PROCEDURES FOR ESTIMATING THE TOTAL LOAD EXPERIENCE OF A HIGHWAY AS CONTRIBUTED BY CARGO VEHICLES

by

Jesse L. Buffington
Assistant Research Economist
Dale L Schafer
Systems Analyst
William G. Adkins
Research Economist

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ABSTRACT

The primary purpose of this research study was to develop and test procedures for making accurate estimates of the total load in terms of 18-kip axle equivalents that a highway will experience from cargo vehicles over its design period. Such an endeavor involved an evaluation of vehicle weight and classification count data previously collected at existing loadometer and manual count stations located throughout the State of Texas.

Two procedures were used to make estimates of the actual total 18-kip axle equivalents generated by cargo vehicles weighed at each of the 21 conventional static weight loadometer stations during 1967 and 1964-68. One procedure used multiple regression models in which the "dummy" variables represent various characteristics of the vehicles weighed. The sets of variables entered into the models included vehicle type, body type, fuel type, time of weighing (night, day of week, summer and year) and load status. The other procedure used axle weight frequency distribution sets composed of one-kip (1000-pound) weight classes, 40 for single axles and 50 for tandem axles. The frequency sets developed were as follows: (1) Combined stations, (2) Combined stations by vehicle type, (3) Combined stations by fuel type, (4) Combined stations by load status, (5) Combined stations by highway system and vehicle type and, (6) Combined stations by highway system. Frequency Set 5 proved to be the most accurate. In fact, it was more accurate than the regression models.

Another purpose of this research study was to test the adequacy of previously collected vehicle weight and count samples at the various loadometer stations. These samples were tested for representativeness of the vehicle traffic and reliableness of statistics generated therefrom. To determine the above, the weighing and counting schedules and sample sizes were evaluated. Also, conventional loadometer station data were compared with limited weigh-in-motion station data. The weight and count sample size requirements were established through the use of a statistical formula which utilizes sample averages and variances with 10 percent error and 95 percent probability level criteria.

It was found that a considerable amount of station to station variation in the sample statistics was due to differences in the weighing or counting schedules and sample sizes. Combining stations and/or years made the data more representative and increased the reliability of the sample statistics.

SUMMARY OF FINDINGS

This report presents procedures and findings which relate primarily to estimating the total load experience (measured in 18-kip axle equivalents) of an existing or future highway over its design life through the use of adequate cargo vehicle weight and annual average daily traffic (AADT) count data. Such estimates are needed as considerations in highway design. The most important findings of this research effort are summarized here.

An analysis of vehicle and axle weight distributions developed from previously collected loadometer data gave the following results:

1. Significant differences exist between most of the station and highway system averages within vehicle type. Even the grouping of stations according to highway system failed to produce homogeneous weight distributions. Various geographical groupings of stations also showed significant differences.
2. Much of the station to station or system to system variation is due to changes in the proportion of loaded and empty tandem axle vehicles. Such proportions change with vehicle and body types.

An analysis to determine the adequacy of cargo vehicle and axle weight samples taken at loadometer stations during the past few years gave the following results:

1. Part of the station to station variation in the averages of vehicle and axle weights is due to differences in the weighing schedule. Additional between station variation is

due to small samples which are susceptible to greater chance differences. Therefore, samples from the 21 stations combined produced a more accurate estimate of the true population variance than samples from only one station. However, if continuous seven-day weighing periods for every season of the year were used, the number of stations might be reduced drastically.

2. The number of vehicles weighed in 1967 at all 21 stations combined was more than enough to produce reliable averages of vehicle 18-kip axle equivalents. The same was true for the combined stations of the interstate highway (IH) system, but the reverse was true for those of the other systems. Therefore, the number of weighings of certain vehicle types could be reduced, especially those at stations on the IH system.
3. Considerably more vehicles must be weighed to obtain accurate average <u>vehicle</u> weights in 18-kip axle equivalents than to obtain accurate average <u>axle</u> weights in 18-kip axle equivalents.

An analysis to determine the adequacy of cargo vehicle manual classification count samples taken at loadometer stations during the past few years gave the following results:

1. Considerable variation in the averages and variances of 24-hour volume counts for five-axle semitrailer vehicles occurred at individual stations. Contributing to this variation is the time of counting, the length of counting periods and the number of 24-hour volume counts.

2. Considerable variation in the averages and variances of 24-hour volume counts for five-axle semitrailer vehicles occurred from station to station. Consequently, the number of counts necessary varied extensively between stations. However, only a few stations required a larger number of counts.
3. The number of 24-hour volume counts necessary to collect at each station varied widely between vehicle types.
4. Within-year and between-year fluctuations in the estimated base AADT count for each vehicle type are much less when based on three 24-hour counts per year for four years than when based on only one 24-hour count per year.
5. Of four methods used to estimate the AADT count of five-axle semitrailers at a station, those employing only 24-hour volume counts of <u>this vehicle type</u> in the calculations showed the least within-year and between-year fluctuations.

An analysis of loadometer data to develop and test procedures for use in estimating each loadometer station's total load experience measured in 18-kip axle equivalents produced the following results:

1. Of five sets of axle weight frequency distributions Set 5 (based on data classified according to highway system and vehicle type) produced the most accurate station estimates.
2. Of two multiple regression models, Model 2 (based on sets of "dummy" variables) produced the more accurate station estimates.

3. Of the two estimating procedures, the axle weight frequency distributions of Set 5 produced the more accurate station estimates.

4. Neither of the above estimating procedures produced station estimates which were within 10 percent of the actual value for every station.

5. The multi-year (1964-68) loadometer data produced more accurate estimates of total 18-kip axle equivalents at each station than did the one-year (1967) data, thus removing some of the differences due to sample size and weighing schedule.

These findings do not fully satisfy the requirements of all the objectives. For instance, more weigh-in-motion loadometer data need to be collected before Objective 2 (see list in introductory section) can be properly researched. Findings based on additional data from this source could affect the results presented here for the other three objectives.

IMPLEMENTATION STATEMENT

The research findings reported here can be used immediately by the various government agencies responsible for designing and maintaining highways. They can be applied to the loadometer weight and manual classification count data to make more accurate estimates of a highway's total load experience, measured in 18-kip axle equivalents. A proposed new procedure using multiple regression models was evaluated and rejected in favor of a more accurate conventional procedure using axle weight frequency distribution sets. Among the frequency distribution sets developed, Set 5 is recommended for use in estimating a station's total 18-kip axle equivalents. This set was generated from multi-year (1964-68) loadometer data by classifying the 21 stations according to highway system and vehicle type. The applicable percentage frequencies for Set 5 are presented in Appendix A of the report.

Then, to arrive at an estimated annual average daily traffic (AADT) count of each vehicle type for the base year of a highway, it was concluded that at least several 24-hour volume counts per year for three or four years should be used. Of the methods used in making AADT count estimates for the cargo vehicle types, Method 2 is recommended.

Further research is recommended to determine true station to station differences in vehicle type weights and counts. The type of data which will probably aid most in this determination should be that collected at several weigh-in-motion stations on each highway system over continuous seven-day a week weighing periods during each season of the year. The resulting percentage axle weight frequency distributions and estimated based year vehicle type AADT's would probably be more representative of the stream of cargo vehicle traffic and generate more reliable weight and count statistics than have been generated in the past. The number of weighing stations needed also could be determined more accurately.

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INTRODUCTION

In September 1967, the Texas Transportation Institute in cooperation with the Texas Highway Department and the U. S. Department of Transportation, began a study entitled "Studies of Truck Characteristics Relating to Highway Use and Taxation in Texas".

During the first year of the study, research efforts were concentrated on the first two of six objectives which dealt with determining whether Texas cargo vehicles of various types and weight classes were being equitably taxed (fuel imposts plus licenses and fees) in relation to their highway use. The findings of this research endeavor were published in May 1968, as Research Report 131-1, entitled "Fuel Tax Differentials of Texas Cargo Vehicles".

During the last two years of the study, research efforts have been concerned with the four remaining objectives which are as follows:

1. To determine the frequency distributions of axle weights by cargo vehicle classes on various highway systems, to compare these data with total loadometer data and to derive associated highway use and taxation inferences.
2. To analyze the potential of the weigh-in-motion station in Austin as a tool for simplifying data development.
3. To test the adequacy of samples at various count and loadometer stations.
4. To develop and test techniques for loadometer data reduction and analysis.

A partial report of findings from these research efforts was submitted to the sponsors in an unpublished interim report entitled "Procedures for Estimating Cargo Vehicle 18-Kip Axle Equivalents and Determining the Adequacy of Loadometer and Count Station Samples", dated August 21, 1969.

Problem Statement

Officials of the Highway Planning Survey Division of the Texas Highway Department (THD) are constantly striving to upgrade their data collection and analytical procedures so that they can furnish the other divisions and districts within that organization more accurate projections necessary for optimum highway engineering and highway economy. The four objectives mentioned previously indicate areas which currently need immediate attention. Other related problems can be explored at a later date.

Cargo vehicles make up only a small proportion of the total traffic stream, but they account for a very large percentage of the total load experience of the public roads of Texas. The collection of adequate vehicle weight and volume samples and identification of critical cargo vehicle characteristics are necessary for making accurate estimates of the actual load experience of a particular road in a given time period.

Underestimating the load experience of a proposed highway would result in an underdesigned facility having a shorter physical life than planned for. Thus, road replacement and repairs (resulting in additional costs) would be needed much sooner than expected.

The objectives of this research effort do not require an analysis on the basis of costs. Instead, they call for the development of a procedure which will provide reasonable assurances that estimates of the load experience are kept within the 10 percent margin of error requested by the THD. Acceptance of such a margin of error is admission that it is very difficult to make extremely accurate estimates of the actual load experience of a facility using historical data.

Scope of Study

The study is limited to an analysis of data collected at loadometer and count stations in recent years. It is not designed to determine the representativeness of loadometer and count stations in measuring the vehicle weight and number frequencies on the various highways in the State. Further, the study is limited to an analysis of the heavier cargo vehicles (excluding the 2-axle 4-tire vehicles) which greatly influence the weight bearing design of proposed highways. Last, the vehicle weight estimates in terms of 18-kip axle equivalents are applicable only to flexible pavement. However, the same techniques developed in this study can be used in making estimates that apply to rigid pavement.

Source of Data

The study is based on data collected by the Highway Planning Division of the THD at its loadometer and manual classification count stations located throughout Texas.

Cargo vehicles are weighed at the 21 conventional loadometer stations and one weigh-in-motion station shown in Figure 1. Nineteen of the conventional stations are located in rural areas and two in urban areas. On a highway system basis, the 19 conventional rural stations are located as follows: Nine along Interstate routes, 10 along U. S. Numbered routes and one along a State Numbered route. One of the urban stations is located along a U. S. Numbered route and the other along a Farm-to-Market route.

During March 1969, the THD began operating a new portable weigh-in-motion scale at a rural location along Interstate Highway 35 just south of Austin, and it is labeled as Station 35-2 in Figure 1. Thus far, weighings have been made at this station over one continuous seven (24-hour) day period. These weighings were limited to vehicles using the outside lane.

Since the initial weighings, the weighing device has had to undergo necessary changes to permit easier monitoring when it is in operation. Therefore, it was not possible to obtain as much data as was expected for use in this study.

For several years, the THD has been taking vehicle classification counts at approximately 188 manual count stations, 21 of which are the permanent loadometer stations mentioned above.

The classification count stations are located primarily in rural areas along Farm-to-Market roads, State highways, U. S. Numbered highways and Interstate highways. About 55 percent of these stations are located at intersections of the above mentioned roads and highways, allowing separate counts to be made on each type of road involved. Thus, about 300 separate road counts can be taken rather than one for each of the 188 stations. About 37 percent of the 300 separate road counts are two directional.

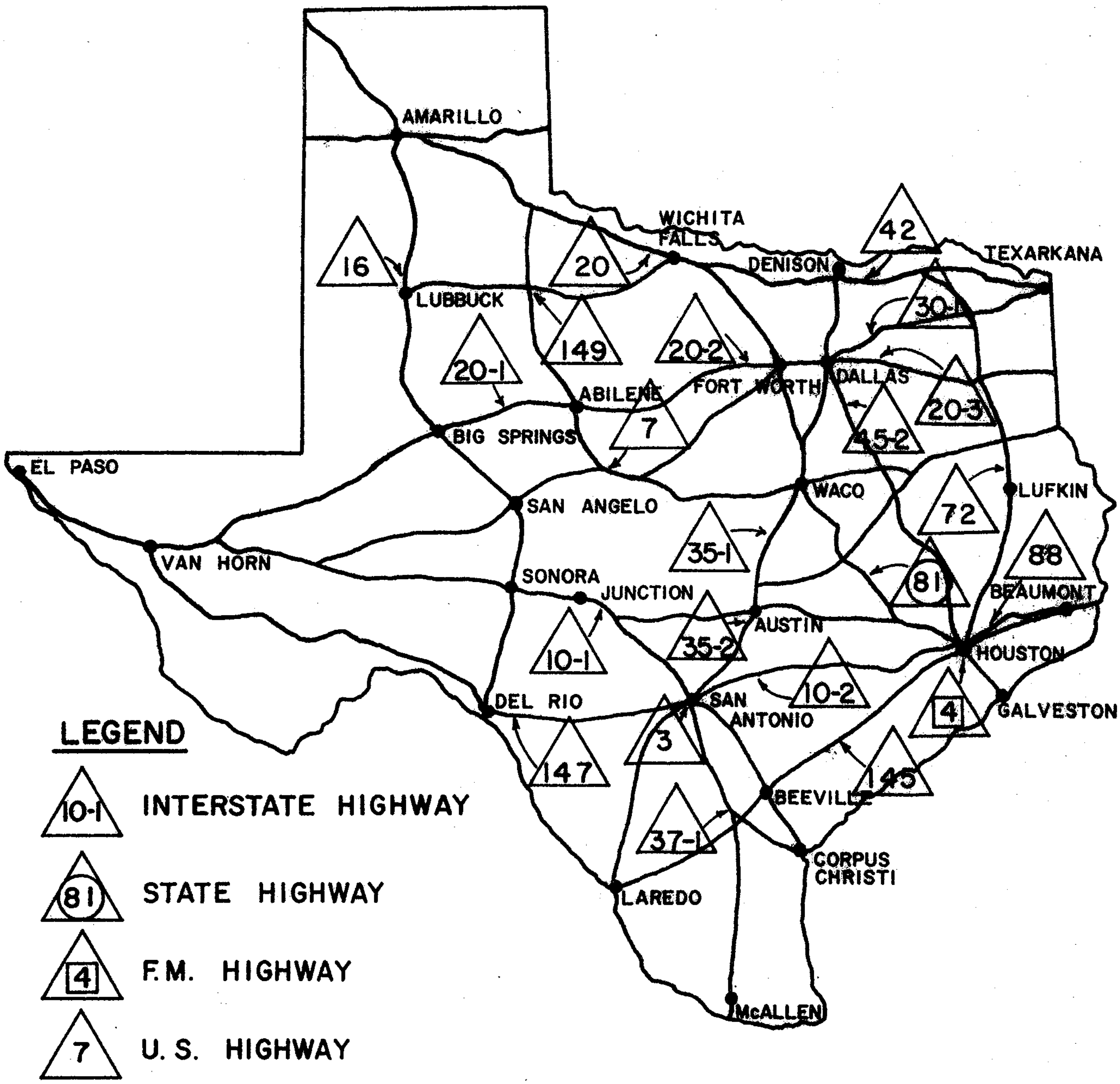

Figure 1. Map showing the location of 22 loadometer stations where weighings of cargo vehicles used in study were recorded.

The special weigh-in-motion loadometer station (35-2) provided a continuous seven-day classification count of all vehicles by axle configuration during one week in March 1969.

Automatic recording stations are located at or near the loadometer and manual count stations to give accurate annual average daily traffic (AADT) count data. These data were used to a limited extent in the analyses in this study.

Division of Study

The study procedures and results of analyses are dealt with under four major headings as follows: (1) Estimating the total load experience of a highway; (2) Determining the adequacy of cargo vehicle weight and classification count samples; (3) Reducing and analyzing loadometer data; and (4) Appendices.

ESTIMATING THE TOTAL LOAD EXPERIENCE OF A HIGHWAY

Procedures

Estimates of the total weight in 18-kip axle equivalents generated by cargo vehicles on a given day at a loadometer station can be accomplished by applying several different procedures. In this study, two procedures were used: (1) axle weight frequency distributions and (2) multiple regression models.

These two procedures are first summarized, then the results of the two procedures are presented and compared.

Axle Weight Frequency Distributions

The wheel weights obtained at loadometer stations are combined into single and tandem axle weights by AASHO recommendations (1).

The two groups of axles are divided into weight classes of 1,000 pound increments to obtain frequency distributions of axle weights for a station or group of stations. This frequency distribution, expressed in percentages, is used as an estimate of the mixed traffic load and is projected over the design life of a road section to obtain the total design load experience of a highway (2).

The percentage axle weight frequency distributions may be applied to road locations with only truck traffic estimates if one may assume that the percentage axle weight frequency distribution is similar to a particular known frequency distribution.

Each loadometer station has a unique frequency distribution so that some method of selection is necessary. If the nearest loadometer station is selected, an assumption is made of a geographical traffic characteristic. Stations with some common characteristic may be grouped. Three assumptions which were investigated by Heathington and Tutt (3) were as follows:

1. Grouping stations by percent of trucks
2. Grouping stations by highway system
3. Grouping stations by statewide area

Estimations of 18-kip axle equivalents at three selected locations yielded estimating errors from seven to fifty percent. Grouping stations by highway systems evidently gave some improvement over statewide averages, but no data were presented that nearness of geographical location improved prediction.

At the present time, three years of data are used by the THD to help overcome sampling fluctuations in the preparation of data from each loadometer station as follows:

1. Weight data for the three most recent years are used.
2. The data are tabled by single axles and tandem sets, by vehicle type and weight group.
3. Average daily traffic (ADT) counts by vehicle type for the the three most recent years are used.
4. The number of single axles and tandem sets for each vehicle type is calculated.
5. The table produced by the weight data (Step 2) is prorated by the counted data (Step 4).
6. All single axles are combined by weight group, and all tandem sets are combined by weight group.
7. The number of axles in each weight group is shown as a percent of the total.
8. This table of percentages is then used as the basic weight data.

The loadometer station axle weight frequencies are made one time each year as new data become available.

When a load experience estimate is requested for highway design purposes, the following steps are used in making this estimate:

1. The ADT and percent trucks for the highway section in question is developed from representative automatic traffic recorder and manual count stations.
2. The axle factor (converting number of trucks to axles) and percent single axles are developed.

3. The most representative basic weight table is selected.
4. The percent of single axles of the highway section in question is used to prorate the percentages in the basic weight table.
5. The total number of axles for the highway section in question is multiplied by the percent of axles in each weight group and by the 18-kip axle equivalency factor for each weight group. The product is accumulated.
6. The total accumulation is multiplied by the number of days in the design period.

Step 3 (the selection of the basic weight table) is the most critical. A poor selection can result in large errors in the estimation of 18-kip axle equivalents used in pavement design. Therefore, an attempt is made in the present study to explore several sets of single and tandem axle weight frequency distributions in order to determine which set would produce the most accurate estimates. The steps in the analytical process leading to this determination are as follows:

1. Decide which axle weight frequency distributions should be explored.
2. Generate frequency charts and averages, variances, standard deviations and standard errors for each of the selected axle weight frequency distributions.
3. Perform visual and statistical analyses to determine the extent of differences between various axle weight frequency distributions.
4. Select alternative sets of axle weight frequency distributions to transform into percentage frequency distributions for making estimates of total axle weights at a location.

5. Compute estimates of each station's total axle weights in 18-kip axle equivalents.
6. Compute each station's actual total axle weights in 18-kip axle equivalents.
7. Determine which set of axle weight percentage frequency distributions produced the most accurate axle weight estimates for each station.

When using axle weight frequency distributions to estimate a location's total axle weight in 18-kip axle equivalents for a design period, two assumptions are made:

1. The axle weight distribution will remain constant over the design period.
2. The AASHO Road Test equations for generation of equivalency factors are applicable to Texas conditions over the design period.

Multiple Regression Models

An alternative to the above procedure is to develop from loadometer data a multiple regression model capable of making estimates of total vehicle weights in 18-kip axle equivalents at a particular location.

The specific sequence in this research effort is as follows:

1. Generate 18-kip axle equivalents on a per vehicle basis for data to be used in developing model.
2. Generate frequency charts for visual inspection of the shape of the distribution of vehicle 18-kip axle equivalents.

3. If needed, convert the 18-kip axle equivalents per vehicle to logarithms (log-kip axle equivalents).
4. Generate frequency charts for visual inspection of the distribution of vehicle log-kip axle equivalents.
5. Compute averages, variances, standard deviations and standard errors for selected distributions of 18-kip and log-kip axle equivalents.
6. Test for significant variation between the averages of selected distributions of log-kip axle equivalents.
7. Select vehicle characteristics to be considered as independent variables in the regression model.
8. Measure the change in 18-kip axle equivalents between vehicles with the multiple regression technique.
9. Estimate the total 18-kip axle equivalents generated by cargo vehicles weighed at each loadometer station using the resultant coefficients of the regression model.
10. Compare the actual and estimated station totals to determine the level of accuracy achieved.

