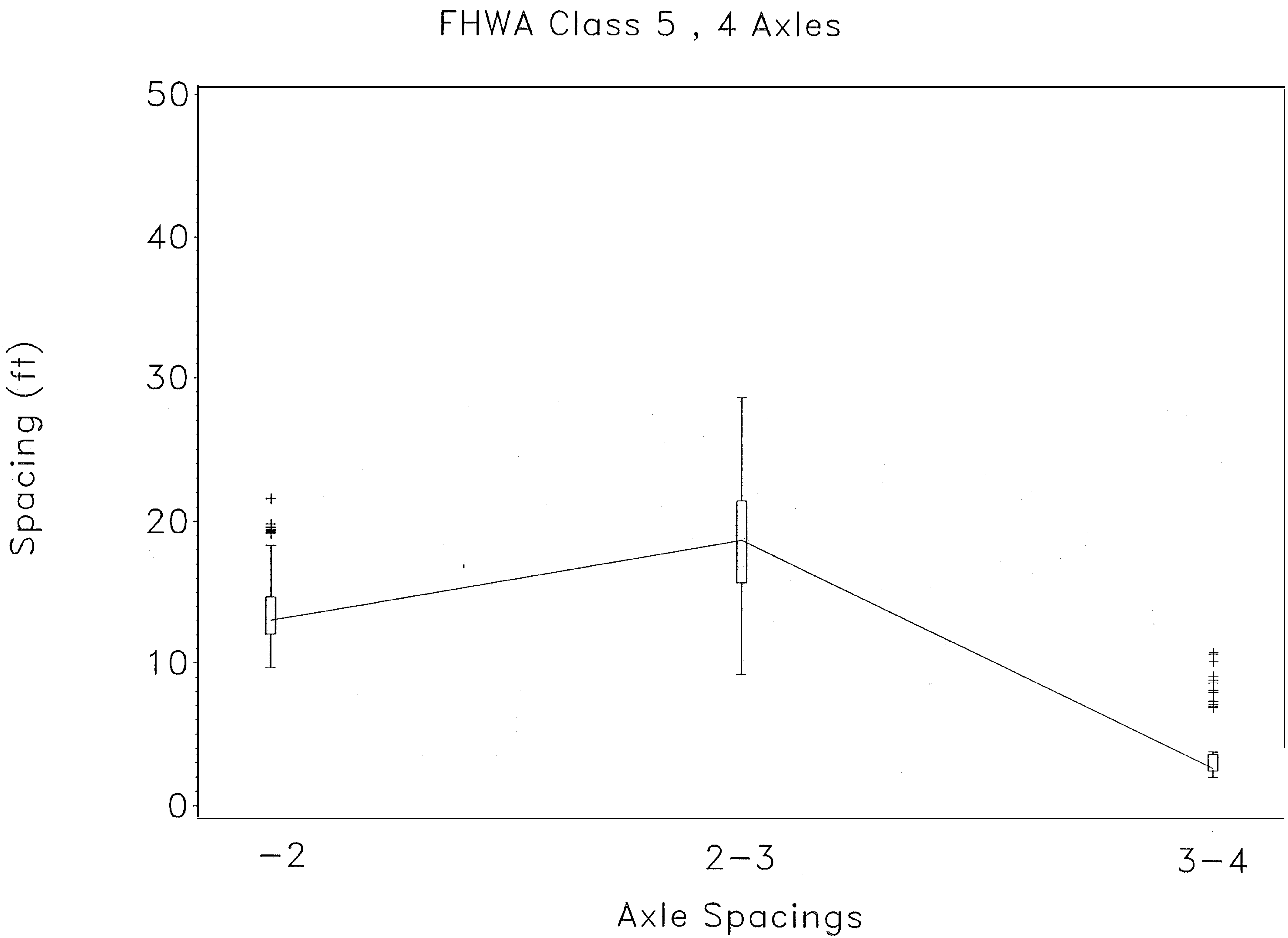

FHWA Class 3 , 5 Axles
Spacing (ft)
50
40
30
20
10
0
1-2
2-3
3-4
4-5
Axle Spacings

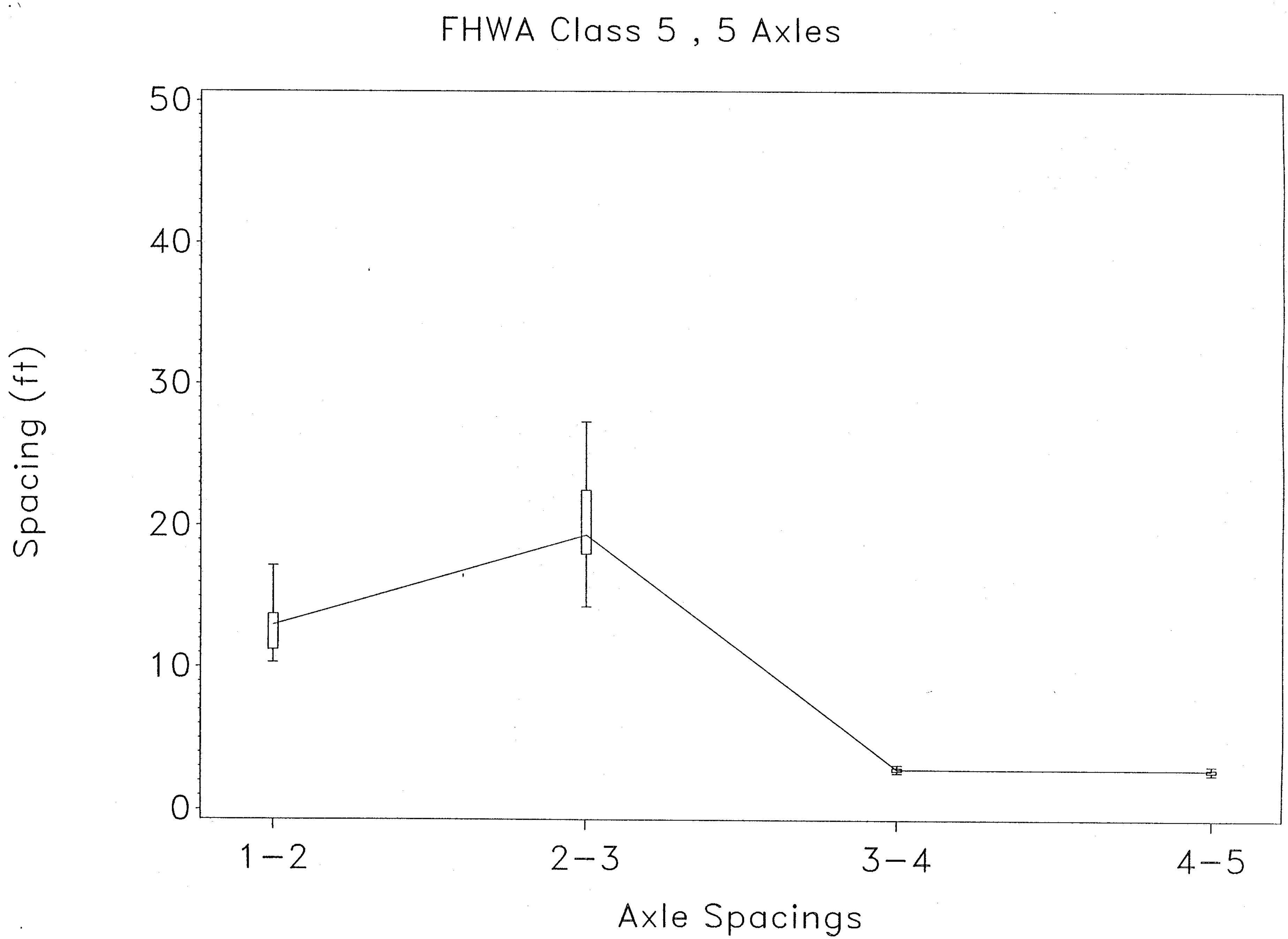

FHWA Class 4 , 2 Axles
Spacing (ft)
0
10
20
30
40
50
1-2
Axle Spacings

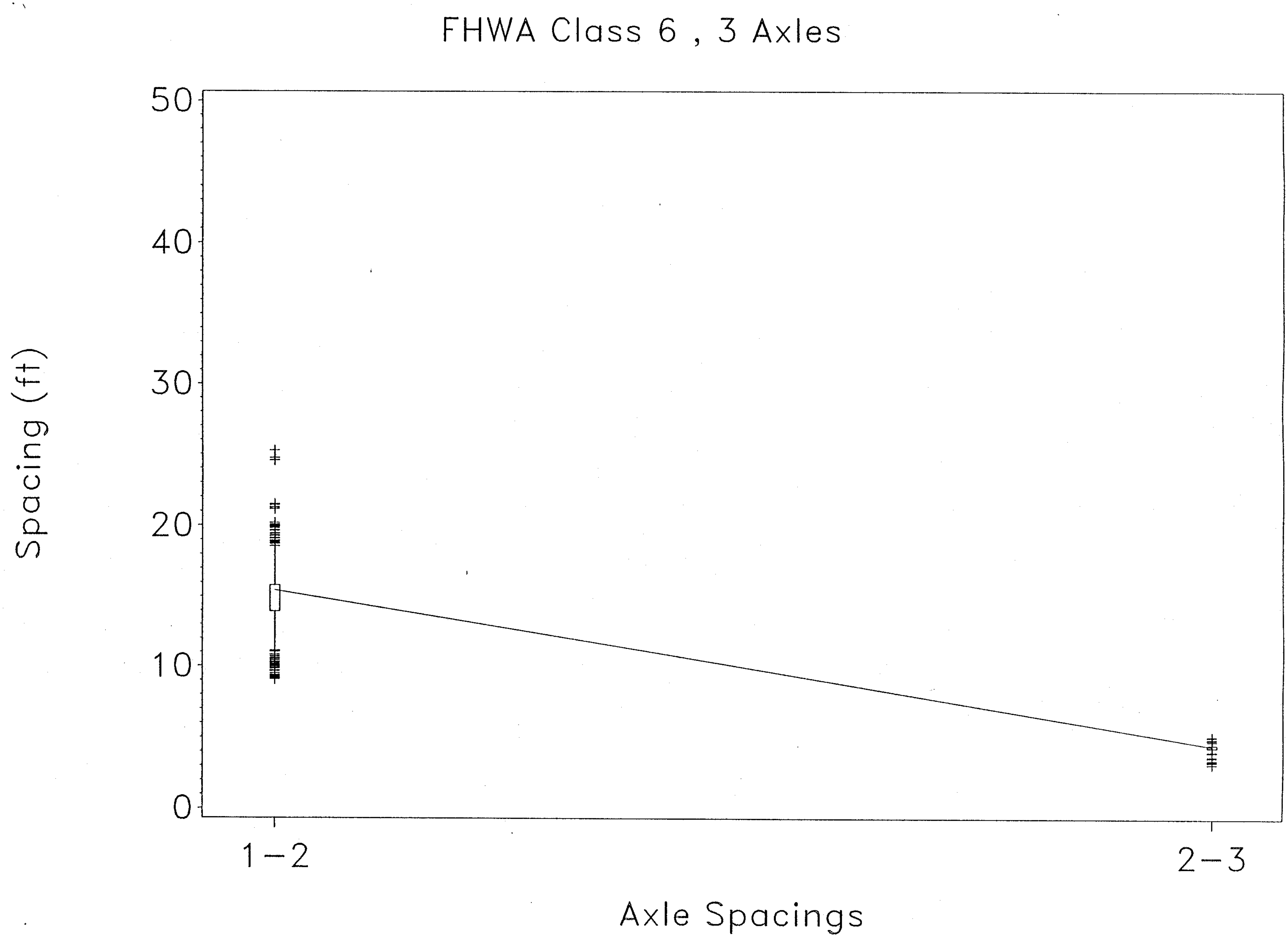

FHWA Class 4 , 3 Axles
Spacing (ft)
50
40
30
20
10
0
1−2
2−3
Axle Spacings


FHWA Class 5 , 2 Axles
Spacing (ft)
50
40
30
20
10
0
1-2
Axle Spacings