Concerning Step 1, it has already been noted that the THD applies a commonly used procedure to calculate total 18-kip axle equivalents which separates the single and tandem axles of all cargo vehicles and then makes a frequency distribution of the axles by one-kip weight groups which are multiplied by corresponding equivalency factors. This method has the advantage of simplicity. However, some accuracy may be sacrificed in obtaining the actual total 18-kip axle equivalents for a station. In contrast, the procedure used here calculates the 18-kip axle equivalents directly; for example, for an 8,200 pound axle (coded to the nearest 200 pounds at the weighing station) by using the AASHO Road Test equivalency equations (4). This is done for each axle on a vehicle, and the results are totaled to obtain the number of 18-kip axle equivalents per vehicle. This procedure allows the study of the 18-kip axle equivalents across vehicle types without having to adjust for differing numbers and types of axles per vehicle.

In regard to Step 3, it was anticipated that the frequency distributions of 18-kip axle equivalents would be highly skewed to the right. If so, a logarithmic transformation would be desirable for use in statistical testing and possibly model building. Therefore, the computer program was altered to generate both 18-kip and log-kip axle equivalents.

The variables selected for the multiple regression model use the numbers of weighed vehicles with specific characteristics; for example, a 3-S2 axle configuration, tank body, user of diesel fuel, weighed at night and weighed on Thursday, A model employing only vehicle characteristics either presently available or obtainable at manual count stations is considered highly desirable. The model generates estimates (coefficients) for each vehicle characteristic obtained visually at the count stations.

The independent variables are of the discrete type, that is, not conventionally measured on a numerical scale. They are also called "dummy" variables. According to Suits, who has worked with dummy variables, "the dummy variable is a simple and useful method of introducing into regression analysis information contained in variables that are not conventionally measured on a numerical scale, e.g., race, sex, region, occupation, etc." (5). In this respect, dummy variables are ideally suited for analyzing loadometer data. Recently, Kentucky researchers used dummy variables on loadometer data to determine traffic parameters for the prediction, projection and computation of equivalent wheel loads (6).

The model assumes a linear additive relationship between the number of 18-kip axle equivalents (dependent variable) and the numbers of vehicles with certain characteristics (independent variables). Actually, when using dummy independent variables, the above assumption is not needed. In fact, Mr. Suits concluded that "by partitioning the scale of a conventionally measured variable into intervals and defining a set of dummy variables on them, we obtain unbiased estimates since the regression coefficients of the dummy variables conform to any curvature that is present" (5). A similar conclusion was reached by Ferber (7). This is one reason why the number of 18-kip axle equivalents, instead of log-kip axle equivalents, was chosen for the dependent variable.

Using the resultant predictive model to estimate the total 18-kip axle equivalents that might be experienced at some location over a design period of say 20 years involves making additional assumptions which are as follows:

1. AASHO Road Test equations for generation of equivalency factors are applicable to Texas conditions over the design period.
2. The average axle load of each type of vehicle identified in a model will remain constant over the design period.
3. The total 18-kip axle equivalents will change by the same percentage rate as the annual ADT predicted for cargo vehicles over the design period.
4. The 18-kip axle equivalents generated by automobiles and 2-axle 4-tire pickups and panel trucks may be predicted using passenger car ADT projections.
5. If the average axle loads of each type of vehicle do not remain constant, it is assumed that the total 18-kip axle equivalents generated by the cargo vehicles will remain in the same proportion to the predicted ADT of cargo vehicles. (This assumption means that if, for instance, the legal vehicle weight limit is raised, then the number of vehicles required to move the cargo would be reduced so that the total 18-kip axle equivalents would grow at the same rate as predicted.)

Results

The results obtained from the application of actual loadometer data to the above procedures are presented and discussed here. The most significant results deal with the comparison of estimates generated from the two alternative procedures.

Axle Weight Frequency Distributions

For exploratory and testing purposes, charts of single and tandem axle weight frequency distributions in kips and the corresponding averages, variances, standard deviations and standard errors were generated from vehicle weighings at the 21 loadometer stations during the 1966-68 period. This period was selected because it contained the latest available data and a workable number of observations with which to generate the many initial frequencies necessary for test purposes.

The principal group of frequency distributions generated and evaluated was that of the vehicle type frequencies for individual loadometer stations. Other groups generated and evaluated on a combined 21 station basis are as follows: By vehicle type; By axle location, overall and by vehicle type; By load characteristic, overall and by vehicle type; By year of weighing; By summer of weighing; and By urban or rural location. In addition to these distributions, three highway system frequency distributions were computed on the basis of vehicle type.

A visual study of all frequency charts revealed that single and tandem axle weight frequency distributions can be divided according to the following shapes:

1. One peak - empty single and tandem axles.
2. One peak and skewed to right - loaded single axles.
3. One peak and skewed to left - loaded tandem axles.
4. Two peaks - tandem axles (combined loaded and empty).

Figure 2 shows the double peaked distribution of tandem axles (combined loaded and empty). The primary cause of a double peaked distribution is the presence of both empty and loaded tandem axles. Thus, to the extent that the proportion of loaded and empty tandem axle vehicles varies from station to station or system to system (as seen in Appendix A), one can expect a similar variation in the visual shapes and, hence, in the axle weight averages.

Appropriate statistical tests, such as Student's t and analysis of variance (ANOV), revealed that there is a significant difference between the averages of the following single and tandem axle weight frequency distributions:

1. Overall average versus individual averages of 21 stations (by ANOV).
2. Overall rural station average versus individual averages of all rural stations (by ANOV).
3. Overall Interstate Highway (IH) average versus individual averages of each IH station (by ANOV).
4. Overall rural station average versus urban station average (by t-test).
5. Overall average of all IH stations versus all other rural stations (by t-test).
6. Overall average of any one major vehicle type versus another, except for single axles of vehicle type 2-S1-2 versus those of the 3-S1-2 and for tandem axles of the vehicle type 3-axle single unit versus those of the 2-S2 (by t-test).

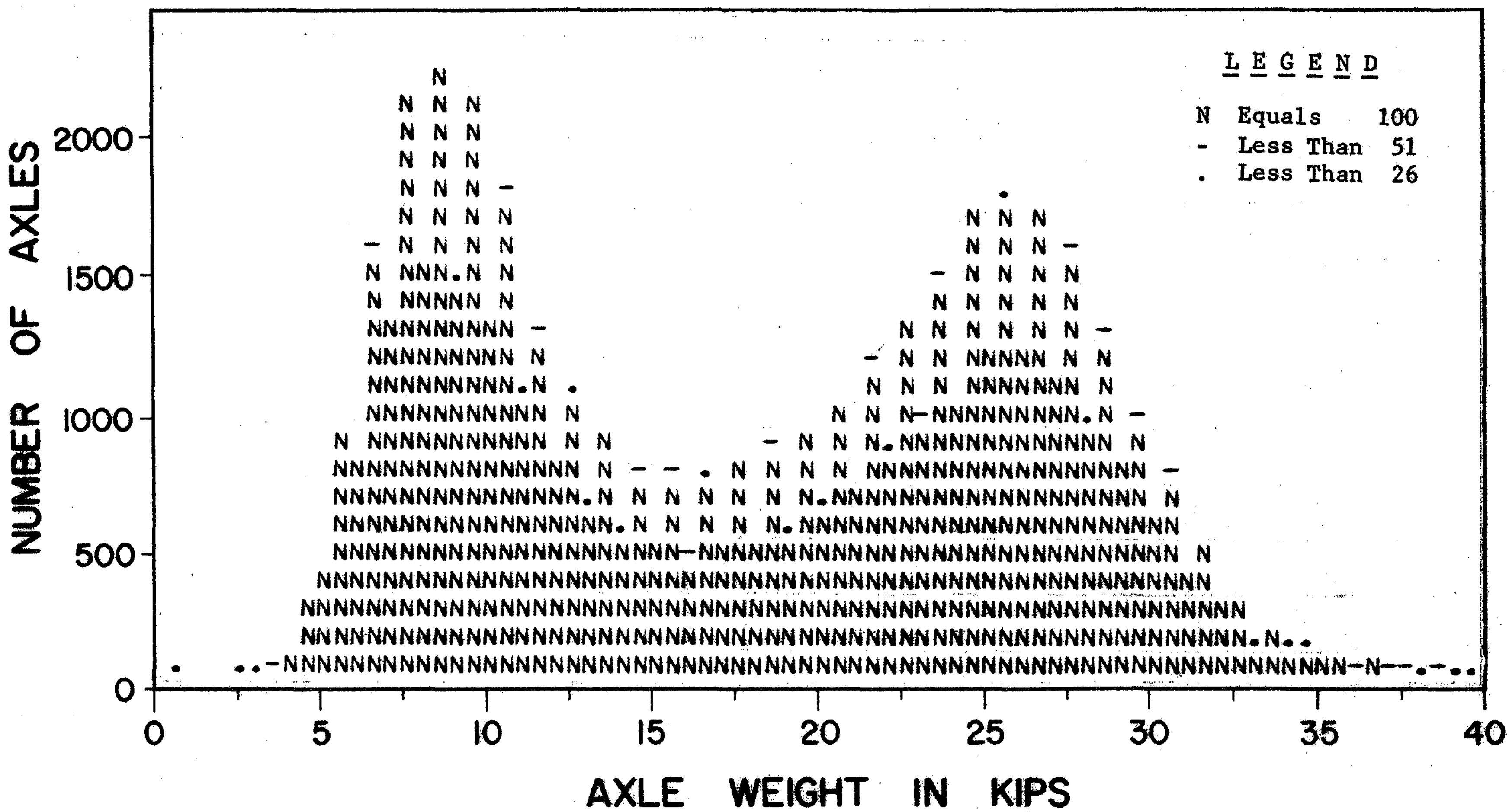

Figure 2. Chart showing tandem axle weight frequency distribution in kips for cargo vehicles studied from 1966-68 weighings at 21 loadometer stations.

7. Overall average of each major vehicle type of all IH stations versus the average of the same vehicle type of all other rural stations (by t-test).

8. Overall average of each major vehicle type of rural stations versus the average of the same vehicle type of urban stations, except the 3-axle single unit and the 2-S2 single axles (by t-test).

9. Overall average of one major vehicle type versus another of each axle location (by t-test).

10. Overall average of one major vehicle type versus another for empty and loaded axles, except for the 2-S1-2 versus 3-S1-2 single empty axles (by t-test).

To summarize, the results of the above statistical tests indicate that, with few exceptions, the major vehicle type distributions for single and tandem axles cannot be combined without giving up some accuracy in estimating the total axle weights in 18-kip equivalents at a particular station. Also, combining the stations by highway system produces unlike groups, but the vehicle type axle weight distributions are also heterogeneous between stations in each group. Stations grouped geographically yield essentially the same results.

In an attempt to determine just how accurate combined station weight frequency distribution sets would be in making weight estimates at individual stations, five diverse sets were chosen. These alternative sets of single and tandem axle weight frequency distributions were used in estimating total axle weights in 18-kip axle equivalents at individual stations. The number of individual frequency distributions and the number of stations required for each set are presented in Table 1. Set 1 requires only two frequency distributions, whereas Set 5 requires 63 separate frequency distributions. Whether Set 5's estimates are more accurate than Set 1's will be shown shortly. Economically speaking, the less complex sets are more desirable, especially if very little accuracy in the estimates is sacrificed.

For estimating purposes, the trial axle weight frequency distributions of Sets 1-5, as identified in Table 1, were generated from 1967 loadometer data. The amount of data used to develop these distributions was reduced in order to save in computer costs. The single axle distributions are made up of 40 one-kip weight classes and those for tandem axles are composed of 50 one-kip classes. The midpoints of these classes are located at each full kip.

The above weight frequency distributions were transformed into the corresponding percentage frequency distributions. Such percentage frequency distributions were applied to the total number of single and tandem axle sets of each vehicle type weighed at a station in order to determine the number of axle sets in each weight class. Next, the total number of 18-kip axle equivalents were generated for each weight class by multiplying the flexible pavement 18-kip axle equivalency factor (for midpoint of weight class) by the number of axle sets in the weight class. Then the weight class totals were summed to obtain the estimated total number of 18-kip axle equivalents for each station. Also, the same procedure was used to calculate the actual total number of 18-kip axle equivalents for each station to determine how much accuracy was achieved.

Table 1

Alternative Sets of Single and Tandem Axle Weight Frequency Distributions for Use in Estimating Axle Weights in 18-Kip Axle Equivalents at Stations

Number of Frequency Distribution Set	Name of Frequency Distribution Set	Number of Individual Frequency Distributions		Number of Loadometer Stations
		Single Axle	Tandem Axle	
1	Combined Vehicle Types[1]	1	1	21
2	Separate Vehicle Types	13	8	21
3	Separate Vehicle Types by Fuel Type[2]	26	16	21
4	Separate Vehicle Types by Load Characteristic[3]	26	16	21
5	Separate Vehicle Types by Highway System:			
	Interstate Rural	13	8	9
	Other Rural	13	8	10
	Urban	13	8	2

[1]Vehicle types as determined by the axle configurations.

[2]Two fuel types, diesel and other.

[3]Two load characteristics, loaded and empty.

Table 2 shows the absolute and percentage estimating errors produced by the frequency distribution sets in estimating each station's actual total 18-kip axle equivalents. It appears that Set 5 produced the most accurate estimates, as it had the lowest average absolute and percentage errors of the five sets. It also had the fewest stations with percentage errors over 10 percent. However, it is also the most complex set.

To determine how much historical data should be used in making station estimates, loadometer data collected during the 1964-68 period were combined to generate new percentage axle weight frequency distributions for not only Set 5 but also Sets 1 and 2. In addition, another set (called Set 6) was generated. This set is the same as Set 5, except it is not broken down according to vehicle type.

Table 3 shows the absolute and percentage estimating errors produced by each of the new frequency distribution sets. Again, Set 5 had the lowest average errors of the four sets. Also, when comparing the average errors of Tables 2 and 3, it can be seen that the frequency distributions generated by multi-year loadometer data produced more accurate station estimates than did those generated by one-year data.

Multiple Regression Models

As was done in the previous analysis, the initial multiple regression models were developed from the loadometer data of cargo vehicles weighed during 1967.

Table 2

Absolute and Percentage Estimating Errors of Five Different Axle Weight Frequency Distribution Sets Used to Estimate the Total Axle Weights in 18-Kip Axle Equivalents Generated by Texas Cargo Vehicles Weighed at Each Loadometer Station in 1967[1]

Loadometer Station by Highway System	Actual Total Weight in 18-Kip Axle Equivalents[2]	Absolute Estimating Errors of Frequency Distribution Set					Percentage Estimating Errors of Frequency Distribution Set				
		1	2	3	4	5	1	2	3	4	5
Interstate Rural											
10-1	151	21	24	24	27	32	13.8	15.9	15.6	17.7	21.3
10-2	537	8	22	22	21	49	1.5	4.1	4.0	4.0	9.1
20-1	796	-79	-51	-45	-2	-16	-9.9	-6.4	-5.7	-0.2	-2.0
20-2	1,007	-46	-4	-19	-44	14	-4.6	-5.4	-1.9	-4.4	1.4
20-3	806	-104	-71	-63	-4	-37	-13.0	-8.8	-7.8	-0.5	-4.6
30-1	686	14	23	26	57	55	2.0	3.3	3.8	8.3	8.0
35-1	918	-8	-41	-40	-76	-4	-0.9	-4.5	-4.3	-8.3	-0.4
37-1	350	21	23	17	16	38	5.9	6.4	4.8	4.5	10.8
45-2	1,318	-248	-186	-193	-144	-131	-18.8	-14.1	-14.6	-11.0	-9.9
Other Rural											
7	132	48	41	40	42	29	36.5	30.8	30.6	31.7	21.7
16	306	112	92	92	52	68	36.7	30.0	30.0	16.9	22.1
20	472	23	31	32	20	-8	4.8	6.6	6.8	4.3	-1.6
42	158	16	7	7	11	-1	10.0	4.2	4.5	6.8	-0.8
72	565	47	27	21	1	-8	8.4	4.8	3.8	0.2	-1.5
81	401	-80	-78	-82	-90	-102	-19.9	-19.5	-20.6	-22.6	-25.4
88	199	-2	-19	-19	-43	-26	-0.8	-9.7	-9.5	-21.3	-13.1
145	404	96	95	89	62	58	23.9	23.4	22.1	15.2	14.4
147	181	-18	-24	-24	-9	-34	-9.8	-13.3	-13.1	-5.0	-18.6
149	228	35	47	48	42	24	15.2	20.7	20.9	18.5	10.6
Urban											
3	104	76	39	38	34	1	72.5	37.5	36.9	32.2	0.8
4	54	68	29	28	23	-1	126.8	53.9	51.2	41.9	-1.6
All Stations											
Total[3]	9,773	1,170	974	969	820	736					
Average[3]	465.4	55.7	46.4	46.1	39.0	35.0	20.7	15.4	14.9	13.1	9.5

[1]These frequency distribution sets are those described in Table 1.

[2]Based on 1,000 pound (midpoint) groupings for application of the equivalency factors.

[3]The signs of the errors were ignored.

Table 3

Absolute and Percentage Estimating Errors of Four Different Axle Weight Frequency Distribution Sets Used to Estimate the Total Axle Weights in 18-Kip Axle Equivalents Generated by Texas Cargo Vehicles Weighed at Each Loadometer Station During 1964-68

Loadometer Station by Highway System	Actual Total Weight in 18-Kip Axle Equivalents[1]	Absolute Estimating Errors of Frequency Distribution Set[2]				Percentage Estimating Errors of Frequency Distribution Set[2]			
		1	2	5	6	1	2	5	6
Interstate Rural									
10-1	816	57	86	118	102	7.0	10.5	14.4	12.5
10-2	2,812	-133	-59	37	5	-4.7	-2.1	1.3	0.2
20-1	3,801	-282	-189	-65	-101	-7.4	-5.0	-1.7	-2.6
20-2	4,194	-33	9	145	181	-0.8	0.2	3.4	4.3
20-3	3,560	-291	-182	-66	-123	-8.2	-5.1	-1.8	-3.5
30-1	3,384	49	110	225	226	1.5	3.2	6.6	6.7
35-1	4,728	-54	-202	-75	187	-1.1	-4.3	-1.6	4.0
37-1	1,595	163	176	231	253	10.2	11.1	14.5	15.9
45-2	5,625	-972	-733	-549	-732	-17.3	-13.0	-9.8	-13.0
Other Rural									
7	750	274	247	205	217	36.6	32.9	27.3	28.9
16	1,503	452	364	298	342	30.1	24.2	19.8	22.8
20	2,398	232	280	128	84	9.7	11.7	5.3	3.5
42	954	-6	-50	-78	-59	-0.6	-5.3	-8.2	-6.2
72	2,917	151	68	-45	-21	5.2	2.3	-1.6	-0.7
81	2,164	-594	-562	-651	-682	-27.5	-26.0	-30.1	-31.5
88	1,458	-100	-154	-202	-176	-6.8	-10.5	-13.9	-12.1
145	2,359	395	378	243	240	16.7	16.0	10.3	10.2
147	788	53	37	-1	6	6.7	4.7	-0.1	0.7
149	1,176	125	196	106	52	10.6	16.6	9.0	4.4
Urban									
3	521	263	94	-1	-48	50.4	17.9	-0.1	-9.1
4	266	253	87	1	48	95.1	32.8	0.1	17.9
All Stations									
Total[3]	47,769	4,932	4,262	3,470	3,885				
Average[3]	2,275	235	203	165	185	16.9	12.2	8.6	10.0

[1]Based on 1000 pound (midpoint) groupings for application of equivalency factors.

[2]Set 6 is composed of all data grouped according to highway system. The other sets are described in Table 1.

[3]The signs of the errors were ignored.

The initial charts of the 18-kip axle equivalents per vehicle frequency distributions confirmed the hypothesis that such frequency distributions were skewed to the right. Thus, the original data were transformed to log-kip equivalents. As a result, the charts of log-kip axle equivalents (18-kip axle equivalents plotted on a logarithmic scale) frequency distributions had shapes approaching normality except for being bimodal. For example, the overall distribution is shown in Figure 3. As was the case with tandem axle (loaded and empty combined) weight frequency distributions, the bimodal characteristic of the above distribution is due to the presence of both loaded and empty vehicles in the same distribution. The loaded vehicles represent about 64 percent of the vehicles in the combined distribution.

Depending on the degree of load, frequency distributions of the log-kip axle equivalents per vehicle for the several vehicle and body types varied from having distinct double peaks to having weak single peaks. For instance, the single unit vehicle types showed what might be loosely defined as a single peaked distribution whereas the 3-S2 tank type showed a distinct double peak. On the other hand, the combined van (excluding insulated van) and panel body types showed weak double peaks, regardless of vehicle type. Charts of some of these frequency distributions are presented in Appendix B.