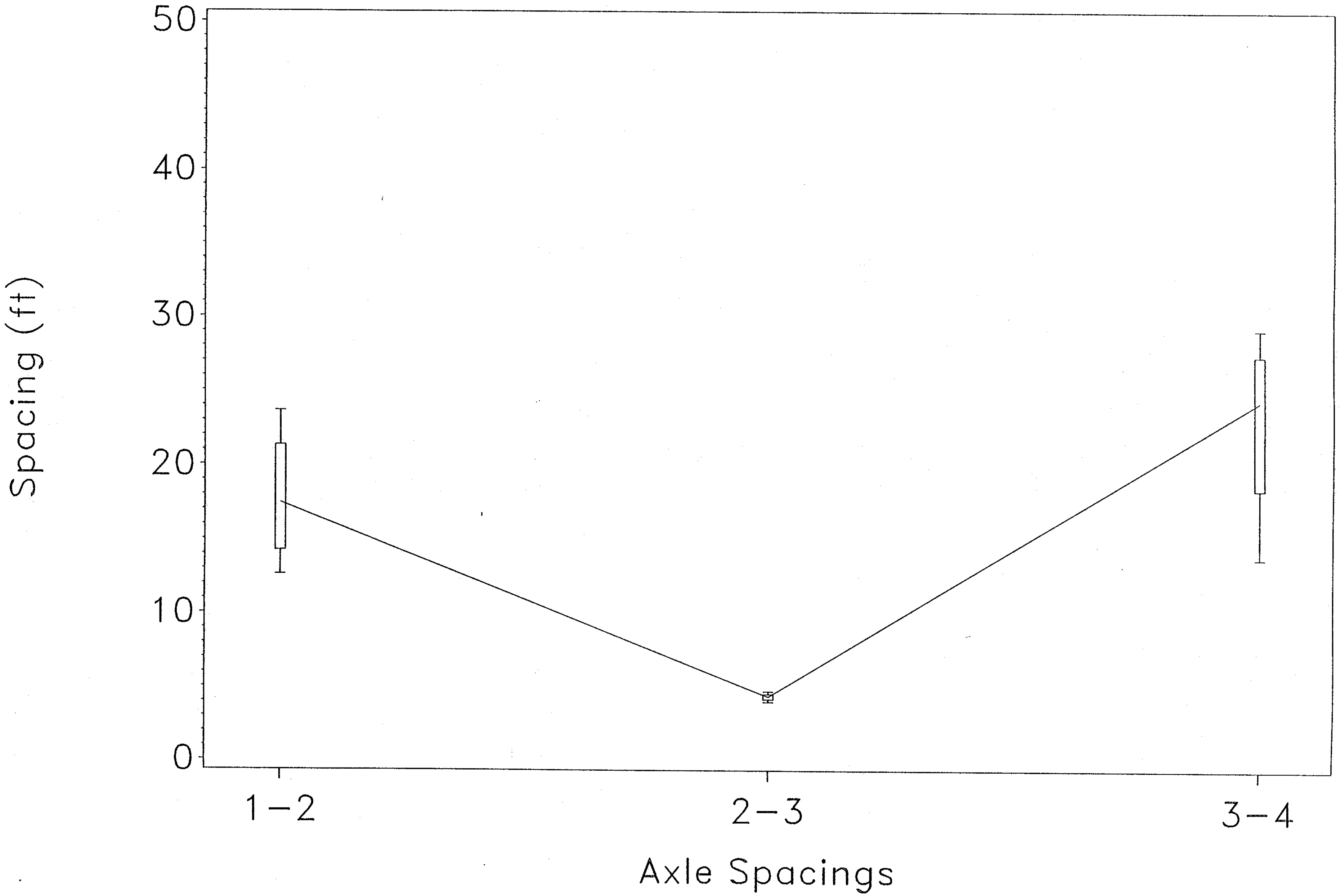

FHWA Class 5 , 3 Axles
Spacing (ft)
50
40
30
20
10
0
1−2
2−3
Axle Spacings

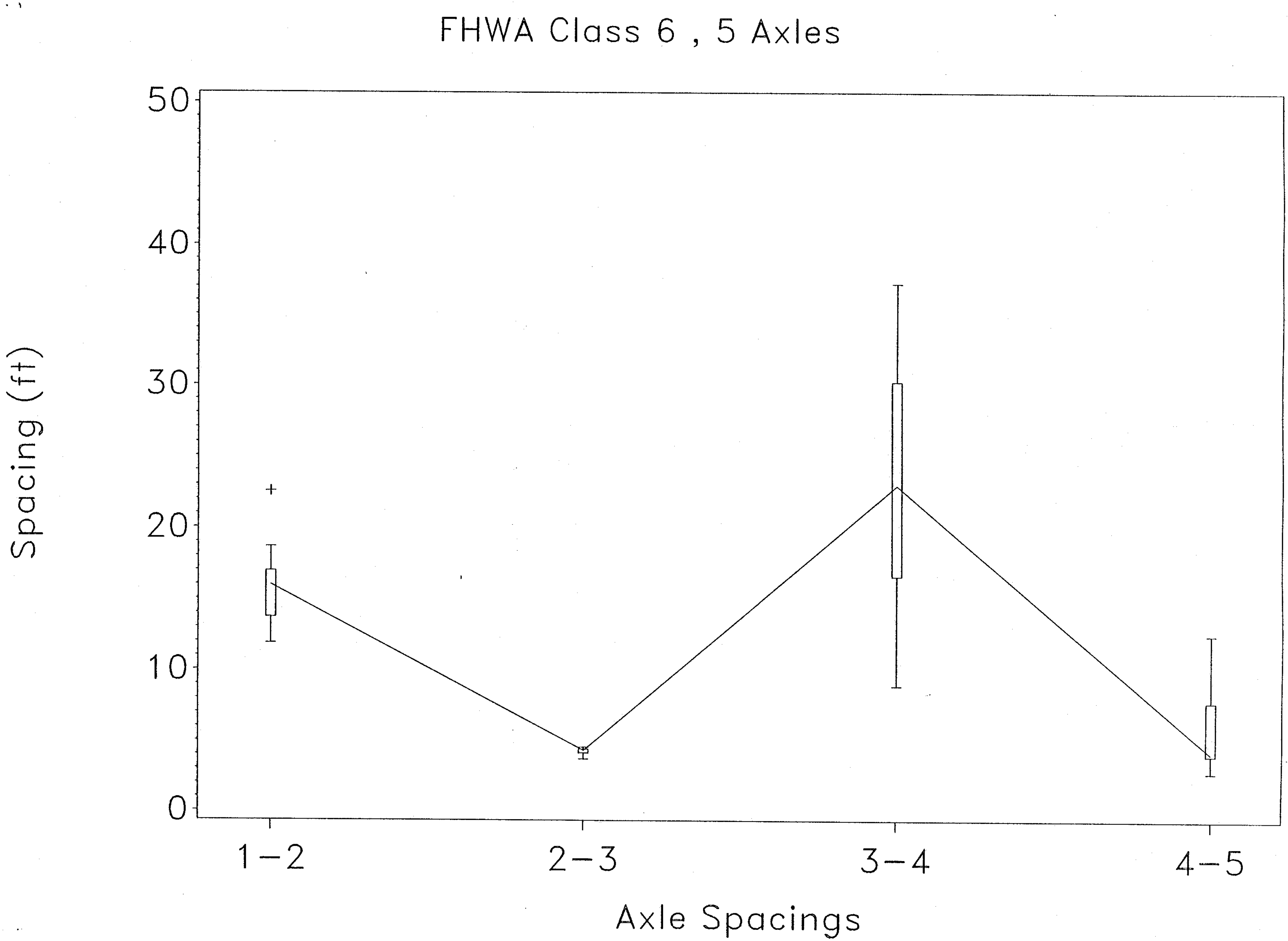

FHWA Class 5 , 4 Axles
Spacing (ft)
50
40
30
20
10
0
-2
2-3
3-4
Axle Spacings


FHWA Class 5 , 5 Axles
Spacing (ft)
0
10
20
30
40
50
1−2
2−3
3−4
4−5
Axle Spacings