Based on the above observations, it is evident that individual loadometer stations have varying shaped frequency distributions of log-kip axle equivalents depending on the proportion of loaded or partially loaded to empty vehicles weighed. This loaded to empty vehicle proportion varied widely from station to station, even within

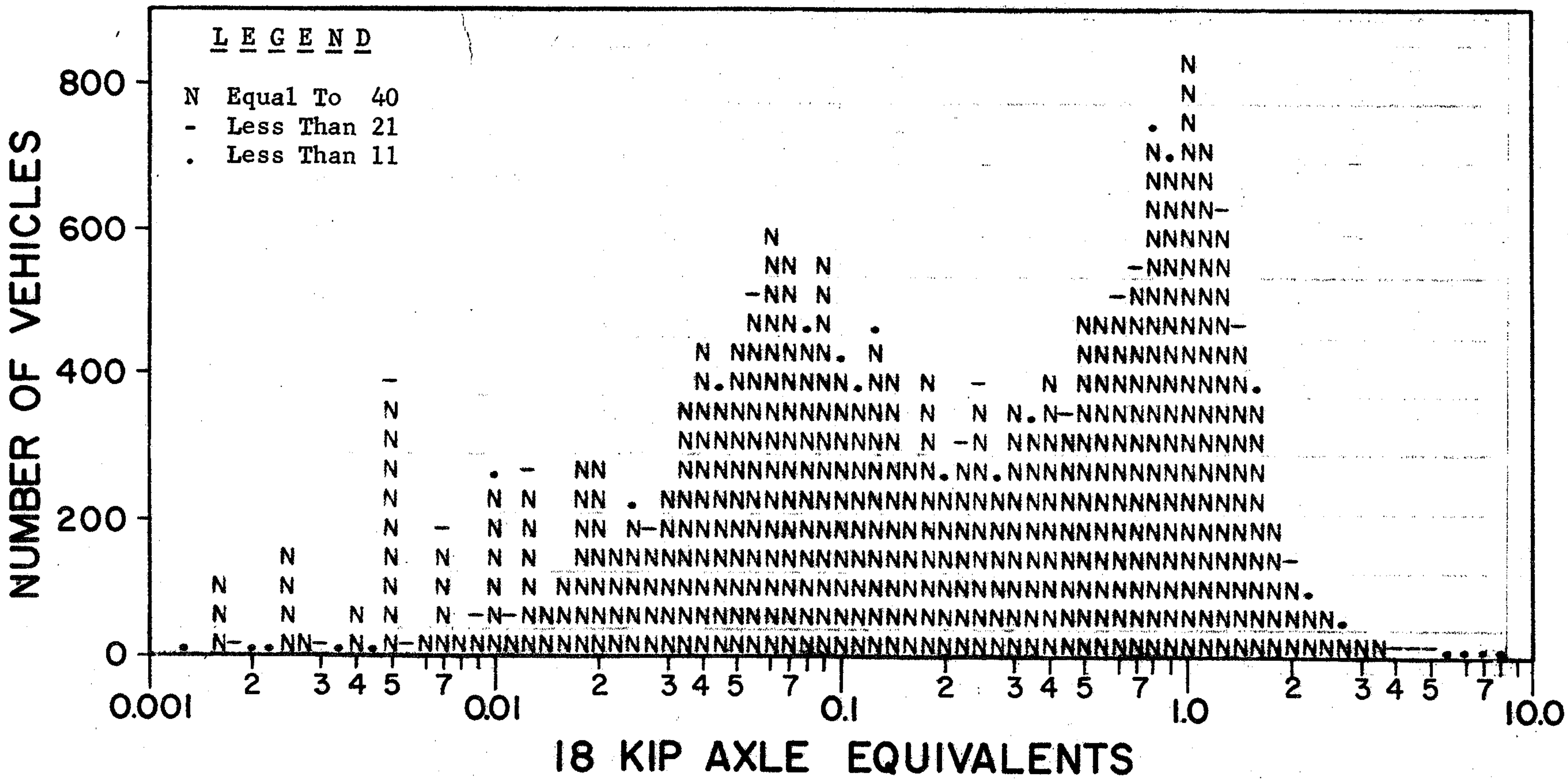

Figure 3. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles studied from the 1967 loadometer weighings.

vehicle types, and is the source of much of the variation in log-kip axle equivalents between vehicles. This was verified by running an ANOV test on the 3-S2 vehicle type. Even when 3-S2 vehicles were separated into loaded and empty groups, the tests still revealed statistically significant between station variation. An inspection of the averages of the station log-kip axle equivalents per vehicle for the other vehicle types indicated that about the same results would have been obtained for those vehicle types. Therefore, no further tests of significance of this kind were made.

Since neither a geographical nor a definite highway system pattern of variation in the per vehicle log-kip axle equivalents between stations could be identified, attention was directed toward using the multiple regression technique on the combined 21 station data to isolate and quantify significant sources of variation between the individually weighed vehicles. It was pointed out earlier that "dummy" variables provide an easy way of quantifying the many qualitative variables available for analyzing loadometer data.

The sets of "dummy" independent variables (characteristics of vehicles weighed) introduced into one or more of the linear multiple regression models are shown in Table 4.

In order that each model be determinant, no single variable or combination of variables could include all the weighed vehicles introduced into the analysis. To accomodate this, the following characteristics of each "dummy" set named in Table 4 were not expressed as independent variables: Day, Other fuel, Miscellaneous body, Friday, Miscellaneous vehicle type and Empty vehicles. For example,

Table 4

Sets of Dummy Independent Variables Introduced Into the Linear Multiple Regression Models

Name	Dummy Variable Set Symbol and Numbers	Characteristics
Time of Day Weighed	X_1	Night (6:00 PM to 6:00 AM)
	None	Day (6:00 AM to 6:00 PM)
Fuel Type	X_2	Diesel
	None	Other fuel
Body Type[1]	X_3	Van or panel single-unit
	X_4	Van or panel multi-unit
	X_5	Oil or platform
	X_6	Cattle or rack
	X_7	Tank
	X_8	Open top
	X_9	Auto transport
	None	Miscellaneous
Day of Week Weighed	X_{10}	Monday
	X_{11}	Tuesday
	X_{12}	Wednesday
	X_{13}	Thursday
	None	Friday
Vehicle Type	X_{14}	2-axle 6-tire single-unit
	X_{15}	3-axle single-unit
	X_{16}	2-S1 axle multi-unit
	X_{17}	2-S2 axle multi-unit
	X_{18}	3-S2 axle multi-unit
	X_{19}	2-S1-2 or 3-S1-2 axle multi-unit
	None	Miscellaneous
Degree of Loading	X_{20}	Loaded
	None	Empty

[1]The groupings of the THD classifications to form the above body type variables are given in Appendix A.

if a vehicle was weighed at night, it was coded a 1; whereas a day weighing was given a 0. All of the vehicles coded 0 are accounted for in the constant term (a) in the model equation. Also, vehicles of nonsignificant variables are averaged in the constant term. Therefore, all the "dummy" models have a constant term to give logical results. To obtain logical results from models without a constant term (where the line of regression passes through the origin), the vehicles coded 0 would have to be included in independent variables corresponding to their characteristics. However, nonsignificant variables (those with nonsignificant regression coefficients) could not be deleted because this would again make the results illogical.

The first 19 dummy variables in Table 4 were introduced into the Model 1 equation which is as follows:

$$Y = a + b_1X_1 + \ldots + b_{19}X_{19}$$

where (Y) is the dependent variable measured in 18-kip axle equivalents per vehicle: (a) is the constant term; the (b's) are partial regression coefficients; and the (X's) are the independent variables.

Also, since the load characteristic was found to be a major source of variation in log-kip axle equivalents between vehicles, a loaded vehicle dummy variable (X_{20}) was introduced with 18 of the above 19 variables into Model 2. Variable X_{10} was deleted to keep the total number of variables at 19, the capacity of the computer program. Model 2 is as follows:

$$Y = a + b_1X_1 + \ldots + b_9X_9 + b_{11}X_{11} + \ldots + b_{20}X_{20}$$

The backward elimination method was used to determine which variables should remain in the above models (8). The method begins with all the variables introduced and then eliminates the variable which has the least significant partial regression coefficient (b) in terms of computed t-values (ratio of each b to its standard error) at the 95 percent confidence level. After each variable elimination, the remaining variables are reintroduced into the models to generate new partial regression coefficients. The method takes as many steps as necessary to delete all variables which do not have statistically significant partial regression coefficients. Also, at each step, the variation in the dependent variable explained by the independent variables remaining in the model is tested for statistical significance using the F-values generated from the ANOV technique. In addition, the R^2 (the proportion of the total variance in the dependent variable explained by the independent variables and σ_u (standard deviation of regression) are calculated at each level (7).

Table 5 shows the variables which have significant partial regression coefficients for the two models. Model 1 had 14 significant variables, and Model 2 had 15. All the nonsignificant variables of Model 1 were those of body type. On the other hand, three of the five nonsignificant variables of Model 2 were day of the week variables. So, the addition of the load characteristic variable caused a considerable change in the significance of the body type and day of week variables. Also, the majority of the signs of the significant regression coefficients are negative. This was not the case with those of Model 1.

Table 5

Dummy Variables with Significant Partial Regression Coefficients for Multiple Regression Models 1 and 2

Variable Symbol and Number	Variable Characteristic	Significant Partial Regression Coefficient[1] Model 1	Model 2
a	Constant term	0.5060	0.2873
X_1	Night Weighing	0.0998	0.0382
X_2	Diesel powered	0.1218	0.1003
X_3	Van or panel single-unit body	N.S.	-0.3383
X_4	Van or panel multi-unit body	-0.0826	-0.3526
X_5	Oil or platform body	N.S.	-0.1693
X_6	Cattle or rack body	N.S.	-0.2277
X_7	Tank body	N.S.	-0.1285
X_8	Open top body	0.1674	N.S.
X_9	Auto transport body	N.S.	-0.1308
X_{10}	Monday weighing	N.S.	2
X_{11}	Tuesday weighing	0.0296	N.S.
X_{12}	Wednesday weighing	0.0447	N.S.
X_{13}	Thursday weighing	0.0554	N.S.
X_{14}	2-axle 6-tire single-unit	-0.3939	-0.3078
X_{15}	3-axle single-unit	-0.3394	-0.2037
X_{16}	2-S1 axle multi-unit	-0.1121	-0.0515
X_{17}	2-S2 axle multi-unit	-0.0763	N.S.
X_{18}	3-S2 axle multi-unit	-0.0960	-0.0299
X_{19}	2-S1-2 or 3-S1-2 axle multi-unit	0.2360	0.2397
X_{20}	Loaded vehicle	2	0.6581

[1]Measuring 18-kip axle equivalents per vehicle, based on 1967 data.
[2]Variables X_{10} and X_{20} were not introduced into model.
N.S. Nonsignificant variables (coefficients).

Table 6 shows the standard statistical measures used to evaluate and compare multiple regression models. As measured by the correlation coefficient (R), the extent of the correlation of the "dummy" variables with 18-kip axle equivalents per vehicle is fairly low. Consequently, the coefficient of determination (R^2), amount of variation in 18-kip axle equivalents per vehicle explained by these variables, is also low. But a comparison of the statistics of the two models shows the superiority of Model 2 over Model 1. Of particular importance is the fact that R^2 more than tripled, reaching 32.8 percent (R^2 x 100) of explained variation. Also, R almost doubled, reaching a more respectable 0.571 out of a possible 1.000. Not to be overlooked is the fact that the amount of variation about the line of regression as measured by σ_u was reduced considerably. Therefore, the introduction of the load characteristic variable seems to have been a step in the right direction. These results may suggest the need to develop a method that will be able to distinguish the loaded vehicles from the empty in count station data used to estimate 18-kip axle equivalents generated by a traffic stream at some location.

However, the really critical test of the validity of the two regression models is how well they perform in estimating each station's actual total 18-kip axle equivalents. Table 7 presents each model's absolute and percentage estimating errors resulting from the application of the regression coefficients to the 1967 loadometer weighings at each station.

Table 6

Correlation of Significant Dummy Variables with 18-Kip Axle Equivalents of a Texas Cargo Vehicle Weighed at Any of the 21 Loadometer Stations in 1967, According to the Multiple Regression Model Used[1]

Statistical Measure	Dummy Model 1	Dummy Model 2
Error Degrees of Freedom	19,223	19,222
Standard Error of Regression (σ_u)	0.1296	0.0718
Correlation Coefficient (R)	0.311	0.573
Coefficient of Determination (R^2)	0.097	0.328
F Ratio	158***	671***

[1]Table 5 shows the significant variables in each model.

***This F ratio is significant at the .001 probability level, indicating that the variance due to regression has less than a 1 in 1000 chance of being due to chance alone.

Table 7

Absolute and Percentage Estimating Errors of Two Dummy Variable Multiple Regression Models Used to Estimate the Total 18-Kip Axle Equivalents Generated by Texas Cargo Vehicles Weighed at Each Loadometer Station in 1967

Loadometer Station by Highway System	Actual Total Weight in 18-Kip Axle Equivalents[1]	Absolute Estimating Errors of Dummy Regression Model		Percentage Estimating Errors of Dummy Regression Model	
		1	2	1	2
Interstate Rural					
10-1	141	25	29	17.7	20.5
10-2	502	6	- 1	1.2	- 0.1
20-1	741	- 37	- 14	- 5.0	- 1.8
20-2	934	12	- 1	1.3	- 0.1
20-3	749	- 79	- 43	-10.5	- 5.7
30-1	638	5	49	0.8	7.6
35-1	852	- 62	-125	- 7.3	-14.7
37-1	325	26	19	8.0	5.8
45-2	1,232	-149	-110	-12.1	- 8.9
Other Rural					
7	127	37	39	29.1	30.7
16	282	84	75	29.8	26.5
20	439	49	45	11.2	10.2
42	146	10	18	6.8	12.3
72	526	- 3	- 23	- 0.6	- 4.3
81	377	- 62	- 70	-16.4	-18.5
88	186	- 26	- 28	-14.0	-15.0
145	373	85	59	22.8	15.8
147	168	- 28	- 9	-16.7	- 5.3
149	212	50	42	23.6	19.8
Urban					
3	97	37	30	38.1	30.9
4	50	18	19	36.0	38.0
All Stations					
Total[2]	9,097	890	849		
Average[2]	433.2	42.4	40.4	14.7	13.9

[1]Based on 200-pound groupings for application of equivalency factors.

[2]Based on ignoring signs of errors.

Using the percentage estimating errors as a basis for evaluating the performance of each model, Table 7 shows that a majority of the percentage errors for both models were over plus or minus 10 percent of the actual station totals. However, most of the large errors (over 10 percent) were overestimates. Also, the performance of both models in making estimates for the interstate rural stations is much better than for the other stations.

Comparing the two models, Model 2's average percentage error for the 21 stations is somewhat smaller than Model 1's. Also, 12 of the percentage errors of Model 2 were less than those of Model 1. So, the addition of the load characteristic variable into Model 2 did allow it to make more accurate estimates (especially for certain stations) than Model 1. For example, Model 1's percentage error for Station 147 was a minus 16.7, whereas, Model 2's was a minus 5.3.

To determine how much historical data should be used in generating and/or used in regression models, loadometer data collected during 1964-68 period were combined and applied to the 1967 partial regression coefficients of Models 1 and 2, as presented in Table 5. The resulting absolute and percentage estimating errors are presented in Table 8. Model 2 still had the lowest average absolute and percentage errors of the two models. When comparing these new estimating errors with those of Table 7, it is found that both models made more accurate multi-year station estimates than single-year estimates. The average percentage errors were smaller for both models, but, Model 2 had one less station with a percentage error of over 10 percent. Also percentage errors of the

Table 8

Absolute and Percentage Estimating Errors of Two Dummy Variable Multiple Regression Models
Used to Estimate the Total 18-Kip Axle Equivalents Generated by Texas Cargo Vehicles
Weighed at Each Loadometer Station During 1964-68

Loadometer Station by Highway System	Actual Total Weight in 18-Kip Axle Equivalents[1]	Absolute Estimating Errors Of Dummy Regression Model		Percentage Estimating Errors of Dummy Regression Model	
		1	2	1	2
Interstate Rural					
10-1	816	49	112	6.1	13.7
10-2	2,809	-323	-235	- 11.5	- 8.4
20-1	3,795	-412	- 85	- 10.9	- 2.2
20-2	4,187	-206	- 8	- 4.9	- 0.2
20-3	3,554	-434	-162	- 12.2	- 4.6
30-1	3,377	-180	63	- 5.3	1.9
35-1	4,726	-684	-601	- 14.5	- 12.7
37-1	1,590	53	49	3.3	3.1
45-1	5,614	-901	-643	- 16.0	- 11.5
Other Rural					
7	753	173	218	23.0	29.0
16	1,500	221	352	14.7	23.4
20	2,393	238	395	10.0	16.5
42	953	- 97	- 19	- 10.2	- 2.0
72	2,911	-202	20	- 6.9	0.7
81	2,164	-601	-470	- 27.8	- 21.7
88	1,456	-303	-219	- 20.8	- 15.1
145	2,358	156	294	6.6	12.5
147	786	- 52	41	- 6.6	5.2
149	1,175	144	191	12.3	16.3
Urban					
3	520	48	26	9.3	5.0
4	265	43	55	16.4	20.8
All Stations					
Total[2]	47,702	5,520	4,258		
Average[2]	2,272	263	203	11.9	10.8

[1]Based on 200 pound groupings for application of equivalency factors.

[2]The signs of the errors were ignored.

urban stations were considerably smaller for Model 2. Next, multi-year data were used in two separate analyses to generate new partial regression coefficients and the corresponding station estimates for other models.

In the first case, 1964-68 data were transformed to log-kip equivalents and applied to all the variables of Model 1, except Variable 15 to keep the number of variables under 20. Also, two other variables were introduced, one for year of weighing and one for summer weighings. The resulting coefficient for the year variable was not significant, but the one for the summer variable was significant. When applying these new significant regression coefficients to 1964-68 loadometer weighings at each station, the overall average (in 18-kip equivalents) percentage error per station was 11.2. This average is considerably lower than the average error generated by Models 1 and 2 using 1967 regression coefficients on single-year (1967) data and also lower than the average percentage error generated by Model 1 using 1967 coefficients on multi-year (1964-68) data. However. Model 2's average was the lowest of all.

In the second case, the 1966-68 data were divided according to loaded and empty vehicle weighings. This model, with two equations, had all of the Model 1 variables introduced, except Variable 10. Again the summer variable was introduced and its resulting coefficient in the empty equation was significant. When applying the new coefficients from each equation to the 1966-68 loadometer weighings at each station, the overall percentage error per station was 12.7 which is larger than the average for the above multi-year (1964-68) analyses but somewhat lower than the average for the single-year (1967) analysis.

Estimates of Alternative Procedures Compared

A comparison can now be made of the estimating accuracy obtained from the two alternative procedures, namely axle weight frequency distribution sets versus multiple regression models. Table 9 shows the percentage estimating errors of each procedure for both one-year and multi-year data. Regardless of the amount of data used, Frequency Set 5 yielded lower average percentage errors than did Regression Model 2. It also generated fewer stations with percentage errors over 10 percent.

The use of multi-year data helped to produce more accurate estimates for both procedures. For the regression method, the greatest improvement occurred in the urban station estimates. For the axle weight frequency distribution method, improvement occurred in the rural station estimates.

Both procedures had difficulty in producing estimating errors lower than 10 percent at five particular loadometer stations. Their numbers are 10-1, 7, 16, 81 and 88. Although these stations are all in the lower range of total 18-kip axle equivalents output, this does not seem to be the only explanation for the large estimating errors. There are other stations with even lower total 18-kip axle equivalents outputs that have very small estimating errors. Also, multi-year data failed to lower the errors of some of these stations. Nor is the cause necessarily geographical, these stations being located in more than one area of the State. Some of the five stations are very close to major metropolitan centers, and others are of a considerable distance from such places.

Table 9

Percentage Estimating Errors of Two Alternative Procedures Used to Estimate the Total 18-Kip Axle Equivalents Generated by Texas Cargo Vehicles Weighed at Each Loadometer Station During One Year (1967) Versus Several Years (1964-68)

Loadometer Station By ghway System	Percentage Estimating Errors			
	One- Year Data		Multi-Year Data	
	Frequency Set 5	Regression Model 2	Frequency Set 5	Regression Model 2
terstate Rural				
10-1	21.3	20.5	14.4	13.7
10-2	9.1	- 0.1	1.3	- 8.4
20-1	- 2.0	- 1.8	- 1.7	- 2.2
20-2	1.4	- 0.1	3.4	- 0.2
20-3	- 4.6	- 5.7	- 1.8	- 4.6
30-1	8.0	7.6	6.6	1.9
35-1	- 0.4	- 14.7	- 1.6	- 12.7
37-1	10.8	5.8	14.5	3.1
45-2	- 9.9	- 8.9	- 9.8	- 11.5
her Rural				
7	21.7	30.7	27.3	29.0
16	22.1	26.5	19.8	23.4
20	- 1.6	10.2	5.3	16.5
42	- 0.8	12.3	- 8.2	- 2.0
72	- 1.5	- 4.3	- 1.6	0.7
81	- 25.4	- 18.5	- 30.1	- 21.7
88	- 13.1	- 15.0	- 13.9	- 15.1
145	14.4	15.8	10.3	12.5
147	- 18.6	- 5.3	- 0.1	5.2
149	10.6	19.8	9.0	16.3
ban				
3	0.8	30.9	- 0.1	5.0
4	- 1.6	38.0	0.1	20.8
l Stations				
Total[1]	199.7	292.5	177.6	226.1
Average[1]	9.5	13.9	8.6	10.8

ie signs of the errors were ignored.

As was indicated earlier, the estimates obtained from axle weight frequency distributions used 1,000 pound weight classes for applying the 18-kip axle equivalency factors. On the other hand, the estimates from the multiple regression models used 200 pound weight classes for the application of the equivalency factors. Therefore, it was necessary to determine how sensitive the total output of 18-kip axle equivalents would be to the size of the weight class. The results of such an analysis showed that it made very little difference which weight class was used. In fact, the difference between the multi-year totals was negligible (See Tables 3 and 8). For the 1967 totals, in Tables 2 and 7, the 7.4 percent difference is not due to the size of the weight class. Instead, it is due to a less accurate interpolation program which was used to compute the 1967 totals for the 200 pound weight class. The more accurate program was used to generate the multi-year totals and is the one presented in Appendix C.

DETERMINING THE ADEQUACY OF CARGO VEHICLE WEIGHT AND CLASSIFICATION COUNT SAMPLES

Procedures

This section of the report is directed toward determining the adequacy of cargo vehicle weight and classification count samples collected at the previously mentioned stations to represent the unknown population of vehicles passing them, individually or as a group.

The problem requires a two directional approach. One task is to determine the adequacy of loadometer samples for use in establishing accurate base weight characteristics of the various vehicle types. The other task is to determine the adequacy of manual classification count samples for use in establishing accurate annual average daily traffic (AADT) counts of the various vehicle types.

The adequacy of a sample taken from a larger population is measured in terms of the representativeness of its individual observations and the reliableness of its statistics. In the case of this study, weight and classification count samples of cargo vehicles were evaluated as to their representativeness of the population of cargo vehicles passing the stations and as to their ability to produce reliable estimates of population parameters, such as the average axle or vehicle weight in kips or 18-kip axle equivalents and the AADT count by vehicle type.

Representativeness of Samples

In theory, a collection system which gives every vehicle passing a station an equal chance to be counted, classified or weighed is one that obtains a representative or random sample. To determine whether the samples are reasonably representative, collections obtained according to the time of day, day of the week, week of the month, month of the year and year of the planning period should be studied.

With the above criterion in mind, the present and past weighing and counting schedules and the samples collected therefrom are reviewed and evaluated to determine the degree of representativeness obtained.

Reliableness of Samples

If a representative sample has been collected at each station, then the initial foundation is laid for yielding reliable estimates of the populations parameters. But an additional prerequisite for generating reliable estimates is that of obtaining a sample large enough to overcome large chance sampling errors.

In this study, an attempt is made to determine how many vehicles to weigh at loadometer stations and how many 24-hour volume counts to make at manual count stations in order to overcome chance sampling errors of stated magnitude at a designated probability level. In other words, the sample size depends on the accuracy needed in the estimates, the extent of variation in the sample observations and the stated probability level.

The THD has indicated that the level of accuracy desired for estimating the average vehicle weights and counts of a population is an error of no more than 10 percent. The absolute size of this error is based on the averages of the sample data evaluated in this study. Also, the extent of the expected variation in the individual observations of a population is assumed to be the same as that reflected by sample data used in this study. Last, the 95 percent probability level for avoidance of large sampling errors in the estimates was considered acceptable.

Since statistics of previously collected samples have to be used in estimating the required size of future samples, it is important that such base samples themselves be of adequate size. Therefore, multi-station and/or multi-year data were used to generate estimates of adequate sample size. However, when multi-year sample data were used, a trend adjustment was made before generating sample statistics. For example, to estimate the population variance in multi-year 24-hour volume counts, a trend adjustment was applied.

Sample sizes may vary according to the statistic being estimated even when using the same sample base data for example, the sample size can be different for estimating average vehicle weight in 18-kip axle equivalents and for estimating average axle weight in 18-kip axle equivalents. Also, the sample sizes could vary according to how the base data are stratified, such as by vehicle type only or by additional stratifications like load characteristic and highway system. Therefore, these sample size variations are demonstrated in this report.

The limited data collected from the weigh-in-motion station are used to give some indication of the variations in data collected over a continuous seven-day period versus that collected over a non-continuous five-day period.

Results

The results of analyzing previously collected cargo vehicle weight and classification counts for representativeness and reliableness are presented here, according to the type of sampling station.

Loadometer Station Weight Samples

Vehicle weight data collected at the 21 stations during 1964-68 were used in the various analyses. The 1964-66 data were obtained from the 19 rural stations during 12 eight-hour periods (three per season) per year and from the two urban stations during three periods of the summer season. In 1967, the amount of data collected at the 19 rural stations was reduced by one-third because no weighings were made after August 31st. In 1968, the amount of data collected was reduced further at these stations, because weighings were made only during three eight-hour periods in the summer months. The number of weighing periods for the urban stations remained the same throughout the 1964-68 period.

The three eight-hour weighing periods used by the THD are as follows: 6:00 AM to 2:00 PM, 2:00 PM to 10:00 PM and 10:00 PM to 6:00 AM.

Representativeness. The THD has not been collecting weight samples with a system developed entirely on a theoretical basis to yield purely random sample data. This is partially due to scheduling difficulties that would have greatly increased the costs of collecting data at the 21 conventional stations. Too, the gradual reduction of the weighing operations to cover only the summer months instead of all months in the year has contributed to the nonrepresentativeness of the data. Although the weighings were made during every month of the year, the 19 rural stations were scheduled in the same sequence. However, the weighings on particular days of the week or eight-hour periods of the day were in a nonsequential order, somewhat random in nature.

The above mentioned eight-hour periods for 1964-66 were distributed evenly over the three eight-hour periods required to account for one 24-hour day each season of the year at each of the 19 rural stations. The same was true for summer weighings of 1968. But in 1967, only the spring and summer seasons had three of these eight-hour periods at each of the 19 rural stations.

All of the weighings were done on weekdays at the 21 stations. Therefore, the data may not adequately represent that of a full seven day week.

All the five weekdays were not represented at all of the stations. Prior to 1967, only three stations, two of them urban, had missing days. In 1967, as many as two days were missing, and only three stations had all days represented. In 1968, nearly all the stations had three missing days.

None of the stations had exactly the same distribution of eight-hour periods over the five weekdays. Some stations were heavy on Monday weighing periods. Others were heavy on Tuesday and so on. However, with all 21 of the stations combined the number of weighing periods were distributed about evenly across weekdays.

Not all of the above three eight-hour periods necessary to make one 24-hour day were represented on a particular weekday at a station. Some weekdays were heavy on 2:00 PM to 10:00 PM weighing periods. Others were heavy on one of the other weighing periods. Cancellations due to bad weather contributed to the above imbalance in numbers and types of eight-hour periods.

During each weighing period, two directional weighings were made. This was accomplished by weighing vehicles coming from one direction for four hours and then weighing vehicles coming from the opposite direction for four hours.

Aggregation of stations helps to even out the number and type of eight-hour weighing periods across days of the week, tending to make the combined station data more representative than individual station data. This is one argument in favor of using statistics developed from all stations grouped together rather than those from one station.

The analysis of the data used in this study indicates that the number of weighings of each vehicle type was generally proportional to the number of each vehicle type passing a station during any given eight-hour period or group of eight-hour periods. Table 10 shows this to be true for both annual (1966) and summer (1968) data collected at selected high, low and medium volume loadometer stations.

Part of the station to station variation in the percent of vehicles weighed and counted within vehicle types was caused by differences in the days and eight-hour periods in which these activities took place. In addition, seasonal and annual (trend) variations enter into the year to year differences.

The problem of not being able to obtain a 100 percent weight sample for a given time period can be overcome by using weigh-in-motion scales. Then it is possible to make continuous weighings for all time periods critical to obtaining a proportional or representative sample. Unfortunately, the only test data available represent weighings taken for one week during the month of March, 1969 at one location. Therefore, only a few comparisons can be made to establish how representative past data collections have been.

Table 11 shows the number and percentage distributions of vehicles weighed by vehicle type at the weigh-in-motion station in 1969 and the conventional stations in 1967. A comparison of the weigh-in-motion station's percentage distribution with that of the 21 conventional stations reveals only small differences between them for each vehicle type. They differ greatest among the lowest volume vehicle types. But when the distribution of one conventional station (35-1) is compared

Table 10

Percentage Distributions of Vehicles Weighed and Counted by Vehicle Type at Selected Loadometer Stations During 1966 and 1968[1]

Vehicle Type	Percent of Vehicles by Loadometer Station and Year of Weighing									
	Station 10-1		Station 20-1		Station 45-2		Station 81		Station 147	
	1966	1968	1966	1968	1966	1968	1966	1968	1966	1968
Single-Unit										
2-axle 6-tire										
Counted	20.2	19.6	20.6	17.5	11.3	12.0	16.8	22.3	24.3	28.0
Weighed	13.5	16.2	14.7	14.8	8.5	9.6	20.4	22.2	23.6	21.8
3-axle										
Counted	3.7	7.5	2.8	2.0	2.1	2.8	2.3	2.4	4.3	3.4
Weighed	2.3	7.4	3.3	1.8	2.0	2.5	2.3	1.5	3.9	1.4
Multi-Unit										
2-S1										
Counted	9.4	4.3	8.7	5.8	6.6	6.2	5.8	5.6	8.4	5.6
Weighed	7.9	4.4	8.9	6.6	6.6	7.1	9.1	6.4	7.6	0.0
2-S2										
Counted	16.8	14.6	17.9	15.5	15.2	14.4	15.1	14.7	16.9	15.5
Weighed	16.8	12.5	16.4	17.3	14.6	15.4	19.6	13.8	17.3	15.9
3-S2										
Counted	48.3	47.2	49.4	57.0	63.6	62.0	59.8	53.9	44.9	45.3
Weighed	56.5	52.9	55.7	57.5	66.6	62.3	48.7	55.1	47.3	59.5
2-S1-2										
Counted	0.3	3.7	0.3	1.7	0.7	1.6	0.1	0.9	0.5	2.2
Weighed	0.0	2.9	0.5	1.8	1.0	2.3	0.0	1.0	0.3	1.4
3-S1-2										
Counted	1.3	3.1	0.3	0.4	0.5	1.0	0.1	0.2	0.1	0.0
Weighed	3.0	3.7	0.5	0.2	0.7	0.8	0.0	0.0	0.0	0.0
TOTAL										
Counted	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Weighed	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1]The counts and weighings were taken during the same eight-hour periods, but due to bad weather cancellations, the number of eight-hour periods varied from station to station in the case of the 1966 data. During 1966, the number of periods were as follows: Station 147 had nine; Stations 10-1, 45-2, and 81 had eight; and Station 20-1 had six. During the summer of 1968, each station had three periods.

Table 11

Number and Percentage Distributions of Vehicles by Type Weighed at the Weigh-in-Motion and Conventional Loadometer Stations[1]

	Weigh-in-Motion Station 35-2		Conventional Stations Station 35-1		21 Stations	
Vehicle Type	Number	Percent	Number	Percent	Number	Percent
Single-Unit						
2-Axle 6-Tire	547	22.1	480	26.7	4,134	21.8
3-Axle	184	7.4	94	5.2	716	3.8
Multi-Unit						
2-S1	166	6.7	195	10.8	1,439	7.6
2-S2	279	11.3	232	12.9	2,760	14.6
3-S2	1,219	49.1	779	43.3	9,643	51.0
2-S1-2	63	2.5	15	0.8	126	0.7
3-S1-2	22	0.9	5	0.3	103	0.5
All Vehicle Types	2,480	100.0	1,800	100.0	18,921	100.0

[1]Data from Station 35-2 represents seven consecutive 24-hour days of vehicle weighings obtained during one week in March 1969. Data from the conventional stations represent various eight-hour period week-day weighings obtained during the first 10 months of 1967.

with that of the weigh-in-motion station, greater differences are revealed. The differences between these distributions are due to several factors. Chief among these are seasons, days and hours of weighings. In the case of the last two, the weigh-in-motion station reflects continuous weighings all seven days of the week, and the 21 conventional stations reflect variable eight-hour period weighings taken during a maximum of four days of the week at any one station. It was found that very few of the conventional stations had full 24-hour day weighings for each day of the week.

Table 12 shows the extent of the differences in the percentage distributions of 3-S2's and other vehicle types by day of weighing at both types of stations. Although wide differences show up between the distributions of the two data sources, they are minimized between the weigh-in-motion station and the combined 21 stations. Also, between vehicle types, both of these distributions show nearly the same proportions, regardless of day of weighing. In the case of Station 35-1 versus Station 35-2, the above is not true.

Further analysis of the weigh-in-motion data revealed that the frequency of weekend weighings average about one-half that of weekday weighings, regardless of vehicle type.

As a result of all of the above comparisons, one conclusion definitely can be made. When loadometer data from the existing and previous weighing schedules are used to generate vehicle weight statistics, the combined station data are more likely to be representative of the actual population of all vehicles passing a station than the data collected at one station, even when it is used to represent itself.

Table 12

Percentage Distribution of 3-S2's and Other Vehicle Types by Day of Weighing at the Weigh-in Motion Station and the Conventional Stations[1]

	Percent of Vehicles					
	Weigh-in-Motion		Conventional Stations			
	Station 35-2		Station 35-1		21 Stations	
Day of Weighing	3-S2's	Other Types	3-S2's	Other Types	3-S2's	Other Types
Monday	11.6	17.4	31.7	40.7	15.7	19.8
Tuesday	10.2	10.7	9.0	14.0	23.2	20.9
Wednesday	20.1	20.7	41.5	36.3	21.7	19.9
Thursday	31.7	26.6	17.8	9.0	23.1	21.7
Friday	26.4	24.6	*	*	16.3	17.7
All Days	100.0	100.0	100.0	100.0	100.0	100.0

1 Data from Station 35-2 represent seven consecutive 24-hour days of vehicle weighings obtained during one week in March 1969. Data from the conventional stations represent various eight-hour period week day weighings obtained during the first 10 months of 1967.

* No weighings.

Reliableness. The results of an analysis to determine the reliableness of the data may tend to confirm or reject the conclusion reached from analyzing the loadometer data for representativeness.

The analysis of individual station's average vehicle and axle weights according to vehicle types, load characteristic and highway system indicated that such averages vary significantly between stations (See Appendix A for tables of the averages). Much of the station to station variation between these averages is due to the nonrepresentativeness of the data on an individual station basis.

There are other station to station differences not caused directly by the weighing schedule. For instance, there are those due to chance, which become quite large in the case of very small samples. This is indicated by the fact that, in most cases, the number of vehicles (by type) weighed at individual stations in 1967 is too small compared to the number of vehicles required by the station's own statistics in order to overcome chance sampling errors of a given magnitude and stated probability level. The formula used in this evaluation is as follows:

$$N = \frac{t^2 S^2}{E^2}, \text{ where}$$

N is the number of vehicles necessary to weigh; t^2 is the square of the tabulated t-value for the degrees of freedom at the 95 percent probability level; S^2 is the variance of the characteristic in the sample; and E^2 is the square of 10 percent of the average generated from the sample data. The E actually stands for the standard error of the average (mean), and E^2 is the sampling variance. The magnitude of the latter is inversely proportional to the sample size and directly proportional to the variance of the characteristic measured in the population (7). Since the variance of the population is not known, the variance (S^2) of the characteristic in the sample is used as its best estimate. Therefore, the variance generated by a small sample at one station may be suspect. So the samples of several stations combined should produce a better estimate of the population variance than only one. Thus, variations due to chance and the weighing schedule make it all the more important to use combined station data in generating sample statistics and sample size estimates.

No geographical pattern in the magnitude of the station averages was found to serve as a basis for grouping the stations. Even grouping the stations by highway system was not clearly justified by the analysis of the data. For within highway systems, many of the station averages and/or variances were significantly different. Hence, to compute statistics used in estimating sample sizes and to generate other estimates, all 21 stations were combined in most instances.

If the weight characteristic to be estimated for the population is the average vehicle weight in 18-kip axle equivalents, then Table 13 shows the number of vehicles by type that should have been weighed at a station to assure plus or minus 10 percent accuracy at the 95 percent probability level. These calculations are based on 1967 data from all stations combined and also stations grouped by highway system. On an all station basis, the number necessary to weigh is less than the number actually weighed for every vehicle type, except the 3-axle

Table 13

Number and Percent of Vehicles Actually Weighed and Necessary to Weigh of Each Major Vehicle Type to Obtain an Average Vehicle Weight in 18-Kip axle Equivalents Within 10 Percent of the True Population Average on an All Station and Highway System Basis[1]

Vehicle Type	Number of Vehicles		Percent of Vehicles		18-Kip Axle Equivalents Per Vehicle		
	Actually Weighed	Necessary To Weigh	Actually Weighed	Necessary To Weigh	Average	10 Percent of Average	Variance From Average
Single-Unit							
2-Axle 6-Tire							
All Stations	4,134	2,046	22.1	43.7	0.1749	0.0175	0.1630
I H Rural	1,915	1,088	17.6	31.7	0.1744	0.0174	0.0929
Other Rural	1,787	2,554	25.0	46.7	0.1975	0.0198	0.2607
Urban	432	3,218	62.0	43.7	0.0833	0.0083	0.0578
3-Axle							
All Stations	716	929	3.8	19.9	0.3025	0.0303	0.2220
I H Rural	338	883	3.1	25.7	0.3254	0.0325	0.2426
Other Rural	318	870	4.5	15.9	0.2793	0.0279	0.1761
Urban	60	1,556	8.6	21.1	0.3000	0.0300	0.3500
Multi-Unit							
2-S1							
All Stations	1,439	577	7.7	12.3	0.4462	0.0446	0.2988
I H Rural	882	514	8.1	14.9	0.4637	0.0464	0.2879
Other Rural	492	647	6.9	11.8	0.4166	0.0417	0.2926
Urban	65	1,029	9.3	14.0	0.4307	0.0431	0.4923
2-S2							
All Stations	2,760	696	14.8	14.9	0.5363	0.0536	0.5202
I H Rural	1,625	601	15.0	17.5	0.5489	0.0549	0.4713
Other Rural	1,078	848	15.1	15.5	0.5231	0.0523	0.6038
Urban	57	713	8.2	9.7	0.4210	0.0421	0.3157
3-S2							
All Stations	9,643	431	51.6	9.2	0.5855	0.0586	0.3853
I H Rural	6,095	351	56.2	10.2	0.6244	0.0644	0.3789
Other Rural	3,465	551	48.5	10.1	0.5200	0.0520	0.3875
Urban	83	854	11.9	11.6	0.4543	0.0454	0.4581
Totals							
All Stations	18,692	4,679[2]	100.0	100.0	0.4658	0.0466	0.3710
I H Rural	10,855	3,437[2]	100.0	100.0	0.5113	0.0511	0.3592
Other Rural	7,140	5,470[2]	100.0	100.0	0.4219	0.0422	0.3922
Urban	697	7,370[2]	100.0	100.0	0.2065	0.0207	0.2180

[1] Based on 1967 loadometer data and using the standard formula shown in the text of the report. Station 37-1 was included in the Other Rural group of stations.

[2] Only the sum of the vehicles in the above groups.

single-unit. The same is true for the IH rural system. But for the other rural system, the number necessary to weigh is greater than the number actually weighed for every vehicle type, except 3-S2's and 2-S2's. For the urban system, the number necessary to weigh is consistently less than the number actually weighed.

On the basis of vehicle type, Table 13 shows that only the 2-S2's have about the same percent of the total number of vehicles weighed and necessary to weigh, regardless of highway system. For the 3-S2's, the percent of total vehicles necessary to weigh is considerably lower than the percent of total vehicles actually weighed, especially for the rural highway systems. In the case of the other vehicle types, the reverse is true.

The results presented in Table 13 suggest that sampling rates for each vehicle type could be set according to the percent of total vehicles necessary to weigh. In effect, the overall sampling rate for all groups, except the urban group, could be reduced by the above stated percentages.

Dividing the 21 station data according to load characteristic apparently changes the sample size requirements somewhat. For 3-S2's, the required number is 697 (221 loaded and 476 empty). Sample sized for the other vehicle types were not computed.

If the weight characteristic to be estimated for the population is the average axle weight in kips and 18-kip axle equivalents, then Tables 14 and 15 show the number of axles (and vehicles) by vehicle

Table 14

Number of Single and Tandem Axles Actually Weighed and Necessary to Weigh of Each Major Vehicle Type to Obtain an Average Axle Weight in Kips Within 10 Percent of the True Population Average for all Stations Combined[1]

Vehicle Type	Number of Axles: Actually Weighed	Number of Axles: Necessary To Weigh	Number of Vehicles: Actually Weighed[2]	Number of Vehicles: Necessary To Weigh[2]	Kips per Axle: Average	Kips per Axle: 10 Percent of Average	Kips per Axle: Variance From Average
Single-Unit							
2-Axle 6-Tire							
Single	21,084	131	10,542	66	6.555	0.656	14.665
Tandem	*	*	*	*	*	*	*
3-Axle							
Single	1,791	60	1,791	117	7.282	0.728	8.221
Tandem	1,791	117			16.338	1.634	80.993
Multi-Unit							
2-S1							
Single	11,213	72	3,738	24	8.932	0.893	14.791
Tandem	*	*	*	*	*	*	*
2-S2							
Single	14,961	81	7,480	98	9.116	0.912	17.504
Tandem	7,480	98			15.997	1.600	65.171
3-S2							
Single	23,603	14	23,603	38	8.564	0.856	2.562
Tandem	47,206	76			18,926	1.893	70.424
Miscellaneous							
Single	3,825	91	2,013	177	9.107	0.911	19.532
Tandem	712	62			18.007	1.801	52.056
All Types							
Single	76,477	73	48,272	69	8.172	0.817	12.693
Tandem	57,189	81			18.451	1.845	70.947

1 Based on 1966-68 data from the 21 conventional loadometer stations and using the standard formula shown in the text of the report.