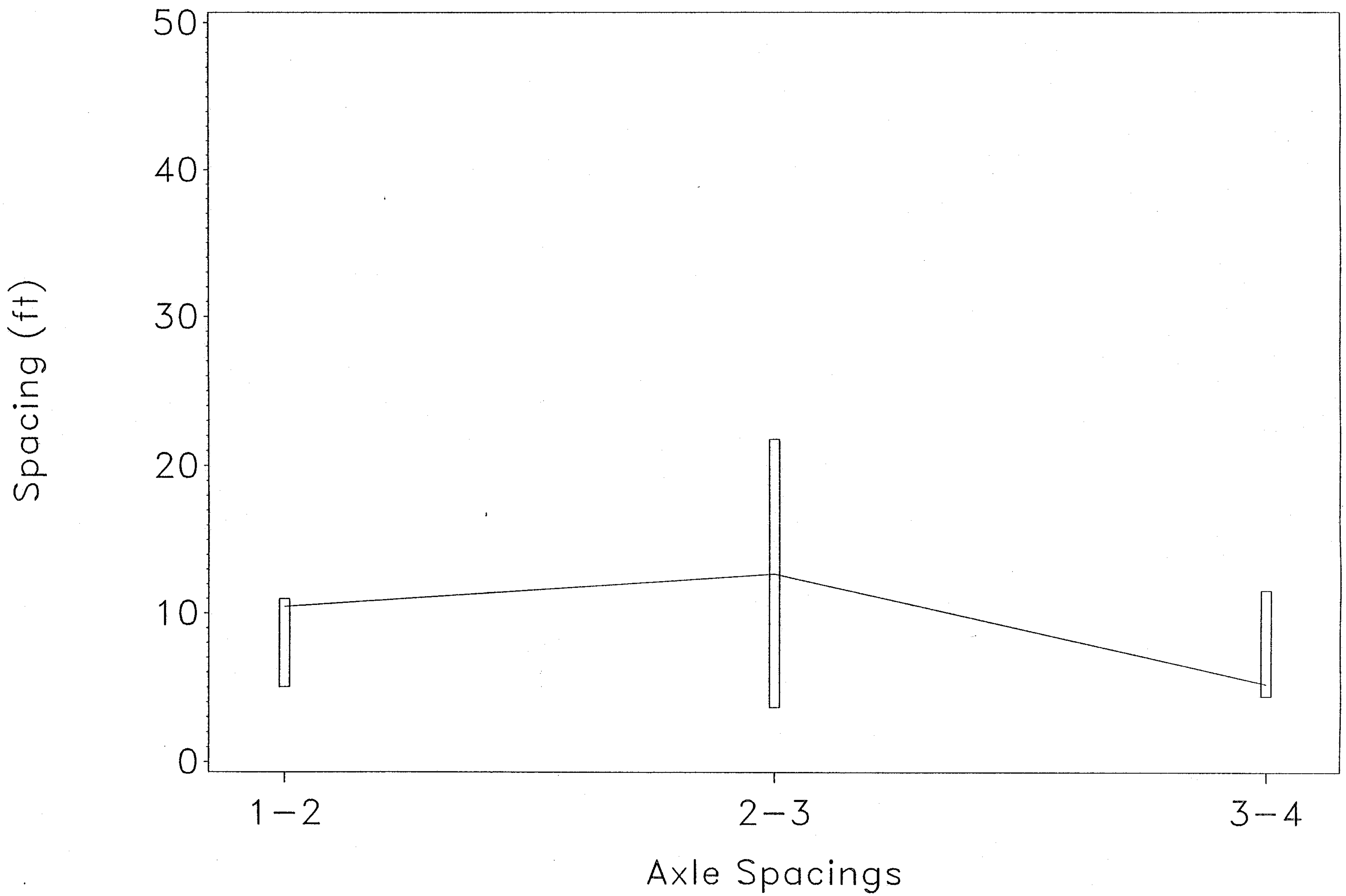

FHWA Class 6 , 3 Axles
Spacing (ft)
0
10
20
30
40
50
1-2
2-3
Axle Spacings

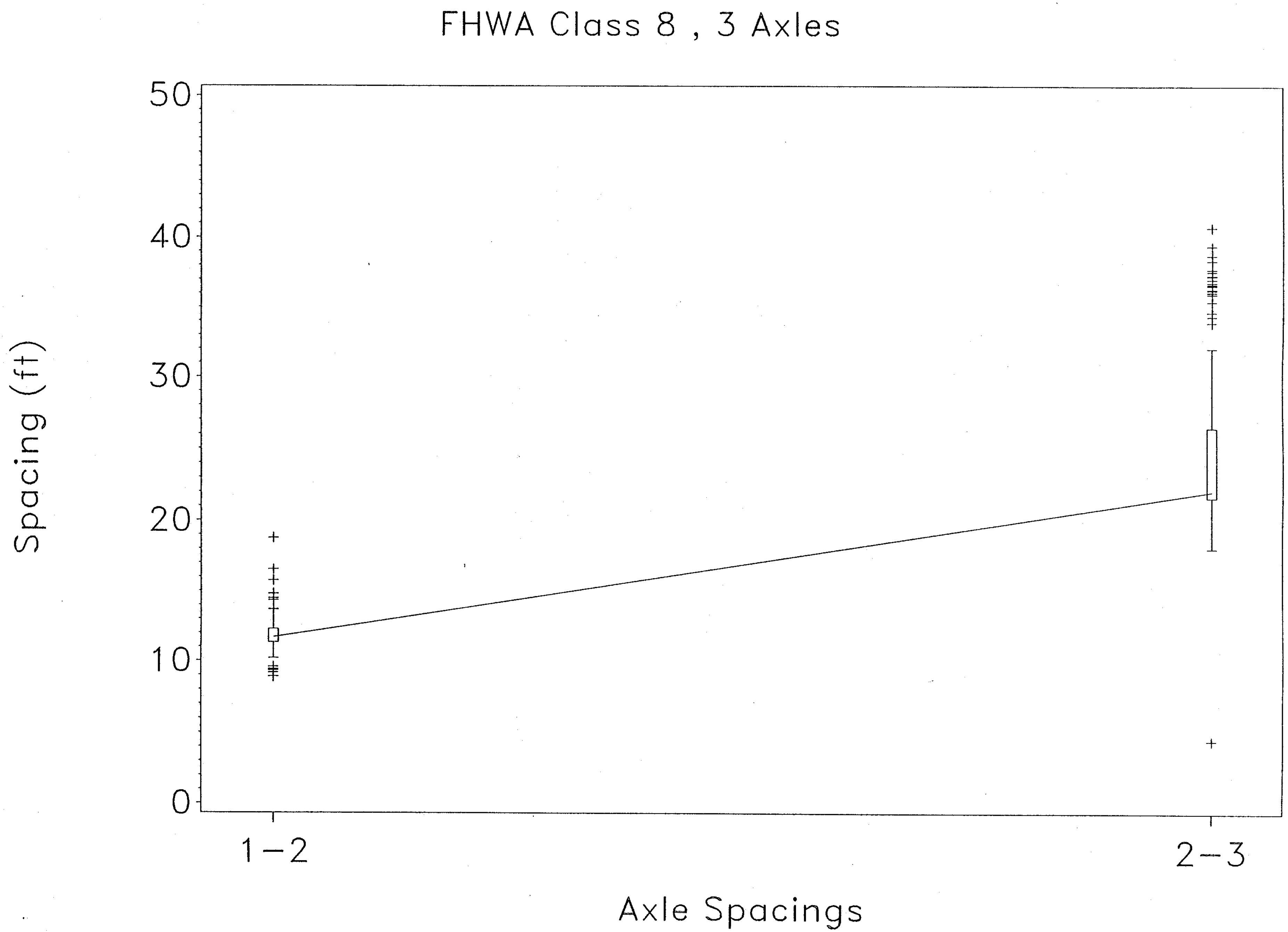
FHWA Class 6 , 4 Axles

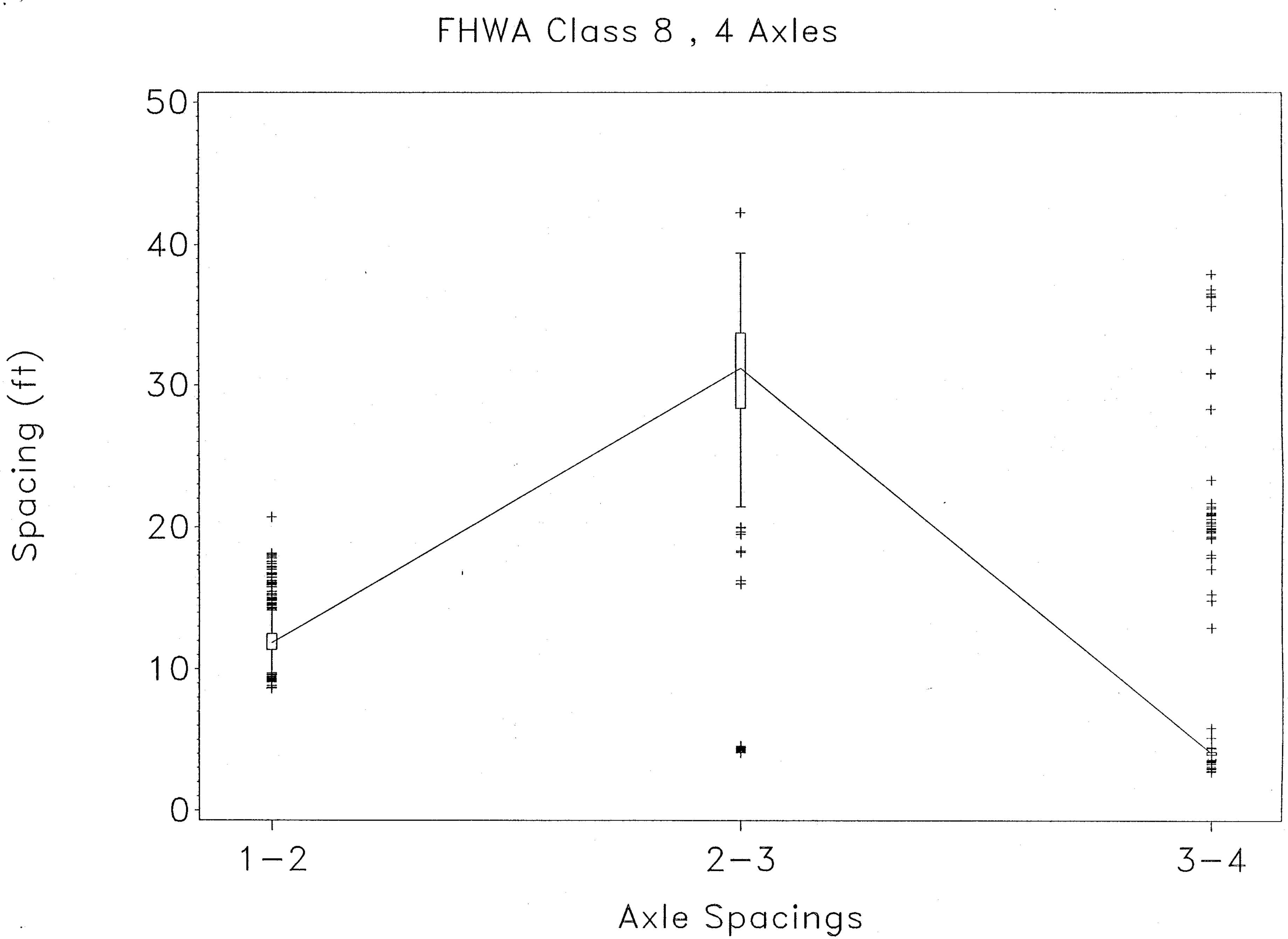



FHWA Class 6 , 5 Axles
Spacing (ft)
0
10
20
30
40
50
1-2
2-3
3-4
4-5
Axle Spacings

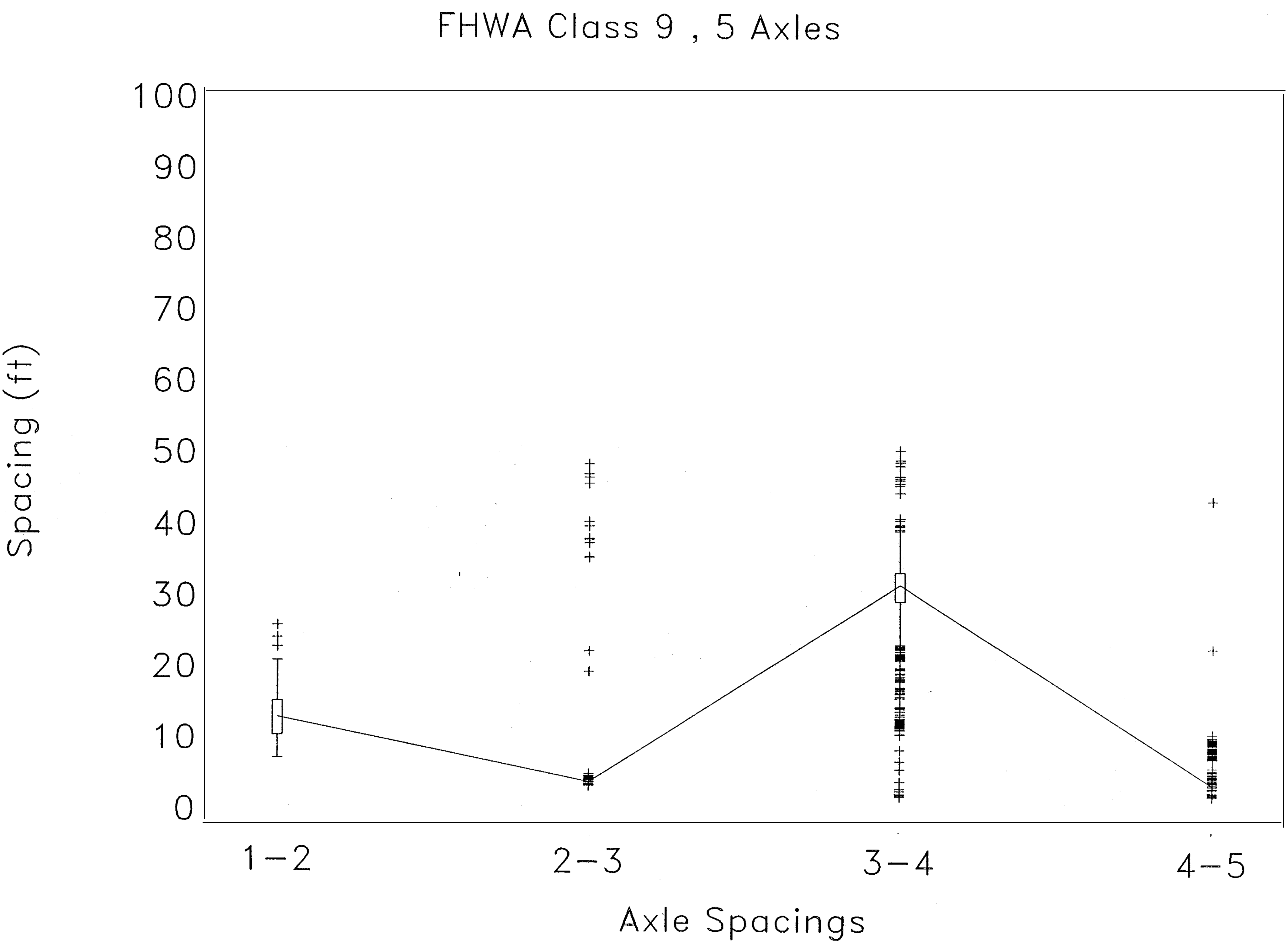
FHWA Class 7 , 4 Axles



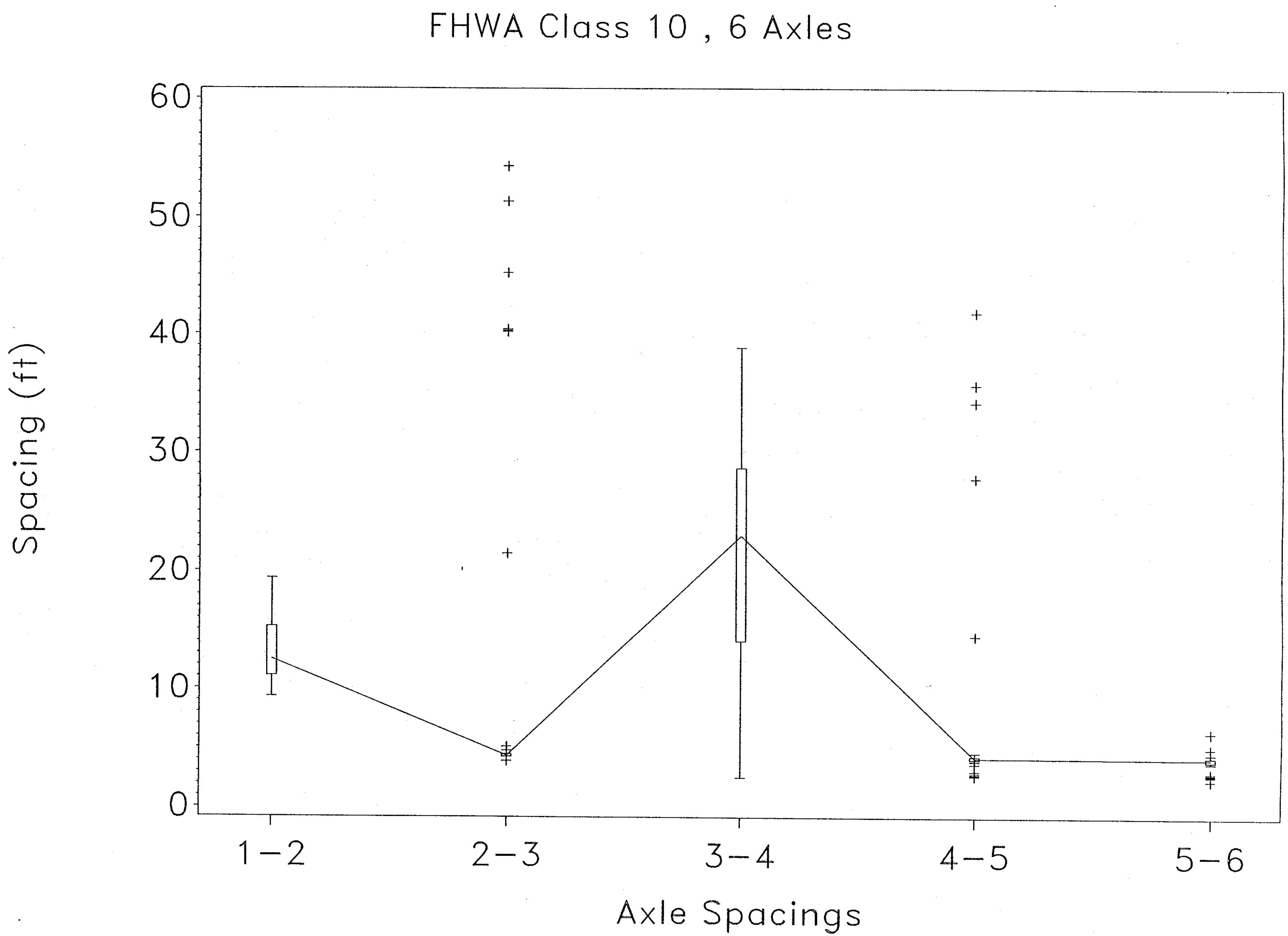

FHWA Class 8 , 3 Axles
Spacing (ft)
0
10
20
30
40
50
1–2
2–3