2 Controlled by the axle requiring the largest number of vehicles of that type.

* Not applicable

Table 15

Number of Single and Tandem Axles Actually Weighed and Necessary to Weigh of Each Major Vehicle Type to Obtain an Average Axle Weight in 18-Kip Axle Equivalents Within 10 Percent of the Population Average for all Stations Combined[1]

Vehicle Type	Number of Axles		Number of Vehicles		18-Kip Axle Equivalents Per Axle		
	Actually Weighed	Necessary To Weigh	Actually Weighed[2]	Necessary To Weigh[2]	Average	10 Percent of Average	Variance from Average
Single-Unit							
2-Axle 6-Tire							
Single	21,084	384	10,542	192	0.099	0.010	0.100
Tandem	*	*	*	*	*	*	*
3-Axle							
Single	1,791	3,000	1,791	3,000	0.076	0.008	0.050
Tandem	1,791	1,260			0.221	0.022	0.160
Multi-Unit							
2-S1							
Single	11,213	1,110	3,738	370	0.164	0.016	0.074
Tandem	*	*	*	*	*	*	*
2-S2							
Single	14,961	1,565	7,480	888	0.199	0.020	0.163
Tandem	7,480	888			0.175	0.018	0.071
3-S2							
Single	23,603	1,688	23,603	1,688	0.080	0.008	0.028
Tandem	47,206	526			0.261	0.026	0.093
Miscellaneous							
Single	3,825	2,257	2,013	2,049	0.207	0.021	0.259
Tandem	712	725			0.201	0.020	0.091
All Types							
Single	76,477	2,279	48,272	1,442	0.127	0.013	0.096
Tandem	57,189	583			0.248	0.025	0.093

1 Based on 1966-68 data from the 21 conventional loadometer stations and using the standard formula shown in the text of the report.

2 Controlled by the axle type requiring the largest number of vehicles of that type.

* Not applicable.

type that should have been weighed at a station to obtain the level of reliableness specified. These calculations were based on 1966-68 data from all 21 stations combined. The results of Table 14 indicate that the number of axles necessary to weigh was very small compared to the number weighed. When put in terms of the number of vehicles of each type, the same was true. Thus, it is relatively easy to obtain reliable average axle weights in kips with the actual number weighed. On the other hand, Table 15 shows that considerably more axles or vehicles must be weighed to obtain reliable average axle weights in 18-kip axle equivalents than to obtain reliable average axle weights in kips. Even so, the number of axles actually weighed was in excess of the number required to be weighed, except for the 3-axle single-unit and miscellaneous vehicle types.

When analyzed on the basis of highway system, the number of single and tandem axles necessary to weigh, of each vehicle type, did not change significantly. At least, this was the case in obtaining reliable average axle weights in kips. It seems likely that the same relationship exists in the case of average axle weights in 18-kip axle equivalents.

Dividing the 21 station data according to load characteristic apparently increases the number of vehicles necessary to weigh in obtaining reliable average axle weight. This conclusion is based on the analysis of 3-S2's, where it was found that a total of 2,762 vehicles, 1,693 loaded and 1,069 empty, would have to be weighed to obtain reliable average axle weights in 18-kip axle equivalents.

When comparing the results of Tables 13 and 15, it is discovered that more vehicles must be weighed to obtain accurate average vehicle weights in 18-kip axle equivalents than to obtain accurate average axle weights in 18-kip axle equivalents. This fact confirms the assumption that there is more variation in the units weighed as vehicles than as axles.

So long as multi-station data are used to generate sample size estimates, multi-year data may not be necessary. This is indicated by the fact that the averages and variances for each vehicle type have not changed significantly from year to year, even when not corrected for trend.

In an effort to cast some light on how many stations may be needed to collect adequate loadometer data, a limited comparison was made between data collected at the weigh-in-motion station and the conventional stations. First, a comparison of Figures 3 and 4 revealed a close similarity between frequency distributions of the two sets of data. Also, Table 16 shows that the standard deviations about the averages of vehicle weights in log-kip axle equivalents for the two sets of data are highly similar. The same is true even on a vehicle type basis. However, the standard deviations measured in 18-kip axle equivalents are quite different. Then too, the averages themselves are statistically different. It seems that the difference between the averages of the two sets of data is primarily due to the type of weighing device. The scale used at conventional stations record static weights, while the one used at the weigh-in-motion station records dynamic weights.

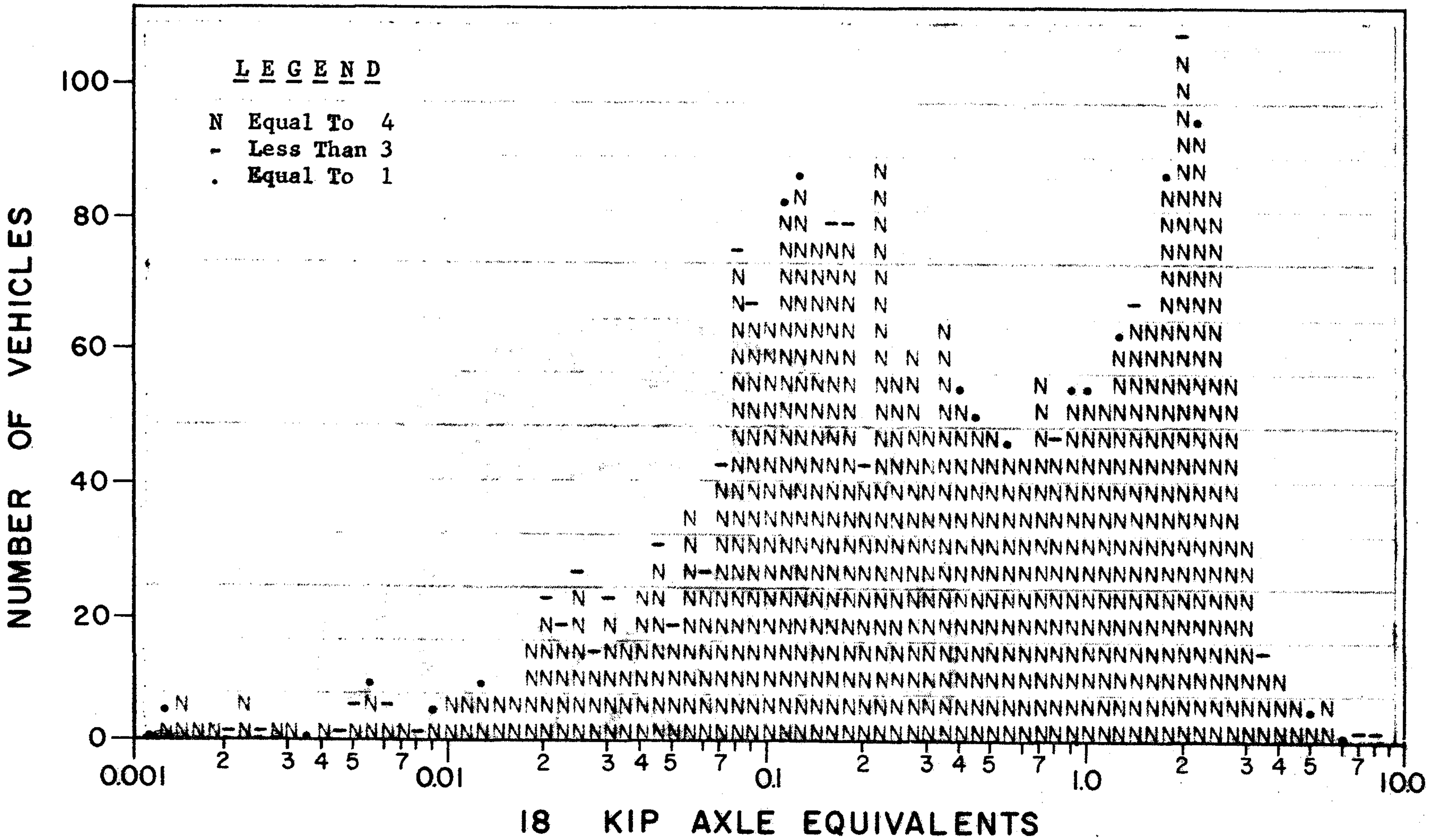

Figure 4. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles studied from the March, 1969 weighings at weigh-in-motion Station 35-2.

Table 16

Numbers, Averages, and Standard Deviations Generated from all Vehicles Weighed at the Weigh-in-Motion Station and the 21 Conventional Loadometer Stations[1]

Item	Weigh-in-Motion Station (35-2)	21 Conventional Stations
Number of Vehicles Weighed	2,590	19,237
Vehicle Weight in 18-Kip Axle Equivalents		
Average	0.8548	0.4729
Standard Deviation from Average	1.5222	0.6313
Vehicle Weight in Log-Kip Axle Equivalents		
Average	-0.5175	-0.7711
Standard Deviation from Average	0.7323	0.7425

1 Data from Weigh-in-Motion Station 35-2 represent seven consecutive days of weighings obtained during March 1969, and data from the 21 conventional stations represent 48.66 nonconsecutive weekdays of weighings obtained during the first 10 months of 1967.

Carrying the above analysis a step further, Table 17 shows a comparison of the averages and standard deviations for the two sets of data according to days of weighing. Again, the standard deviations are highly similar for data collected on weekdays, but the averages are different. Since weekend weighings were not made at the conventional stations, no comparison can be made between the two sets of data on this basis. But weekend versus weekday comparisons were made using the weigh-in-motion data. For 3-S2's, the standard deviations are somewhat different, and averages are definitely different. However, the averages and standard deviations for the combined vehicle types are nearly identical for both sets of data.

Not enough weigh-in-motion data have been collected and analyzed to allow definite conclusions concerning the reliableness of data collections at only one location. However, the results of the above analysis indicate that data collected at only a few stations, perhaps two for each highway system, may be adequate to make weight estimates for highway design purposes. Also, there is enough difference between the weekday and weekend data for a major vehicle type to suggest the necessity of collecting data seven days of the week. The regression analysis has already indicated that there is a significant difference in the weight data between seasons.

Manual Classification Count Samples

Prior to 1970, four 24-hour weekday vehicle classification counts were taken annually at each manual count station. These counts were actually taken during eight-hour periods as follows: 12:00 AM to 8:00 AM,

Table 17

Numbers, Averages, and Standard Deviations Generated from all Vehicles Weighed on Weekdays Compared to Weekends at the Weigh-in-Motion Station and the 21 Conventional Loadometer Stations[1]

Item	Weigh-in-Motion Station (35-2)	21 Conventional Stations
All Vehicle Types		
Weekdays[2]		
Number of Vehicles Weighed	2,152	19,237
Average of Log-Kip Axle Equivalent	-0.5178[3]	-0.7711
Standard Deviation from Average	0.7256	0.7425
Weekends		
Number of Vehicles Weighed	438	*
Average of Log-Kip Axle Equivalent	-0.5159[3]	*
Standard Deviation From Average	0.7646	*
3-S2 Vehicle Type		
Weekdays[2]		
Number of Vehicles Weighed	1,000	9,643
Average of Log-Kip Axle Equivalent	-0.3384[4]	-0.5279
Standard Deviation From Average	0.6114	0.5753
Weekends		
Number of Vehicles Weighed	219	*
Average of Log-Kip Axle Equivalent	-0.1772[4]	*
Standard Deviation From Average	0.5565	*

1 Data from Weigh-in-Motion Station 35-2 represent seven consecutive days of weighings obtained during March 1969, and data from the 21 conventional stations represent 48.66 nonconsecutive weekday of weighings obtained during the first 10 months of 1967.

2 Monday through Friday

3 The difference between these averages is not statistically significant at the .01 probability level.

4 The difference between these averages is statistically significant at the .01 probability level.

* No data available.

8:00 AM to 4:00 PM and 4:00 PM to 12:00 AM. All three of these periods (to make one 24-hour day) were represented one time each season or one period per month. Two continuous 24-hour period weekend counts were taken during the summer at each station having a permanent automatic recording station in the same road section. In 1970, the weekday counting was reduced to 16 hours (8:00 AM to 12:00 AM) per season at each station.

At the loadometer stations, additional counts were made during every weighing period. Also prior to 1967, one continuous 24-hour count for each summer month was taken at the 19 rural stations.

The manual classification count samples taken at loadometer stations were used almost exclusively in determining the adequacy of such data to estimate the base AADT count of cargo vehicles at any station. The weigh-in-motion station counts were used as supplemental data.

Representativeness. To some extent, the findings and conclusions reached concerning the representativeness of previously collected weight samples are applicable to manual count samples. But, generally, the latter samples have been more representative, especially since 1967. One major reason for this is that weekend counting has been done at some of the stations, whereas, no weekend weighings were done at the conventional loadometer stations. Also, the counting schedule includes all seasons, while the present loadometer schedule does not.

However, it is difficult to reflect actual seasonal changes with only one 24-hour count per season. Thus, aggregation of count data by years or stations may help establish adjustments for seasonal and day of week differences.

Reliableness. Assuming that the manual counts taken at the loadometer stations were fairly representative of the traffic, the reliableness of such data for estimating the annual average daily traffic count by vehicle type at a station was evaluated. The criteria applied on the weight data were used here also.

The 1965-68 loadometer manual count samples were used to determine how many 24-hour day manual counts should be made to obtain reliable base AADT's at a station (9). Count data from loadometer stations were more numerous than the same data from other manual count stations. Also, more continuous 24-hour counts were collected from loadometer stations.

From the above data, averages of the 24-hour volume counts and the variances from these averages were utilized in determining the necessary sample sizes. These statistics were used in the same formula applied to the weight data to generate sample size estimates. Also, the error requirements and probability level were the same.

First, it is demonstrated how much the averages and variances changed depending on the time of counting and the number of counts utilized. Data for five-axle semitrailer vehicles taken at Loadometer Station 45-2 serve as an example. As shown in Table 18, there is a considerable difference between the lowest and highest variance. The averages differ to a lesser extent. The number of counts, time of counting and length of the counting periods (24-hour versus 8-hour) apparently contributed to these differences. Such differences influence the number of counts necessary to derive reliable base year AADT estimates.

Table 18

Estimated Number of Counts Necessary to Make of Five-Axle Semitrailer Vehicles Based on the Averages and Variances Computed from Varying Numbers of Actual Counts Taken at Loadometer Station 45-2 During 1965-68

Time of Counting and Count Period	Actual Counts			Number of Counts	
	Average	Variance[1]	10 Percent of Average	Actual	Necessary
1965					
Spring, Summer and Fall 24 and 8-Hour Periods[2]	1,157	2,805	116	5	2
Summer 24-Hour Periods	1,138	4,102	114	3	6
1966					
Spring, Summer and Fall 24 and 8-Hour Periods[2]	1,140	30,401	114	5	19
8-Hour Periods[3]	1,222	7,805	122	3	10
Summer 24-Hour Periods	1,062	33,831	106	3	56
1965-66					
Spring, Summer and Fall 24 and 8-Hour Periods[2]	1,149	14,840	115	10	6
8-Hour Periods[3]	1,207	4,356	121	5	3
Summer 24-Hour Periods	1,100	16,946	110	6	10
1965-68					
Spring, Summer and Fall 24 and 8-Hour Periods[4]	1,150	12,305	115	12	5
Summer 8-Hour Periods	1,153	881	115	3	1

1 This is the variance (S^2) used in the sample size formula shown in the text.

2 The spring and fall counts are based on three eight-hour periods per season, but the summer counts are based on three 24-hour periods.

3 Three eight-hour counts per season, except none for summer of 1965.

4 Same as Footnote 1, except eight-hour periods for summer of 1967 and 1968.

Also, when the number of necessary counts are determined from a small number of actual counts, the t-values used in the sample size formula are quite large and cause the number of counts required to increase. Therefore, as many as 10 or 12 actual counts should be used in making estimates of the number of counts necessary to produce reliable AADT estimates. In fact, this number of actual counts indicates that five counts of five-axle semitrailers are necessary at Station 45-2.

Combining years of 24-hour volume counts seems to be a necessary procedure for making more accurate sample size estimates. Of course, trend adjustments may be required. In general, it seems acceptable to assume a constant trend in absolute terms over the years. If this is correct, the equation to measure or adjust for trend can be stated as follows:

$Y_c = a + bX$, where

Y_c is the computed or trend value of the actual 24-hour volume count of a vehicle type for the year numbered X. The constant a is the value of Y_c when X equals zero, and the constant b is the slope of the trend line or change in Y_c per unit change in X. Data in Table 18 required no such trend adjustment.

Second, it is demonstrated how much the averages and variances changed for the 24-hour volume counts of five-axle semitrailer vehicles, depending on where these counts were made. Table 19 shows these differences, generated from trend adjusted counts. Stations with essentially the same averages had significantly different variances and vice versa. Again, such differences account for the varying number of counts necessary from

Table 19

Estimated Number of Counts Necessary to Make of Five-Axle Semitrailer Vehicles Based on the Averages and Variances Computed from Varying Numbers of Actual Counts Taken at the 21 Loadometer Stations During 1965-68

Loadometer Stations by Highway System	Actual Counts[1]			Number of Counts	
	Average	Variance[2]	10 Percent of Average	Actual[3]	Necessary
Interstate Rural					
10-1	162	518	16	12	10
10-2	477	1,846	48	12	4
20-1	736	1,428	74	12	2
20-2	808	3,868	81	11	3
20-3	679	10,885	68	10	13
30-1	658	1,321	66	12	2
35-1	701	2,183	70	12	3
37-1	288	684	29	12	4
45-2	1,154	12,338	115	12	5
Other Rural					
7	150	164	15	12	4
16	280	1,008	28	11	7
20	520	2,212	52	12	4
42	123	338	12	11	12
72	519	4,728	52	12	9
81	259	2,912	26	12	21
88	122	215	12	12	7
145	418	2,067	42	12	6
147	110	773	11	12	31
149	253	1,003	25	11	8
Urban					
3	159	2,332	16	8	52
4	51	168	5	8	37
All Stations					
Total	8,627	52,991	863	238	244
Average	411	2,523	41	12	12

1 These counts are adjusted for trend, using the linear equation presented in the text of this report.

2 This is the variance used in the sample size formula shown in the text.

3 All stations have counts for spring, summer, and fall, except the urban stations which have only summer counts. Also, see Footnote 3 at bottom of Table 18.

station to station. However, the number of counts necessary was less than the number of actual counts for 15 of the 21 stations. If averaged by highway system, the numbers of counts necessary are as follows: 6 for interstate rural, 11 for other rural and 45 for urban. Therefore, only the urban system shows that more than 12 counts are necessary to produce a reliable AADT count estimate.

Third, it is demonstrated the extent of the differences in the sample size requirements for the major vehicle types. Again, data from Loadometer Station 45-2 are used. The results are presented in Table 20. Based on eight-hour period counts heavily weighted in favor of the summer season, these findings show a wide difference in the number of counts necessary between vehicle types. The number of 24-hour volume counts necessary was greater than that of the actual counts for every vehicle type, except the five-axle semitrailers.

The above analysis demonstrates the need for using an adequate number of sample 24-hour volume counts in arriving at the base year AADT count of each vehicle type. However, the analysis needs to be taken a step further to show the effects of using varying numbers of 24-hour volume counts within years and/or across years in estimating a base year AADT count for each vehicle type. Also, the analysis should show the effects of using manual and automatic recorder counts of <u>all vehicles</u> in making AADT count estimates for cargo vehicles. The above effects are demonstrated by using four methods to estimate the AADT of five-axle semitrailers based on counts taken during the summers at Loadometer

Table 20

Estimated Number of Counts Necessary to Make of the Major Vehicle Types Based on the Averages and Variances Computed From Seven Actual Counts Taken at Loadometer Station 45-2 During 1965-68[1]

Vehicle Type	Actual Counts			Number of Counts	
	Average	Variance[2]	10 Percent of Average	Actual	Necessary
Single-Unit					
2-Axle 6-Tire	218	570	22	7	8
3-Axle	38	96	4	7	40
Multi-Unit (Semitrailer)					
3-Axle	135	932	14	7	31
4-Axle[3]	291	2,882	29	7	20
5-Axle	1,192	3,860	119	7	2

1 Three eight-hour counts per season as follows: Spring and fall of 1965; Spring, summer and fall of 1966; and Summer of 1967 and 1968.

2 This is the variance used in the sample size formula shown in the text.

3 The actual counts were adjusted for trend for this vehicle type, using the linear equation presented in the text of this report.

Station 45-2. The four methods of arriving at the base year AADT count for this or any vehicle type are described here in terms of using only one 24-hour volume count per year as follows:

1. Use the latest year's count.
2. Use the latest year's trend line count (computed from at least three years of data).
3. Use the number of vehicles derived from multiplying the latest year's automatic recorder AADT by the percent of the vehicle type (latest year's count of individual vehicle type divided by the corresponding count all vehicles).
4. Use the number of vehicles derived from multiplying the latest year's automatic recorder AADT by the percent of a vehicle type (sum of at least three yearly counts of an individual vehicle type divided by the corresponding sum of count of all vehicles).