Axle Spacings

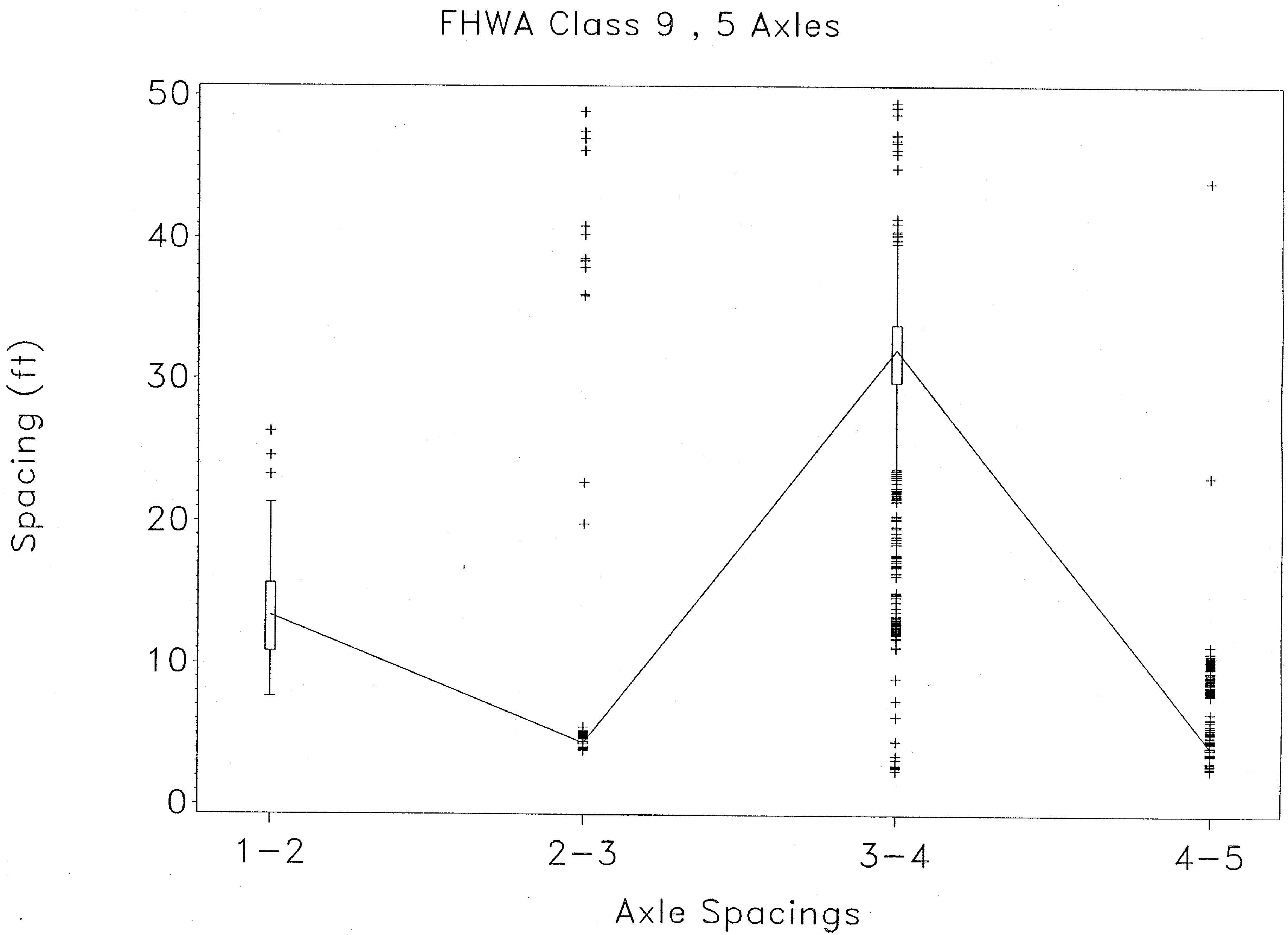


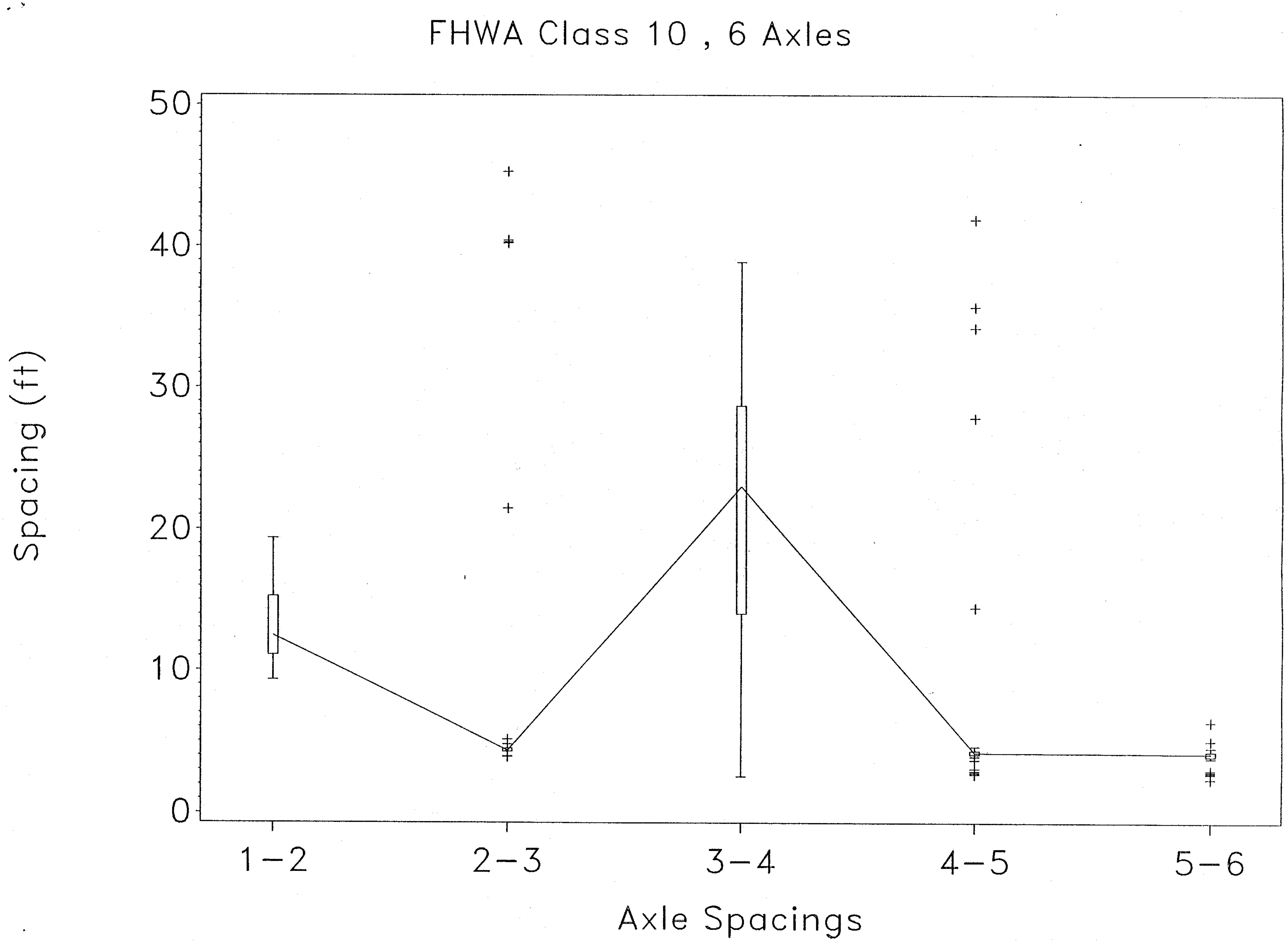
FHWA Class 8 , 4 Axles
Spacing (ft)
0
10
20
30
40
50
1-2
2-3
3-4
Axle Spacings