Methods 1 and 2 use only the actual 24-hour volume counts of each vehicle type to arrive at the base year AADT. Whereas, Methods 3 and 4 applies the 24-hour volume counts of each vehicle type to the corresponding 24-hour volume count of all vehicles and the automatic recorder AADT count of all vehicles to arrive at the base year AADT for each vehicle type. Method 2 assumes a constant absolute change in the actual count of a vehicle type from year to year, and Method 4 assumes that the percent of trucks is constant over the time period used in the calculations.

In applying the four methods to three 24-hour volume counts per year, a weighted annual average number (Methods 1 and 2) or percent (Methods 3 and 4) was used to make the base year AADT count estimates.

Figure 5 shows the AADT count derived from the application of the above four methods using one versus three actual counts per year. Figure 6 shows the AADT manual count of all vehicles based on one versus three actual counts per year and the AADT automatic recorder count of all vehicles. As indicated on the graphs, it was only during the summers of 1965 and 1966 that three manual counts were collected. During 1967 and 1968, only one count was available.

The results of this analysis, as shown in Figure 5, indicate that the within and between-year fluctuations in the estimated AADT counts of five-axle semitrailers for 1965-1967 are very large when using only one count per year, especially in the case of Method 3. The use of three counts per year reduced these fluctuations considerably. The same was true for the AADT manual count of all vehicles shown in Figure 6. In other words, if more than one count per year is used, all four methods will yield more accurate estimates of the base year AADT count. When this analysis was applied to data from other loadometer stations, essentially the same results were obtained.

The results also indicate that the large differences between the estimated AADT counts for each year (especially for 1965 and 1966 are due to employing 24-hour manual counts and AADT automatic recorder counts of <u>all</u> <u>vehicles</u> in the calculations of Methods 3 and 4. Thus, it might be concluded that more accurate base year AADT counts for the cargo

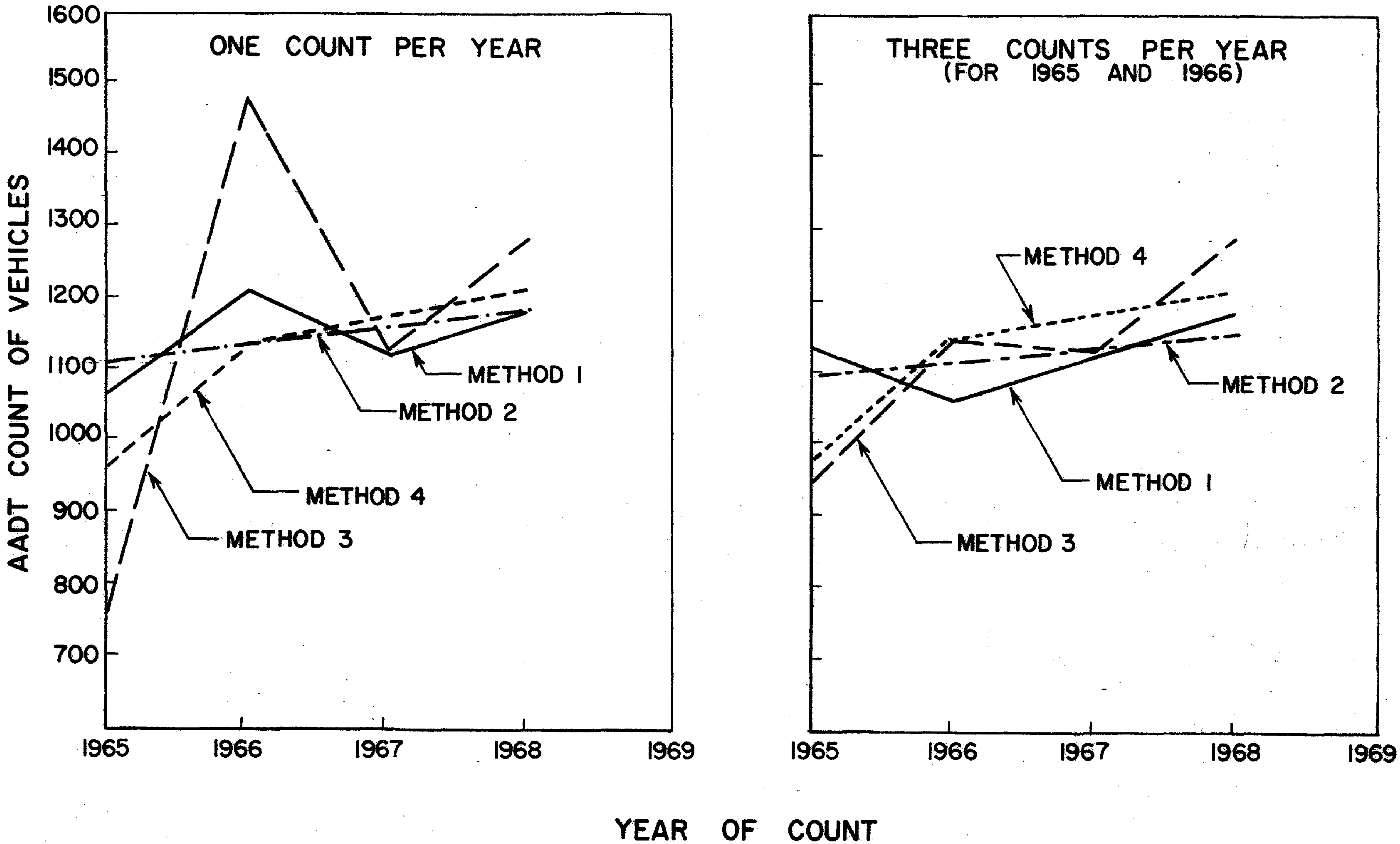

Figure 5. Graph showing the AADT count of five-axle semitrailers derived from four methods with the use of one versus three manual counts per year.

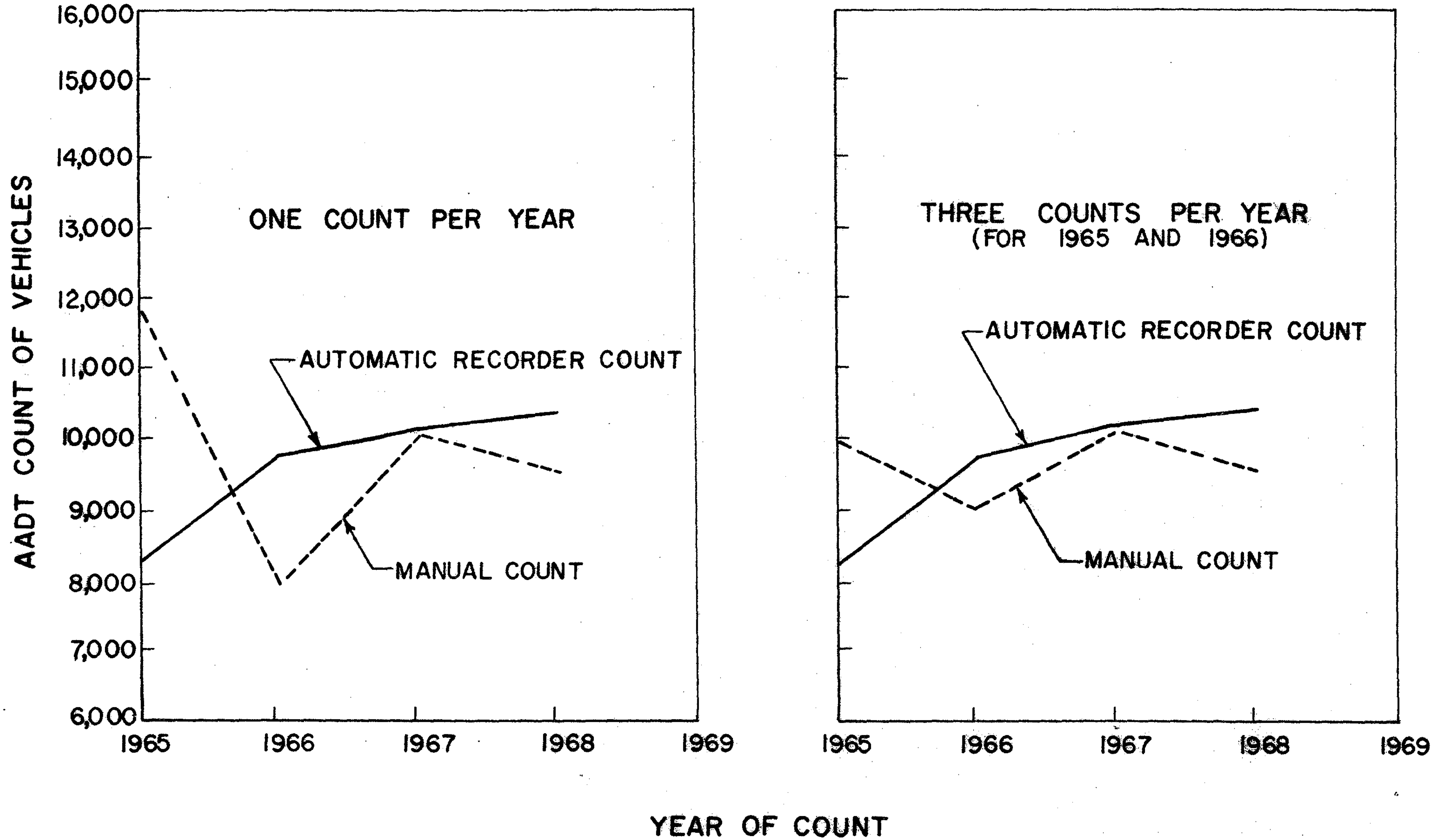

Figure 6. Graph showing the AADT count of all vehicles based on one versus three manual counts per year and the AADT automatic recorder count of all vehicles.

vehicle types can be obtained from Methods 1 and 2. Of these two, Method 2 gives the greatest accuracy, because it depends on the vehicle type counts for all years in the series rather than only one year. Then, to gain even greater accuracy using either method, at least three counts per year should be employed.

In conclusion, it is highly desirable to take at least three counts per year per manual count station in which to estimate the base AADT of each vehicle type. Also, the method of estimating the base AADT count for the cargo vehicle types is of considerable importance.

REDUCING AND ANALYZING LOADOMETER DATA

Reducing and analyzing loadometer data can be formidable tasks if the uses and output requirements are not kept clearly in mind, if improper amounts of input data are collected and if the wrong techniques are used to generate the needed outputs. This statement can be supported by the fact that many studies, in the past, have dealt with such problems. In fact, this research study was conceived to deal with these probelms. Thus, an attempt is made in this section to summarize the requirements for a loadometer data reduction and analytical system which seem to be supported by the findings of this study. Stated more explicitly, the primary purpose of this section of the report is to suggest a methodology developed during the life of the study which will meet the present and foreseeable output needs of the THD as well as other state and federal agencies responsible for highway construction and maintenance.

Uses of Loadometer Data

As a first step in fulfilling the above purpose, the primary uses of loadometer data were conceived through the help of officials in the Planning Survey Division of the THD and from the Federal Highway Administration's instructional memorandum referred to earlier in this report (1). These uses of loadometer data are summarized as follows:

1. To determine the design requirements of highway pavements.
2. To aid in the determination of the geometric design requirements of highways.
3. To help in allocating highway costs among the users.
4. To assist in allocating highway revenues among the various government agencies responsible for building and maintaining highways.
5. To assist in establishing vehicle size and weight limits.
6. To assist governments in the establishment of a sound transportation policy.
7. To furnish basic data for continuing research efforts.

Perhaps other uses could be added to the above list, but they likely would have the same output requirements. Also, those listed are considered to be, by far, the principal uses of loadometer data.

Outputs Required from Loadometer Data

Each of the above uses requires somewhat different outputs from loadometer data. Also, the output for one use may become the input to generate the output for another use. Additional data other than loadometer data are required to obtain certain outputs.

To satisfy the requirements of the above uses, the loadometer data reduction and analytical system must yield adequate outputs according to the vehicle characteristics of each station, each highway system and the combined 21 stations. The principal types of outputs are as follows:

1. Total number of vehicles weighed.
2. Total weight of all vehicles expressed in pounds, kips and 18-kip axle equivalents.
3. Number and percentage distributions of vehicles by weight classes in pounds, kips and 18-kip axle equivalents.
4. Averages, variances, standard deviations and standard errors for each vehicle weight frequency distribution.
5. Total number of axles (single and tandem) weighed.
6. Total weight of all axles by type, expressed in pounds, kips and 18-kip axle equivalents.
7. Number and percentage distributions of single and tandem axles by weight classes in pounds, kips and 18-kip axle equivalents.
8. Averages, variances, standard deviations and standard errors for each axle weight frequency distribution.
9. Estimated total load experience of an existing or proposed highway generated from some of the above outputs using a selected estimating procedure.

Quantity of Loadometer Data to Collect

The findings of this report indicate that as long as the present weighing schedule is followed, the system should combine data collections from all 21 of the conventional loadometer stations to obtain representative input data for load experience estimates. To assure reliable outputs, the minimum quantity of combined station data should be about that collected during one summer. However, if the data are broken down on a station or highway system basis, the quantity of data collections should be increased, especially in the case of the urban system. Much the same results could be accomplished by combining enough data collected during previous years or summers.

The findings tend to indicate that fewer stations could be used to obtain the necessary input data to produce reliable statistics or estimates of the population parameters. Thus, continuous seven-day weighing periods during each season of the year are recommended to be conducted at several stations. Perhaps two or three stations per highway system would be enough. However, a final decision should not be made until more data are generated with the weigh-in-motion scales at several station locations on each highway system. Then, it could be determined whether true station to station differences in vehicle or axle weights actually exist.

Future loadometer data collections should be periodically tested for adequacy, that is, tested for representativeness and reliableness. The procedures used in this study are recommended for such determinations. Also, the same tests should be performed on the manual count data. The continuous need for adequate data to support future research in this area should always be kept in mind.

Selecting an Estimating Technique

Since this study has concentrated on developing a technique to generate more accurate estimates of the total load experience of a highway (required for design purposes), the process of reducing and analyzing loadometer data is oriented toward achieving that goal. The outputs needed for other uses can or will be generated in the process of making the above estimates. Also, the THD has already developed computerized programs to obtain outputs needed for the other uses.

The findings of this study indicate that an axle weight frequency distribution set, such as Set 5, should be used in estimating the total load experience of a highway. The loadometer data requirements and the steps in the analytical process leading to such determination have already been outlined in this report. As in the case of alternative estimating procedures, the axle weight frequency distributions should be updated with the most current loadometer data every two or three years.

Further research is recommended for the purpose of attempting to develop an estimating model which would be more accurate than those presented in this report. A comprehensive analysis of sufficient data collected by weigh-in-motion scales should yield more accurate estimating models for each highway system.

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APPENDIX A

SUPPORTING TABLES

APPENDIX A

Table 1

Texas Cargo Vehicles Defined According to Axle Combination and Corresponding Vehicle Type Code

Axle Combinations	Vehicle Type Code for Axle Combination
Single-Unit Vehicles	
2-Axle, 6 Tires	2
3-Axle	3
Multi-Unit Vehicles	
2-Axle Tractor, 1-Axle Semitrailer	2-S1
2-Axle Tractor, 2-Axle Semitrailer	2-S2
3-Axle Tractor, 1-Axle Semitrailer	3-S1
3-Axle Tractor, 2-Axle Semitrailer	3-S2
2-Axle Tractor, 3-Axle Semitrailer	2-S3
3-Axle Tractor, 3-Axle Semitrailer	3-S3
2-Axle Truck, 1-Axle Balance Trailer	2-1
2-Axle Truck, 2-Axle Full Trailer	2-2
2-Axle Truck, 3-Axle Full Trailer	2-3
3-Axle Truck, 2-Axle Full Trailer	3-2
3-Axle Truck, 3-Axle Full Trailer	3-3
3-Axle Truck, 1-Axle Balance Trailer	3-1
2-Axle Tractor, 1-Axle Semitrailer, 2-Axle Full Trailer	2-S1-2
3-Axle Tractor, 1-Axle Semitrailer, 2-Axle Full Trailer	3-S1-2

Appendix A

Table 2

Texas Highway Department Classifications of Body Types Included in the Body Type Variables as Introduced into the Analyses of Loadometer Data[1]

Variable Symbol and Number	Variable Name	Texas Highway Department Body Types
A	Constant term	Bare chassis, containers, equipment, garbage and refuse, log or pipe, truck-tractor without semi-trailer or trailer, shop, and wrecker.
X_3	Van or panel single unit body	Insulated van, armored car, carryall, or minibus, multistop or standup delivery, dwelling body, furniture or moving van, panel, and van.
X_4	Van or panel combination body	Same as X_3 above, except that all vehicles are of the multi-unit (combination) axle type.
X_5	Oil or platform body	Platform, flat or stake, low-bed trailer, lumber, riggers or oil field.
X_6	Cattle or rack body	Bottles, boat carrier, light utility, rack, livestock rack, and utilities.
X_7	Tank body	Bituminous material distributor, hopper, concrete mixer or agitator, petroleum tank, and tank.
X_8	Open top body	Open top box or van, canopy, dump, express, grain, pickup, personnel and cargo.
X_9	Auto transport body	Automobile transporter.

1 These variables were specifically combined for the dummy variable analyses.

APPENDIX A

Table 3

Percentage Distribution of Single Axles for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Nine Interstate Rural Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Single Axles by Vehicle Type												
	Single-Unit		Multi-Unit										
	2-Axle 6-Tire	3-Axle	2-S1	2-S2	3-S1	3-S2	3-S3	2-S1-2	3-S1-2	2-1	2-2	3-2	Misc.
1	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	0.8	0.0	0.0
2	1.3	0.1	*	*	0.0	*	0.8	0.0	0.0	12.5	6.4	0.0	4.0
3	13.7	1.6	0.6	0.2	0.0	*	3.8	0.4	0.0	22.2	14.0	3.1	12.0
4	22.6	5.8	8.0	2.7	0.2	0.2	1.5	3.2	2.8	14.2	16.6	4.7	10.7
5	17.4	7.5	12.5	8.1	1.6	0.8	3.1	5.0	5.1	13.6	12.5	3.9	1.3
6	11.2	7.8	11.5	10.5	4.4	1.6	2.3	6.8	3.4	6.8	11.3	0.8	10.7
7	7.3	8.2	11.9	9.3	14.9	4.5	7.6	5.6	2.8	8.5	5.3	5.5	2.7
8	5.1	7.1	11.8	8.4	10.4	9.3	4.6	8.8	6.4	5.7	4.9	8.6	9.3
9	3.6	4.6	8.1	5.8	8.9	9.3	7.6	10.6	12.0	2.3	4.5	5.5	4.0
10	3.2	2.1	5.1	3.0	6.4	5.1	6.1	9.8	10.3	2.3	3.4	6.3	9.3
11	2.9	1.7	4.7	1.9	1.6	1.9	10.7	8.4	8.5	0.6	2.3	6.3	4.0
12	2.5	1.4	4.5	2.0	2.4	0.5	3.8	7.8	9.2	1.1	1.5	6.3	5.3
13	1.9	0.7	4.8	2.1	2.0	0.2	4.6	7.6	5.8	0.6	3.0	0.0	1.3
14	1.6	0.5	4.4	2.2	1.8	*	2.3	7.3	4.8	1.1	1.5	2.3	1.3
15	1.4	0.5	3.8	2.6	2.7	*	3.8	6.0	3.9	0.0	0.4	5.5	0.0
16	1.2	0.2	3.4	2.6	4.2	*	1.5	5.1	1.8	0.0	1.1	1.6	0.0
17	1.1	0.1	2.4	2.3	3.1	*	0.8	2.7	1.3	0.6	0.8	1.6	1.3
18	0.9	0.1	1.4	1.5	1.3	*	0.8	2.0	0.4	0.0	1.5	0.8	0.0
19	0.5	0.1	0.7	0.8	0.5	*	0.0	0.8	0.3	0.0	0.4	0.8	0.0
20	0.2	0.1	0.3	0.4	0.2	*	0.0	0.4	0.0	0.0	0.4	0.0	0.0
21	0.1	0.0	0.1	0.2	0.0	*	1.5	0.2	0.0	0.0	0.0	0.0	1.3
22	0.1	0.0	0.1	0.1	0.0	*	0.8	0.0	0.0	0.0	0.0	0.0	1.3
23	*	*	*	*	0.0	*	1.5	0.0	0.0	0.0	0.0	0.0	1.3
24	*	0.0	*	*	0.0	*	0.8	0.0	0.0	0.0	0.0	0.0	0.0
25	*	0.0	*	*	0.0	*	1.5	0.0	0.0	0.0	0.0	0.0	0.0
26	*	*	*	*	0.0	*	0.8	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	*	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	*	0.8	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	*	0.8	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	*	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Table 3 (Continued)

Percentage Distribution of Single Axles for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Nine Interstate Rural Loadometer Station During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Single Axles by Vehicle Type												
	Single-Unit		Multi-Unit										
	2-Axle 6-Tire	3-Axle	2-S1	2-S2	3-S1	3-S2	3-S3	2-S1-2	3-S1-2	2-1	2-2	3-2	Misc.
31	0.0	0.0	0.0	0.0	0.0	*	1.5	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	*	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total[1]	99.8	50.2	100.1	66.7	66.6	33.4	75.7	94.0	78.8	99.5	92.6	63.6	81.1

*Less than 0.05 percent.

[1]The total percent for each vehicle type's single and tandem axles added together should be 100.0 percent for each highway system. However, the values less than 0.05 percent were not added in the totals. Also, those percentages representing axles miscoded were left out of the totals.

APPENDIX A

Table 4

Percentage Distributions of Tandem Axles for Frequency Set 4 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Nine Interstate Rural Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Tandem Axles by Vehicle Type							
	Single-Unit	Multi-Unit						
	3-Axle	2-S2	3-S1	3-S2	3-S3	3-S1-2	3-2	Misc.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	*	0.0	*	0.0	0.0	0.0	0.0
4	0.1	*	0.0	*	0.0	0.0	0.8	0.0
5	0.9	0.2	0.0	0.3	0.0	0.0	0.0	0.0
6	2.9	0.9	0.0	1.0	0.0	0.1	1.6	0.0
7	4.5	2.3	0.0	2.3	0.0	0.1	1.6	0.0
8	3.6	3.0	0.4	3.6	0.0	1.2	1.6	0.0
9	3.4	2.9	0.7	4.0	0.0	0.7	2.3	1.3
10	2.7	2.1	1.6	4.0	0.0	0.6	1.6	0.0
11	2.2	1.6	2.0	3.4	0.8	1.2	0.8	2.7
12	2.4	1.2	2.0	2.4	0.8	0.6	0.0	0.0
13	1.7	0.9	2.7	1.8	0.8	2.2	1.6	1.3
14	1.5	0.9	3.3	1.5	1.5	2.8	2.3	0.0
15	1.2	0.9	2.2	1.4	1.5	2.2	0.8	0.0
16	1.6	0.9	0.5	1.3	0.0	2.1	0.0	4.0
17	0.9	0.8	1.5	1.3	3.8	1.9	0.0	0.0
18	1.2	0.9	0.9	1.4	0.8	1.8	0.8	1.3
19	1.0	0.9	0.7	1.5	1.5	1.2	0.0	0.0
20	0.8	0.9	0.4	1.6	0.0	0.4	0.0	0.0
21	1.0	0.9	0.4	1.8	0.8	0.6	0.8	0.0
22	1.3	0.9	0.4	2.2	1.5	0.3	0.0	0.0
23	1.1	0.9	1.8	2.5	0.0	0.1	0.8	2.7
24	1.2	1.0	1.3	2.9	0.8	0.1	1.6	1.3
25	1.2	1.1	2.2	3.5	1.5	0.1	0.8	0.0

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Table 4 (Continued)

Percentage Distributions of Tandem Axles for Frequency Set 4 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Nine Interstate Rural Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Tandem Axles by Vehicle Type							
	Single-Unit	Multi-Unit						
	3-Axle	2-S2	3-S1	3-S2	3-S3	3-S1-2	3-2	Misc.
26	1.4	1.4	2.0	3.9	0.0	0.0	3.1	0.0
27	1.5	1.2	1.8	3.9	0.8	0.3	1.6	0.0
28	1.5	1.1	3.1	3.6	0.0	0.3	3.1	0.0
29	1.6	1.0	0.7	3.0	1.5	0.0	2.3	1.3
30	1.0	0.8	0.5	2.2	2.3	0.0	3.9	0.0
31	1.2	0.5	0.0	1.6	0.8	0.0	0.0	2.7
32	0.9	0.3	0.0	1.0	0.8	0.0	0.8	0.0
33	0.7	0.2	0.0	0.6	0.8	0.0	0.0	0.0
34	0.4	0.2	0.0	0.4	0.0	0.0	0.0	0.0
35	0.4	0.1	0.2	0.3	0.8	0.0	0.0	0.0
36	0.3	0.1	0.0	0.1	0.0	0.0	0.8	0.0
37	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0
38	*	*	0.0	0.1	0.0	0.0	0.8	0.0
39	0.1	*	0.0	0.1	0.8	0.0	0.8	0.0
40	*	*	0.0	*	0.0	0.0	0.0	0.0
41	*	*	0.0	*	0.0	0.0	0.0	0.0
42	0.0	*	0.0	*	0.0	0.0	0.0	0.0
43	*	*	0.0	*	0.0	0.0	0.0	0.0
44	0.0	*	0.0	*	0.0	0.0	0.0	0.0
45	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0
46	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0
47	*	0.0	0.0	*	0.0	0.0	0.0	0.0
48	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0
49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	*	0.0	0.0	*	0.0	0.0	0.0	0.0
Total[1]	49.5	33.1	33.3	66.6	24.7	20.9	37.0	18.6

*Less than 0.05 percent.

[1]See Footnote 1 at the bottom of Table 3.

APPENDIX A

Table 5

Percentage Distributions of Single Axle for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Ten Other Rural Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Single Axles by Vehicle Type												
	Single-Unit		Multi-Unit										
	2-Axle 6-Tire	3-Axle	2-S1	2-S2	3-S1	3-S2	3-S3	2-S1-2	3-S1-2	2-1	2-2	3-2	Misc.
1	*	0.0	*	*	0.0	0.0	0.0	0.0	0.0	2.9	2.2	0.0	0.0
2	1.3	0.0	0.1	0.1	0.0	*	1.0	0.0	0.0	7.4	6.5	0.0	5.9
3	14.2	2.2	1.4	0.2	0.6	*	2.9	0.0	0.0	18.2	18.5	0.0	7.8
4	24.3	7.1	9.8	4.2	2.8	0.3	5.8	4.0	2.6	23.8	17.4	1.9	7.8
5	16.9	7.9	13.6	10.3	2.8	1.3	2.9	7.4	3.6	12.4	13.6	1.9	5.9
6	10.3	8.5	12.5	12.0	9.0	2.2	8.7	10.3	1.7	7.4	10.9	1.9	5.9
7	6.8	6.9	11.6	9.6	15.3	5.6	5.8	8.9	1.9	6.5	4.9	1.9	7.8
8	4.7	5.9	10.6	6.7	5.6	9.9	4.9	11.4	6.2	3.5	6.0	0.0	5.9
9	3.7	4.4	7.5	4.2	9.6	8.4	11.7	12.9	12.2	1.5	3.3	1.9	3.9
10	3.1	2.4	5.6	2.2	2.8	4.1	5.8	8.5	8.6	1.8	1.6	5.7	7.8
11	2.7	1.4	4.4	1.5	0.6	1.2	6.8	8.1	8.4	1.5	1.1	9.4	3.9
12	2.4	1.1	4.5	1.4	1.7	0.3	3.9	6.3	6.9	0.6	2.2	9.4	2.0
13	1.8	1.1	4.3	1.7	1.1	0.1	1.9	4.8	4.3	2.1	0.5	11.7	2.0
14	1.5	0.5	3.6	2.0	3.4	*	1.9	4.1	3.1	0.6	1.1	5.7	2.0
15	1.2	0.2	3.1	2.4	4.5	*	1.9	3.7	2.4	0.9	0.0	3.8	2.0
16	1.0	0.2	2.6	2.6	4.0	*	0.0	2.6	1.7	0.6	0.0	3.8	0.0
17	1.0	0.1	1.8	2.5	1.1	*	0.0	2.2	1.2	0.6	0.5	0.0	0.0
18	0.9	0.1	1.2	1.5	0.6	*	0.0	0.7	0.0	0.9	0.5	0.0	2.0
19	0.5	0.1	0.7	0.8	1.1	*	1.0	0.0	0.5	0.6	0.5	0.0	0.0
20	0.4	0.1	0.4	0.4	0.0	0.0	0.0	0.4	0.0	0.6	0.0	0.0	0.0
21	0.3	*	0.2	0.2	0.0	*	1.9	0.0	0.2	0.9	0.0	0.0	2.0
22	0.3	*	0.1	0.1	0.0	*	2.9	0.0	0.0	0.6	0.0	0.0	0.0
23	0.2	*	*	0.1	0.0	0.0	1.0	0.0	0.0	1.5	0.0	0.0	0.0
24	0.2	0.1	*	*	0.0	*	0.0	0.0	0.0	1.2	0.0	0.0	0.0
25	0.1	0.0	*	*	0.0	*	0.0	0.0	0.0	0.6	0.0	0.0	0.0

APPENDIX A

Table 5 (Continued)

Percentage Distributions of Single Axle for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Ten Other Rural Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Single Axles by Vehicle Type												
	Single-Unit		Multi-Unit										
	2-Axle 6-Tire	3-Axle	2-S1	2-S2	3-S1	3-S2	3-S3	2-S1-2	3-S1-2	2-1	2-2	3-2	Misc.
26	*	*	0.0	*	0.0	*	1.0	0.0	0.0	0.0	0.5	0.0	0.0
27	*	0.0	*	*	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
29	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
30	*	0.0	0.0	*	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
31	0.0	0.0	0.0	*	0.0	*	0.0	0.0	0.0	0.3	0.0	0.0	2.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	*	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total[1]	99.8	50.3	99.6	66.7	66.6	33.4	73.7	96.3	65.5	100.1	92.3	59.0	76.6

*Less than 0.05 percent.

[1]See Footnote 1 at the bottom of Table 3.

APPENDIX A

Table 6

Percentage Distributions of Tandem Axles for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Ten Other Rural Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Tandem Axles by Vehicle Type							
	Single-Unit	Multi-Unit						
	3-Axle	2-S2	3-S1	3-S2	3-S3	3-S1-2	3-2	Misc.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	*	0.0	0.0	0.0	0.0	0.0	2.0
4	0.2	0.2	0.0	0.1	0.0	0.0	1.9	0.0
5	1.4	0.8	0.0	1.0	0.0	0.0	0.0	0.0
6	4.1	2.3	1.1	2.6	0.0	0.0	0.0	0.0
7	3.6	3.4	0.6	3.5	0.0	0.5	1.9	0.0
8	3.7	3.5	0.6	4.4	0.0	0.0	1.9	0.0
9	2.3	2.4	2.3	4.1	1.0	0.5	3.8	0.0
10	2.7	1.7	0.6	3.7	1.0	1.9	0.0	3.9
11	2.5	1.1	2.3	2.9	1.0	0.2	0.0	0.0
12	1.8	1.0	3.4	2.2	2.9	1.4	0.0	0.0
13	1.6	0.8	0.6	1.5	0.0	2.6	3.8	0.0
14	1.7	0.7	1.1	1.3	0.0	2.1	0.0	0.0
15	1.6	0.6	1.1	1.2	2.9	1.7	0.0	2.0
16	1.8	0.7	2.8	1.1	0.0	3.1	3.8	3.9
17	0.9	0.6	1.1	1.2	2.9	3.3	0.0	2.0
18	1.1	0.6	1.1	1.5	1.0	3.3	0.0	0.0
19	1.0	0.8	1.1	1.7	0.0	2.1	0.0	2.0
20	0.9	0.8	0.6	2.0	1.9	1.4	0.0	0.0
21	0.8	0.8	0.6	2.2	2.9	1.2	0.0	0.0
22	1.1	0.9	1.1	2.5	1.0	1.9	1.9	0.0
23	1.3	1.1	2.8	3.0	1.0	1.2	0.0	0.0
24	1.5	1.2	0.6	3.5	1.0	1.0	0.0	0.0
25	1.5	1.4	4.0	3.7	1.0	1.7	1.9	0.0

APPENDIX A

Table 6 (Continued)

Percentage Distribution of Tandem Axles for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Ten Other Rural Loadometer Stations During 1964-68

	Percent of Tandem Axles by Vehicle Type							
	Single-Unit	Multi-Unit						
Midpoint of Class	3-Axle	2-S2	3-S1	3-S2	3-S3	3-S1-2	3-2	Misc.
26	1.3	1.3	1.1	3.4	0.0	1.0	0.0	0.0
27	1.6	1.2	0.6	2.9	0.0	0.7	3.8	0.0
28	1.1	0.9	1.1	2.5	0.0	1.0	5.7	3.9
29	1.1	0.7	0.0	2.0	0.0	0.2	1.9	2.0
30	1.1	0.6	0.0	1.5	3.9	0.0	0.0	0.0
31	1.1	0.4	0.0	1.2	0.0	0.2	0.0	0.0
32	0.6	0.3	0.6	0.7	0.0	0.2	1.9	0.0
33	0.6	0.2	0.0	0.4	0.0	0.0	0.0	0.0
34	0.5	0.2	0.6	0.3	0.0	0.0	0.0	0.0
35	0.4	0.1	0.0	0.2	1.0	0.0	0.0	0.0
36	0.3	0.1	0.0	0.1	0.0	0.0	0.0	2.0
37	0.3	*	0.0	0.1	0.0	0.0	1.9	0.0
38	0.1	*	0.0	*	0.0	0.0	0.0	0.0
39	0.2	*	0.0	0.1	0.0	0.0	1.9	0.0
40	0.0	*	0.0	*	0.0	0.0	1.9	0.0
41	0.1	0.0	0.0	*	0.0	0.0	0.0	0.0
42	0.0	*	0.0	*	0.0	0.0	0.0	0.0
43	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0
44	*	0.0	0.0	*	0.0	0.0	0.0	0.0
45	0.0	0.0	0.0	*	0.0	0.0	0.0	0.0
Total[1]	49.5	33.4	33.5	66.3	26.4	34.4	39.9	23.7

*Less than 0.05 percent.

[1]See Footnote 1 at bottom of Table 3.

APPENDIX A

Table 7

Percentage Distributions of Single Axles for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Two Urban Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Single Axles by Vehicle Type												
	Single-Unit		Multi-Unit										
	2-Axle 6-Tire	3-Axle	2-S1	2-S2	3-S1	3-S2	3-S3	2-S1-2	3-S1-2	2-1	2-2	3-2	Misc.
1	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7	0.0	0.0
2	1.9	0.0	0.8	0.2	0.0	0.0	0.0	0.0	0.0	16.0	13.0	0.0	0.0
3	13.7	1.1	2.9	0.8	0.0	0.4	0.0	0.0	0.0	16.0	26.1	0.0	0.0
4	21.7	3.4	8.8	4.0	0.0	1.7	0.0	0.0	0.0	20.0	17.4	0.0	0.0
5	18.8	4.9	14.5	6.5	0.0	2.5	0.0	4.0	3.3	8.0	8.7	0.0	0.0
6	14.7	6.9	12.5	9.5	16.7	2.6	0.0	4.0	13.3	16.0	4.3	0.0	0.0
7	9.9	8.3	11.5	11.0	16.7	5.1	0.0	8.0	10.0	0.0	8.7	0.0	0.0
8	5.8	10.1	10.5	9.1	16.7	8.4	0.0	8.0	10.0	8.0	0.0	16.7	0.0
9	3.4	7.2	9.5	7.0	0.0	6.2	25.0	16.0	6.7	0.0	4.3	16.7	0.0
10	2.3	3.5	6.3	2.3	0.0	5.0	25.0	4.0	3.3	8.0	4.3	0.0	0.0
11	1.6	1.6	4.3	2.5	0.0	1.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0
12	1.5	1.9	3.7	2.1	0.0	0.4	0.0	12.0	3.3	0.0	0.0	0.0	0.0
13	1.4	0.7	3.3	1.2	0.0	0.0	0.0	4.0	10.0	4.0	4.3	0.0	0.0
14	0.8	0.2	2.5	1.5	0.0	0.0	0.0	16.0	3.3	0.0	0.0	0.0	0.0
15	0.7	0.4	2.4	0.9	0.0	0.0	0.0	8.0	3.3	0.0	0.0	0.0	0.0
16	0.5	0.0	2.1	1.6	16.7	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
17	0.3	0.4	1.1	1.2	0.0	0.0	0.0	8.0	3.3	0.0	0.0	0.0	0.0
18	0.4	0.0	1.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.2	0.0	0.3	1.6	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.1	0.0	0.9	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	*	0.0	0.8	0.5	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0
22	0.1	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	*	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.1	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
25	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX A

Table 7 (Continued)

Percentage Distributions of Single Axles for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Two Urban Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Single Axles by Vehicle Type												
	Single-Unit		Multi-Unit										
	2-Axle 6-Tire	3-Axle	2-S1	2-S2	3-S1	3-S2	3-S3	2-S1-2	3-S1-2	2-1	2-2	3-2	Misc.
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total[1]	99.8	50.6	99.9	66.5	66.8	33.3	75.0	100.0	79.8	96.0	99.8	33.4	00.0

*Less than 0.05 percent.

[1]See Footnote 1 at the bottom of Table 3.

APPENDIX A

Table 8

Percentage Distributions of Tandem Axles for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Two Urban Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Tandem Axles by Vehicle Type							
	Single-Unit	Multi-Unit						
	3-Axle	2-S2	3-S1	3-S2	3-S3	3-S1-2	3-2	Misc.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
5	0.2	0.1	0.0	0.3	0.0	0.0	0.0	0.0
6	0.5	0.7	0.0	0.2	0.0	0.0	0.0	0.0
7	2.1	0.5	0.0	1.4	0.0	0.0	0.0	0.0
8	5.8	1.3	0.0	2.2	0.0	0.0	0.0	0.0
9	4.2	2.8	0.0	2.7	0.0	3.3	0.0	0.0
10	2.5	3.4	0.0	3.6	0.0	0.0	0.0	0.0
11	2.8	3.0	0.0	4.0	0.0	0.0	0.0	0.0
12	1.6	3.6	0.0	5.5	0.0	0.0	0.0	0.0
13	2.7	2.8	16.7	6.1	0.0	0.0	0.0	0.0
14	4.4	2.0	0.0	3.9	0.0	3.9	0.0	0.0
15	3.4	0.9	0.0	3.4	0.0	0.0	0.0	0.0
16	2.8	1.2	0.0	1.8	0.0	0.0	0.0	0.0
17	1.8	0.5	0.0	1.0	25.0	0.0	0.0	0.0
18	1.8	0.8	0.0	1.0	0.0	6.7	0.0	0.0
19	1.8	0.7	0.0	1.8	0.0	3.3	0.0	0.0
20	0.9	0.9	0.0	1.6	0.0	0.0	0.0	0.0
21	0.2	0.7	0.0	1.6	0.0	3.3	16.7	0.0
22	0.5	0.5	0.0	1.6	0.0	0.0	16.7	0.0
23	0.9	0.1	0.0	1.8	0.0	0.0	0.0	0.0
24	0.5	1.5	16.7	1.5	0.0	0.0	0.0	0.0
25	0.5	0.6	0.0	1.2	0.0	0.0	0.0	0.0

APPENDIX A

Table 8 (Continued)

Percentage Distributions of Tandem Axles for Frequency Set 5 Based on the Number of Axles in Each Kip Class as Generated by Each Type of Texas Cargo Vehicle Weighed at Two Urban Loadometer Stations During 1964-68

Axle Weight in Kips at Midpoint of Class	Percent of Tandem Axles by Vehicle Type							
	Single-Unit	Multi-Unit						
	3-Axle	2-S2	3-S1	3-S2	3-S3	3-S1-2	3-2	Misc.
26	0.7	0.7	0.0	2.5	0.0	0.0	0.0	0.0
27	0.4	0.6	0.0	1.6	0.0	0.0	0.0	0.0
28	1.2	0.5	0.0	1.3	0.0	0.0	16.7	0.0
29	0.2	0.5	0.0	1.5	0.0	0.0	16.7	0.0
30	0.2	0.2	0.0	1.7	0.0	0.0	0.0	0.0
31	0.5	5.0	0.0	1.0	0.0	0.0	0.0	0.0
32	0.5	0.5	0.0	2.1	0.0	0.0	0.0	0.0
33	0.4	0.4	0.0	1.0	0.0	0.0	0.0	0.0
34	0.7	0.4	0.0	1.2	0.0	0.0	0.0	0.0
35	0.2	0.0	0.0	0.8	0.0	0.0	0.0	0.0
36	0.2	0.4	0.0	0.8	0.0	0.0	0.0	0.0
37	0.2	0.0	0.0	0.4	0.0	0.0	0.0	0.0
38	0.2	0.1	0.0	0.2	0.0	0.0	0.0	0.0
39	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0
40	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0
41	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0
44	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total[1]	49.4	38.0	33.4	65.0	25.0	20.5	66.8	00.0

*Less than 0.05 percent.

[1]See Footnote 1 at the bottom of Table 3.

Table 9

Number of Texas Cargo Vehicles Weighed at 21 Loadometer Stations
in 1967, by Station and Vehicle Type

Station	Number of Vehicles by Vehicle Type						
	2-Axle 6-Tires	3-Axle Single Unit	3-Axle 2-S1	4-Axle 2-S2	5-Axle 3-S2	4-6 Axles Other[1]	All Vehicles Types
Interstate Final, Rural							
Station 20-1	209	30	101	190	798	42	1,370
20-3	152	43	113	248	738	35	1,329
30-1	257	29	88	237	733	18	1,362
45-2	196	41	168	271	1,253	67	1,996
Other Main Roads, Rural							
Station 7	98	13	36	46	156	14	363
16	262	50	40	138	356	18	864
20	190	27	51	99	541	49	957
42	112	12	18	79	132	4	357
72	328	37	90	190	549	39	1,233
81	126	17	51	96	322	15	627
88	156	33	30	57	139	7	422
10-1	65	9	14	46	196	5	335
10-2	174	58	67	163	575	25	1,062
145	243	57	57	171	459	19	1,006
147	91	13	23	46	145	12	330
149	49	5	35	56	313	28	486
20-2	382	34	136	238	1,023	56	1,869
35-1	480	94	195	232	779	52	1,832
37-1	132	54	61	100	353	26	726
Other Roads, Urban							
Station 3	212	36	54	33	65	7	407
4	220	24	11	24	18	7	304
Total							
All Stations	4,134	716	1,439	2,760	9,643	545	19,237

[1]Contains the following combinations: 2-1, 2-2, and 3-2 truck-trailer combinations; 3-S1 tractor-semitrailer combinations; and 2-S1-2 and 3-S1-2 tractor-semitrailer-trailer combinations.