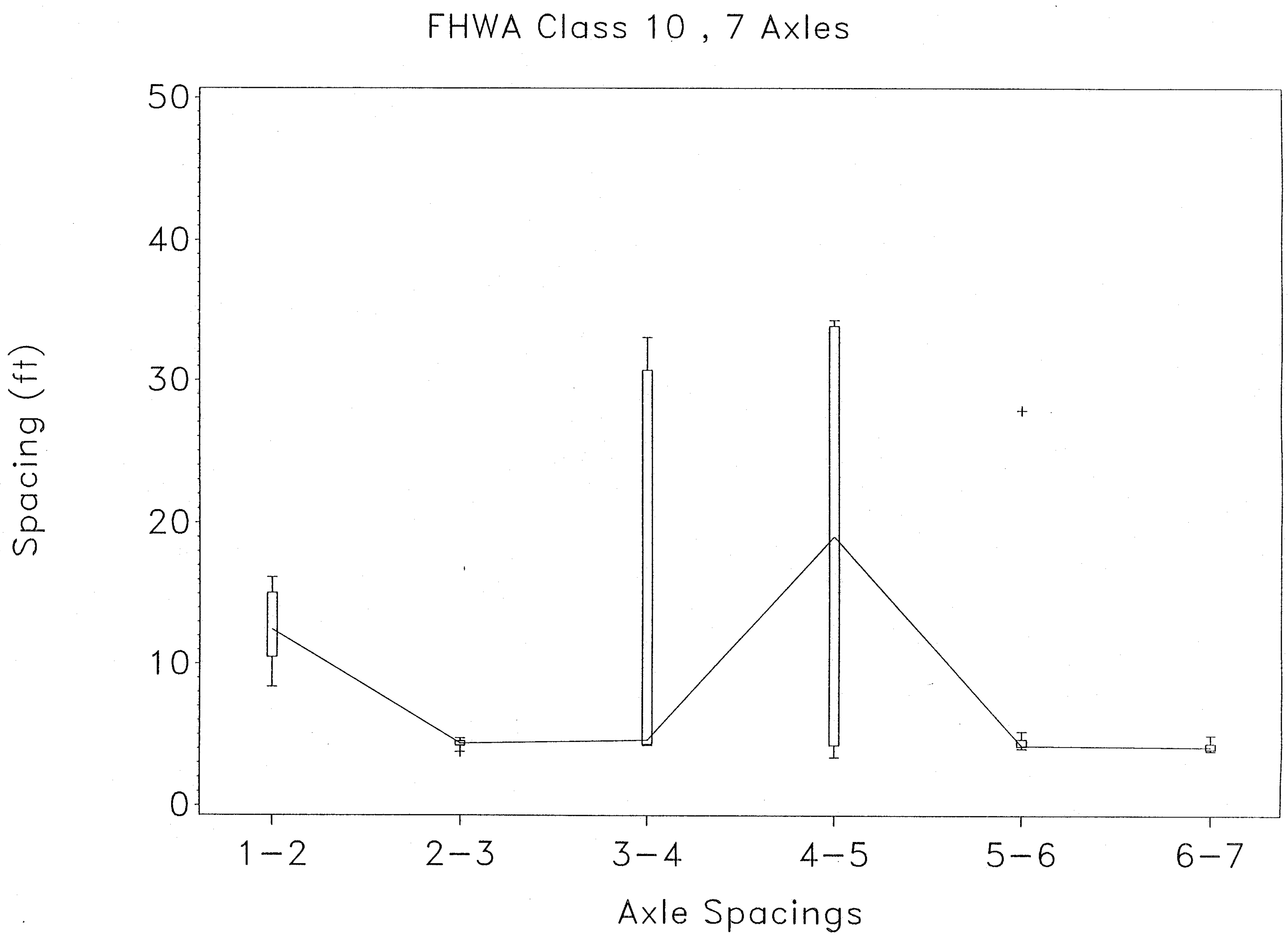


FHWA Class 9 , 5 Axles
Spacing (ft)
0
10
20
30
40
50
60
70
80
90
100
1-2
2-3
3-4
4-5
Axle Spacings

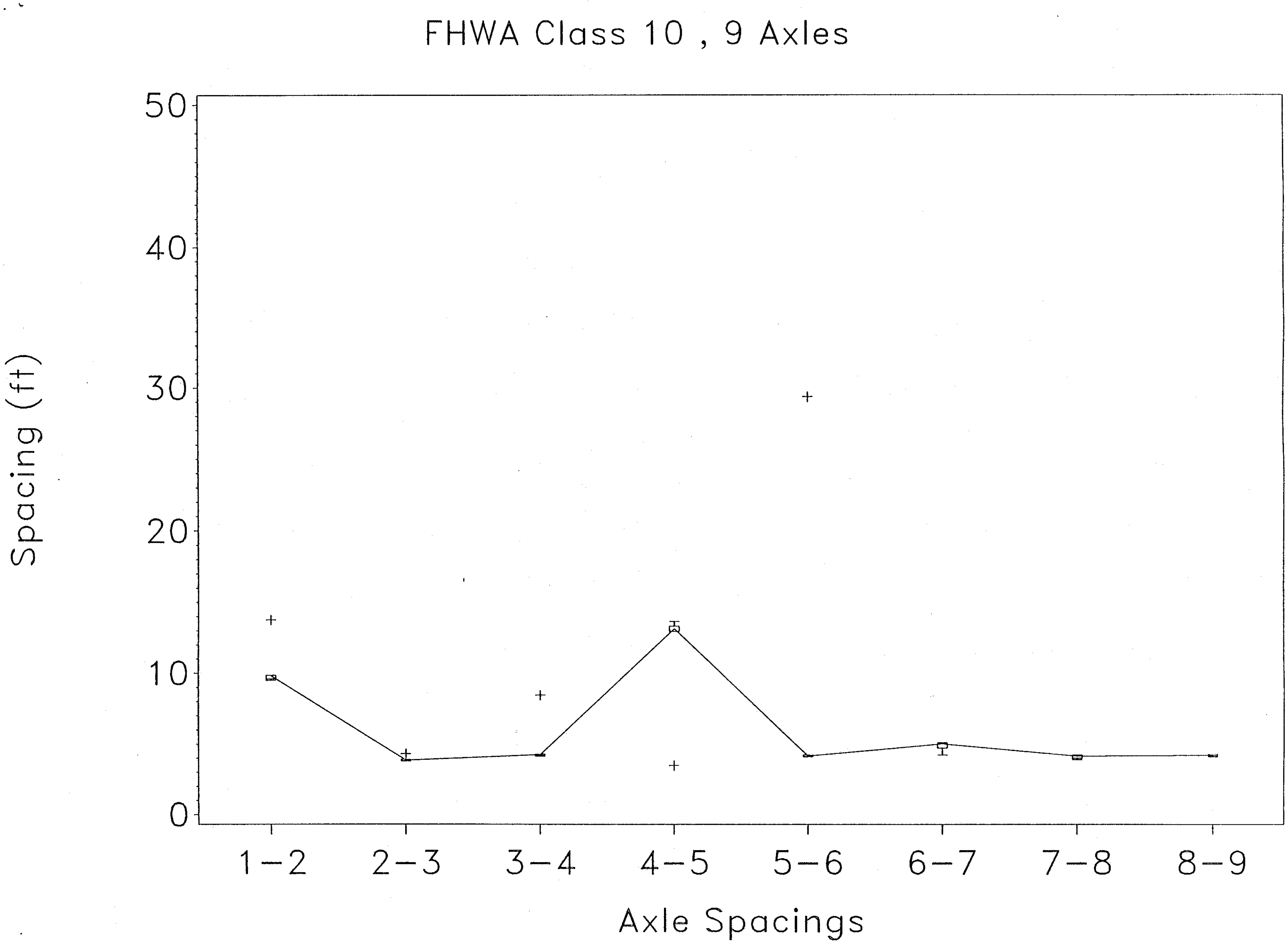

FHWA Class 10 , 6 Axles
60
50
40
30
20
10
0
Spacing (ft)
1−2
2−3
3−4
4−5
5−6
Axle Spacings

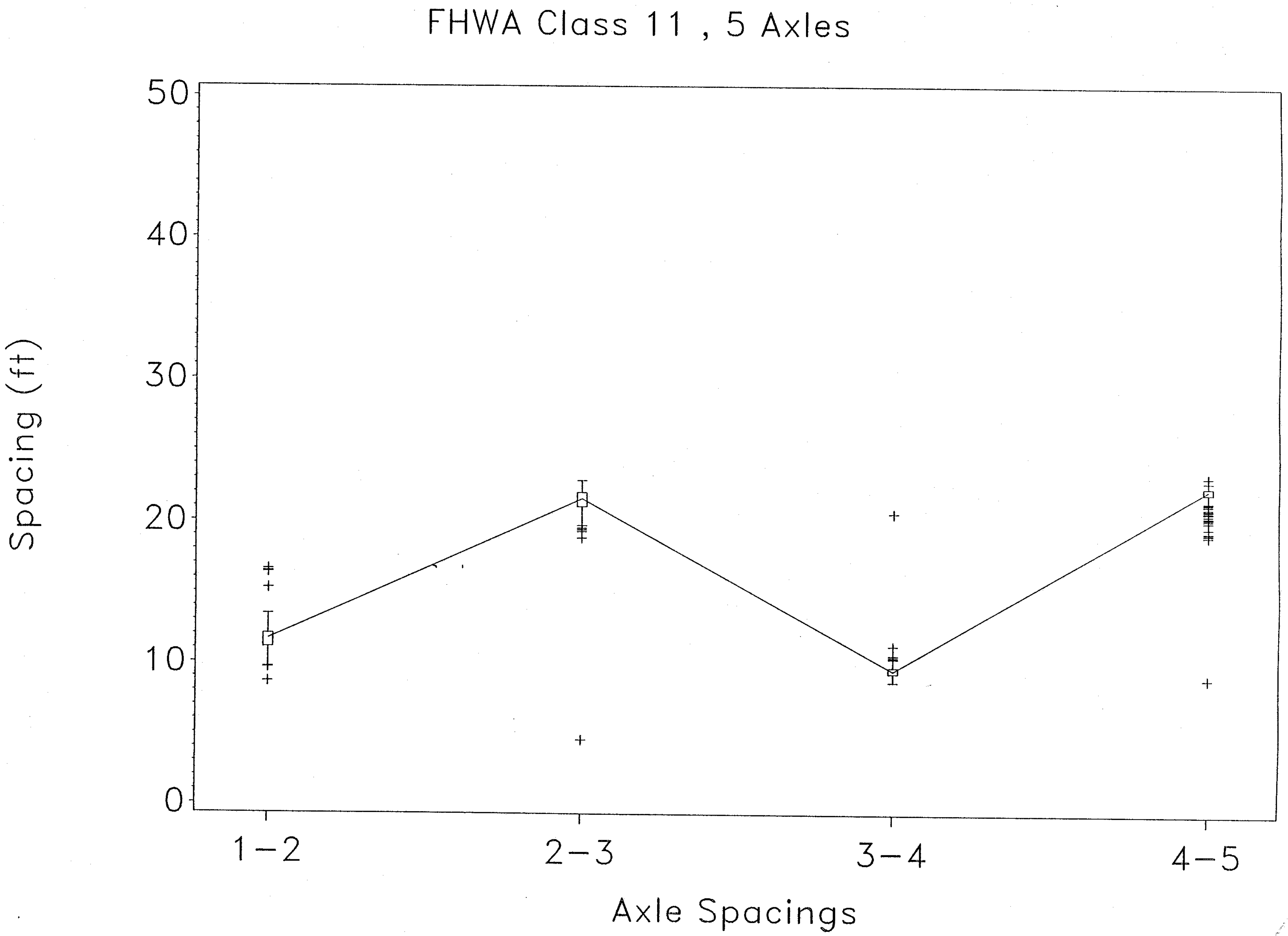

FHWA Class 9 , 5 Axles
Spacing (ft)
0
10
20
30
40
50
1-2
2-3
3-4
4-5
Axle Spacings

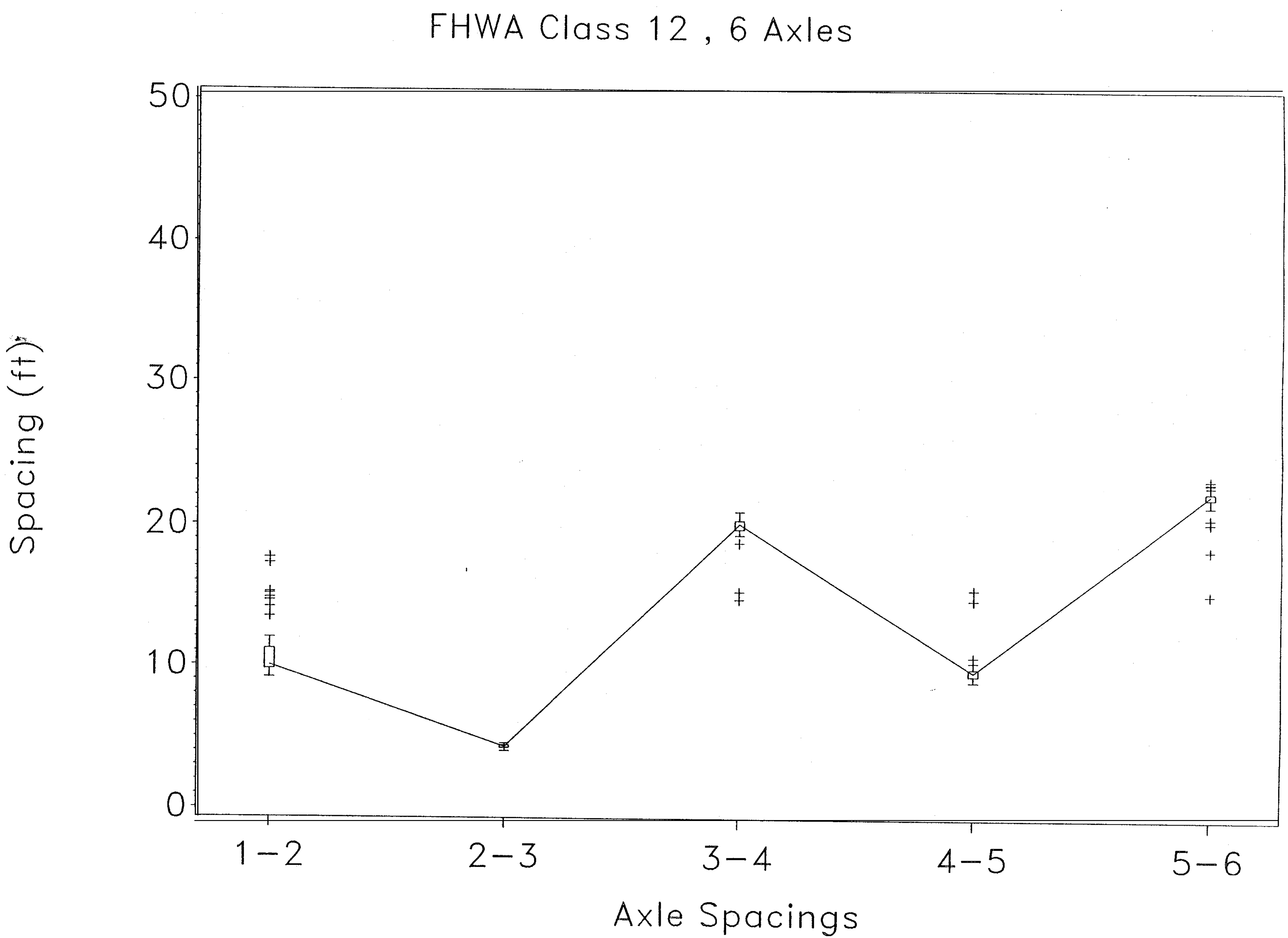

FHWA Class 10 , 6 Axles
Spacing (ft)
0
10
20
30
40
50
1-2
2-3
3-4
4-5
5-6
Axle Spacings



FHWA Class 10 , 7 Axles
Spacing (ft)
0
10
20
30
40
50
1−2
2−3
3−4
4−5
5−6
6−7
Axle Spacings


FHWA Class 10 , 9 Axles
Spacing (ft)
0
10
20
30
40
50
1−2
2−3
3−4
4−5
5−6
6−7
7−8
8−9
Axle Spacings


FHWA Class 11 , 5 Axles
Spacing (ft)
0
10
20
30
40
50
1-2
2-3
3-4
4-5
Axle Spacings


FHWA Class 12 , 6 Axles
50
40
30
20
10
0
Spacing (ft)
1−2
2−3
3−4
4−5
5−6
Axle Spacings