APPENDIX A

Table 10

Number and Percentage Distribution of Texas Cargo Vehicles Weighed at 21 Stations During 1964-68, 1966-68 and 1967 by Vehicle Type

Vehicle Type	Number of Vehicles 1964-68	Number of Vehicles 1966-68	Number of Vehicles 1967	Percent of Vehicles 1964-68	Percent of Vehicles 1966-68	Percent of Vehicles 1967
Single-Unit						
2-Axle 6-Tire	21,823	10,542	4,134	22.11	21.84	21.49
3-Axle	3,328	1,781	716	3.37	3.69	3.73
Multi-Unit						
2-S1	8,449	3,739	1,439	8.56	7.75	7.49
2-S2	18,207	7,506	2,760	18.45	15.56	14.35
3-S1	244	196	62	0.25	.40	0.32
3-S2	45,662	23,538	9,643	46.27	48.77	50.13
3-S3	59	59	23	0.06	.12	0.11
2-S1-2	276	264	126	0.28	.55	0.66
3-S1-2	236	231	103	0.24	.48	0.54
2-1	182	182	100	0.18	.37	0.52
2-2	152	151	86	0.15	.31	0.45
3-2	52	47	25	0.05	.09	0.12
Miscellaneous	34	34	19	0.03	.07	0.09
All Vehicle Types						
Total	98,704	48,270	19,237	100.00	100.00	100.00

[1]Contains 2-S3, 3-1, 2-3 and 3-3 multi-units.

Appendix A

Table 11

Number and Percentage Distribution of Texas Cargo Vehicles Weighed at 21 Loadometer Stations in 1967, by Body and Vehicle Type

Body Type	Vehicle Type									
	3-S2		2-S2		2-S1		All Others[1]		All Vehicles	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Vans and Panels	2,710	28.1	795	28.8	846	58.8	1,345	25.0	5,696	29.6
Platform, Lumber, and Stakes	1,425	14.8	778	28.2	148	10.3	740	13.7	3,091	16.1
Open Tops	1,688	17.5	417	15.2	90	6.2	681	12.6	2,876	14.9
Insulated Vans	1,578	16.3	192	6.9	54	3.8	644	12.0	2,468	12.8
Tank Trucks	1,583	16.4	206	7.4	64	4.4	379	7.0	2,232	11.6
Cattle and Racks	546	5.7	248	9.0	67	4.7	961	17.8	1,822	9.5
Automobile Transports	38	.4	64	2.3	158	11.0	50	.9	310	1.6
Bare Chassis and Miscellaneous	75	.8	60	2.2	12	.8	595	11.0	742	3.9
Totals										
All Vehicles	9,643	100.0	2,760	100.0	1,439	100.0	5,395	100.0	19,237	100.0

1 Contains the following vehicle types: 2-1, 2-2, and 3-2 truck-trailer combinations; 3-S1 tractor - semitrailer combination; and 2-S1-2 and 3-S1-2 tractor - semitrailer-trailer combinations.

APPENDIX A

Table 12

Number of Stations, Percentages of Loaded Vehicles, and Range of Station Percentages Involving Various Combinations of Vehicle and Body Types of Vehicles Weighed at Loadometer Stations, 1964-68

Body Type	Vehicle Type: 2-Axle 6-Tires	3-Axle Single Unit	2-S1	2-S2	3-S2	2-Bottom	Miscel-laneous	All Vehicle Types
Vans and Panels								
Number of Stations	21	21	21	21	21	17	15	21
Percentage of Loaded Vehicles	73	64	72	73	80	90	70	76
Range of Station Percentages	20	67	14	19	25	18	60	13
Oil and Platform								
Number of Stations	21	21	21	21	21	2	19	21
Percentage of Loaded Vehicles	54	53	58	59	59	53	58	58
Range of Station Percentages	21	59	40	15	24	75	73	18
Open Top								
Number of Stations	21	21	20	21	21	*	14	21
Percentage of Loaded Vehicles	54	56	53	56	61	*	71	58
Range of Station Percentage	27	73	65	44	30	*	67	21
Tank								
Number of Stations	21	20	16	21	21	*	7	21
Percentage of Loaded Vehicles	60	47	55	53	56	*	50	56
Range of Station Percentages	32	45	84	40	28	*	75	29
Cattle and Racks								
Number of Stations	21	21	21	20	21	4	14	21
Percentage of Loaded Vehicles	70	59	58	58	60	*	58	64
Range of Station Percentages	29	71	42	37	30	*	53	15
All Body Types								
Number of Stations	21	21	21	21	21	18	21	21
Percentage of Loaded Vehicles	64	50	65	62	68	87	60	65
Range of Station Percentages	15	35	17	16	29	27	62	14

*No data or less than two vehicles for each station.

APPENDIX A

Table 13

Percentage Distribution of Loaded Vehicles With Various Combinations of Vehicle and Body Types Weighed at Each of 21 Loadometer Stations, 1964-68.

	Percentage of Loaded Vehicles by Loadometer Station																					
Vehicle Body and Axle Types	20-1	20-3	30-1	45-2	7	16	20	42	72	81	88	10-1	10-2	145	147	149	20-2	35-1	37-1	3	4	Sum
Single Unit Vans and Panels	73	72	66	71	86	78	77	74	73	71	76	69	70	74	85	74	75	67	66	67	70	72
Combination Vans and Panels	80	82	80	81	66	73	79	74	79	75	76	83	75	78	77	75	76	71	76	71	73	77
2-S1	80	74	74	70	70	74	71	70	74	68	69	66	72	76	78	67	74	69	76	70	66	72
2-S2	79	75	73	73	65	76	74	74	68	66	72	79	72	77	78	67	78	69	67	60	78	73
3-S2	79	88	83	87	63	72	81	76	82	82	80	87	77	78	76	76	76	73	78	75	88	80
Oil and Platform	59	63	59	60	59	57	57	55	59	61	55	57	58	54	58	57	56	61	55	49	45	58
2-S1	54	61	55	58	54	58	53	70	60	78	56	59	38	56	67	63	64	60	56	70	47	58
2-S2	64	61	63	58	61	58	58	51	64	60	54	65	62	50	52	57	56	63	62	58	51	59
3-S2	60	65	59	62	61	54	63	55	58	64	56	56	56	57	65	57	58	60	50	57	41	59
Open Top	63	61	57	56	63	58	59	57	60	63	56	61	57	53	64	66	57	53	59	45	46	58
2-S1	58	25	67	55	61	45	7	51	62	52	60	71	42	71	64	1	89	56	44	49	60	53
2-S2	61	47	49	55	61	53	62	55	54	67	60	62	50	52	38	65	57	54	57	40	82	56
3-S2	65	75	67	56	62	61	60	61	66	63	55	59	61	48	69	67	58	60	57	46	50	61
Tank	58	58	56	56	56	58	57	70	55	59	52	52	51	60	52	60	54	52	53	46	41	56
2-S2	58	57	52	52	51	56	56	73	46	61	41	35	43	61	52	42	50	56	51	50	33	53
3-S2	58	58	57	57	60	59	61	67	55	57	49	53	64	59	49	63	53	51	52	39	53	56
Cattle and Rack	67	68	66	66	62	66	64	66	53	67	61	65	61	65	63	60	63	72	56	58	56	64
All Body and Vehicle Types	69	70	66	66	63	63	66	66	64	66	61	67	64	63	70	66	66	64	59	56	56	65
2-S1	72	65	62	64	59	65	62	67	63	65	62	62	64	70	76	69	70	64	68	63	61	65
2-S2	67	63	63	62	58	62	62	62	62	65	57	66	62	57	59	60	63	61	58	52	59	62
3-S2	72	77	72	67	61	61	68	69	69	66	63	72	66	63	74	67	68	66	59	63	49	68

[1] This cell had only one loaded vehicle.

Appendix A

Table 14

Number and Percentage Distribution of Texas Cargo Vehicles Weighed at 21 Loadometer Stations in 1967, by Station and Across Body Type

Body Type	Loadometer Station																				
	20-1	20-3	30-1	45-2	7	16	20	42	72	81	88	10-1	10-2	145	147	149	20-2	35-1	37-1	3	4
Vans and Panels																					
Single Units																					
Number of Vehicles	85	87	100	93	37	125	80	35	106	61	61	16	89	101	34	16	141	228	63	94	79
Percent of Vehicles	6.2	6.6	7.4	4.6	1.0	14.5	8.4	9.8	8.6	9.7	14.5	4.8	8.4	10.0	10.3	3.3	7.5	12.5	8.7	23.1	26.0
Combinations																					
Number of Vehicles	568	644	538	740	108	156	281	110	338	140	60	98	392	255	97	193	613	790	243	60	9
Percent of Vehicles	41.5	48.5	39.5	37.1	3.0	18.1	29.4	30.8	27.4	22.3	14.2	29.2	36.9	25.4	29.4	39.7	32.8	43.1	33.5	14.7	3.0
Platform, Lumber and Stakes																					
Number of Vehicles	226	223	202	313	48	117	141	73	332	128	98	76	181	206	29	69	267	196	69	32	65
Percent of Vehicles	16.5	16.8	14.8	15.7	1.3	13.5	14.7	20.5	26.9	20.4	23.2	22.7	17.1	20.5	8.8	14.2	14.3	10.7	9.5	7.9	21.4
Open Tops																					
Number of Vehicles	183	136	138	467	51	155	205	44	75	143	71	70	97	99	21	77	434	171	126	81	32
Percent of Vehicles	13.3	10.2	10.1	23.4	1.4	17.9	21.4	12.3	6.1	22.8	16.8	20.9	9.1	9.8	6.4	15.9	23.2	9.3	17.3	19.9	10.5
Tank Trucks																					
Number of Vehicles	129	87	224	193	28	172	100	31	151	89	56	33	163	158	51	42	185	138	143	48	11
Percent of Vehicles	9.4	6.6	16.5	9.7	7.7	19.9	10.4	8.7	12.2	14.2	13.3	9.9	15.4	15.7	15.4	8.6	9.9	7.5	19.7	11.8	3.6
Cattle and Racks																					
Number of Vehicles	120	103	94	105	58	101	103	41	116	44	36	36	103	111	68	75	134	196	60	49	69
Percent of Vehicles	8.8	7.6	6.9	5.3	16.0	11.7	10.8	11.5	9.4	7.0	8.5	10.7	9.7	11.0	20.6	15.4	7.2	10.7	8.3	12.0	22.7
Auto Transports																					
Number of Vehicles	18	18	32	51	10	4	7	0	30	6	2	0	9	11	3	4	32	61	10	2	0
Percent of Vehicles	1.3	1.4	2.3	2.5	2.8	0.5	0.7	0.0	2.5	1.0	0.5	0.0	0.8	1.1	0.9	0.8	1.7	3.3	1.4	0.5	0.0
Miscellaneous																					
Number of Vehicles	41	31	34	34	23	34	40	23	85	16	38	6	28	65	27	10	63	52	12	41	39
Percent of Vehicles	3.0	2.3	2.5	1.7	6.3	3.9	4.2	6.4	6.9	2.6	9.0	1.8	2.6	6.5	8.2	2.1	3.4	2.9	1.6	10.1	12.8
All Body Types																					
Number of Vehicles	1370	1329	1362	1996	363	864	957	357	1233	627	422	335	1062	1006	330	486	1869	1832	726	407	304
Percent of Vehicles	100.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	100.0

Appendix A

Table 15

Number and Percentage Distribution of Texas Cargo Vehicles Weighed at 21 Loadometer Stations in 1967, by Station and Across Fuel Type and Time of Day

Vehicle Characteristic	Loadometer Station																				
	20-1	20-3	30-1	45-2	7	16	20	42	72	81	88	10-1	10-2	145	147	149	20-2	35-1	37-1	3	4
Fuel Type																					
Diesel																					
Number of Vehicles	914	926	862	1302	172	411	618	186	565	315	141	196	635	483	170	345	1198	937	351	83	20
Percent of Vehicles	66.7	69.7	63.3	65.2	47.4	47.6	64.6	52.1	45.8	50.3	33.4	58.5	59.8	48.0	51.5	71.0	64.1	51.1	48.3	20.4	6.6
Gasoline, Butane, etc.																					
Number of Vehicles	456	403	500	694	191	453	339	171	668	312	281	139	427	523	160	141	671	895	375	324	284
Percent of Vehicles	33.3	30.3	36.7	34.8	52.6	52.4	35.4	47.9	54.2	49.7	66.6	41.5	40.2	52.0	48.5	29.0	35.9	48.9	51.7	79.6	93.4
Time of Day																					
Night (6 p.m. to 6 a.m.)																					
Number of Vehicles	541	546	553	787	137	170	389	97	295	184	85	142	362	454	105	212	557	656	305	59	31
Percent of Vehicles	39.4	41.1	40.6	39.4	37.7	19.7	40.6	27.2	23.9	29.3	20.1	42.4	34.1	45.1	31.8	43.6	29.8	35.8	42.0	14.5	10.2
Day (6 a.m. to 6 p.m.)																					
Number of Vehicles	829	783	809	1209	226	694	568	260	938	443	337	193	700	552	225	274	1312	1176	421	348	273
Percent of Vehicles	60.6	58.9	59.3	60.6	62.3	80.3	59.4	72.8	76.1	70.6	79.9	57.6	65.9	54.9	68.2	56.4	70.2	64.2	58.0	85.5	89.8
Degree of Load																					
Loaded																					
Number of Vehicles	956	944	926	1356	235	497	600	239	716	387	234	215	678	585	230	309	1183	1119	459	231	168
Percent of Vehicles	69.8	71.0	68.0	67.9	64.7	57.5	62.7	66.9	58.1	61.7	55.5	64.2	63.8	58.2	70.0	63.6	63.3	61.1	63.2	56.8	55.3
Empty																					
Number of Vehicles	414	385	436	640	128	367	357	118	517	240	188	120	384	421	100	177	686	713	267	176	136
Percent of Vehicles	30.2	29.0	32.0	32.1	35.3	42.5	37.3	33.1	41.9	38.3	45.5	35.8	36.2	41.8	30.0	36.4	36.7	38.9	36.8	43.2	44.7
All Vehicles of Each Characteristic																					
Number of Vehicles	1370	1329	1362	1996	363	864	957	357	1233	627	422	335	1062	1006	330	486	1869	1832	726	407	304
Percent of Vehicles	100.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	100.0

Appendix A

Table 16

Number and Percentage Distribution of Texas Cargo Vehicles Weighed at 21 Loadometer Stations in 1967, by Station and Across Weekdays

Week Day	Loadometer Station																				
	20-1	20-3	30-1	45-2	7	16	20	42	72	81	88	10-1	10-2	145	147	149	20-2	35-1	37-1	3	4
Monday																					
Number of Vehicles	0	592	149	0	104	143	135	23	113	0	81	67	168	158	108	181	404	676	84	41	176
Percent of Vehicles	0.0	44.6	11.0	0.0	28.6	16.5	14.1	6.4	9.2	0.0	19.1	20.0	15.8	15.7	32.7	37.2	21.6	36.9	11.6	10.1	57.9
Tuesday																					
Number of Vehicles	355	206	176	986	115	0	312	80	0	150	30	140	257	413	47	141	302	217	199	0	120
Percent of Vehicles	25.9	15.5	12.9	49.4	31.7	0.0	32.6	22.4	0.0	24.0	7.1	41.8	24.2	41.1	14.2	29.0	16.2	11.8	27.4	0.0	39.5
Wednesday																					
Number of Vehicles	252	161	390	0	98	175	253	0	213	177	0	63	424	161	0	0	743	705	183	0	8
Percent of Vehicles	18.4	12.1	28.6	0.0	27.0	20.3	26.4	0.0	17.3	28.2	0.0	18.8	39.9	16.0	0.0	0.0	39.7	38.5	25.2	0.0	2.6
Thursday																					
Number of Vehicles	548	370	0	549	46	180	0	207	454	259	125	0	138	137	88	120	420	234	187	247	0
Percent of Vehicles	40.0	27.8	0.0	27.5	12.7	20.8	0.0	58.0	36.8	41.3	29.6	0.0	13.0	13.6	26.7	24.7	22.5	12.8	25.7	60.7	0.0
Friday																					
Number of Vehicles	215	0	647	461	0	366	257	47	453	41	186	65	75	137	87	44	0	0	73	119	0
Percent of Vehicles	15.7	0.0	47.5	23.1	0.0	42.4	26.9	13.2	36.7	6.5	44.1	19.4	7.1	13.6	26.4	9.1	0.0	0.0	10.1	29.2	0.0
All Week Days																					
Number of Vehicles	1370	1329	1362	1996	363	864	957	357	1233	627	422	335	1062	1006	330	486	1869	1832	726	407	304
Percent of Vehicles	100.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	100.0

Appendix A

Table 17

Number and Average 18-Kip Axle Equivalents Generated by Texas Cargo Vehicles Weighed at 21 Loadometer Stations in 1967, by Station and Body Type

Body Type	Loadometer Station																				
	20-1	20-3	30-1	45-2	7	16	20	42	72	81	88	10-1	10-2	145	147	149	20-2	35-1	37-1	3	4
Vans and Panels																					
Single Units																					
Number of 18-Kip Equivalents	13	17	12	15	8	18	13	3	15	5	14	5	17	11	5	1	23	43	13	5	5
Average of 18-Kip Equivalents	0.15	0.20	0.12	0.16	0.21	0.15	0.16	0.07	0.14	0.08	0.23	0.30	0.19	0.11	0.14	0.09	0.17	0.19	0.21	0.05	0.07
Combinations																					
Number of 18-Kip Equivalents	355	392	260	450	31	49	138	57	154	67	26	49	225	92	49	77	297	433	103	23	3
Average of 18-Kip Equivalents	0.63	0.61	0.48	0.61	0.28	0.31	0.49	-.52	0.45	0.48	0.44	0.50	0.57	0.36	0.51	0.40	0.49	0.55	0.43	0.38	0.32
Platform, Lumber and Stakes																					
Number of 18-Kip Equivalents	109	124	79	220	33	41	47	30	167	71	53	26	82	89	28	30	99	95	27	8	7
Average of 18-Kip Equivalents	0.48	0.56	0.39	0.70	0.69	0.35	0.33	0.41	0.50	0.55	0.54	0.34	0.45	0.43	0.95	0.43	0.37	0.48	0.39	0.25	0.11
Open Tops																					
Number of 18-Kip Equivalents	128	76	82	341	21	65	141	25	24	156	39	35	58	39	18	44	334	116	70	31	16
Average of 18-Kip Equivalents	0.70	0.56	0.59	0.73	0.40	0.42	0.69	0.57	0.32	1.09	0.54	0.51	0.60	0.39	0.84	0.58	0.77	0.68	0.55	0.39	0.51
Tank Trucks																					
Number of 18-Kip Equivalents	73	57	147	128	11	71	36	7	64	52	30	11	72	80	26	21	94	73	79	21	3
Average of 18-Kip Equivalents	0.57	0.66	0.66	0.67	0.40	0.41	0.36	0.21	0.43	0.59	0.54	0.34	0.44	0.51	0.51	0.49	0.51	0.53	0.55	0.44	0.31
Cattle and Racks																					
Number of 18-Kip Equivalents	41	58	32	45	17	30	45	17	33	17	10	14	39	32	32	35	44	74	18	5	11
Average of 18-Kip Equivalents	0.34	0.56	0.34	0.42	0.29	0.30	0.44	0.42	0.28	0.38	0.28	0.40	0.38	0.29	0.47	0.46	0.33	0.38	0.29	0.11	0.15
Auto Transports																					
Number of 18-Kip Equivalents	9	18	14	23	4	2	1	0	11	5	1	0	4	3	1	3	28	16	11	1	0
Average of 18-Kip Equivalents	0.49	0.98	0.43	0.45	0.45	0.48	0.21	0.00	0.35	0.80	0.41	0.00	0.49	0.29	0.49	0.75	0.88	0.27	1.05	0.66	0.00
Miscellaneous																					
Number of 18-Kip Equivalents	13	7	12	10	2	6	18	7	58	4	12	1	5	27	9	1	15	2	4	1	5
Average of 18-Kip Equivalents	0.31	0.22	0.36	0.30	0.09	0.17	0.46	0.30	0.69	0.22	0.33	0.12	0.17	0.41	0.34	0.14	0.23	0.04	0.36	0.03	0.14
All Body Types																					
Number of 18-Kip Equivalents	741	749	638	1232	127	282	439	146	526	377	186	141	502	373	168	212	934	852	325	97	50
Average of 18-Kip Equivalents	0.54	0.56	0.47	0.62	0.35	0.33	0.46	0.41	0.43	0.60	0.44	0.42	0.47	0.37	0.51	0.44	0.50	0.47	0.45	0.24	0.17

Appendix A

Table 18

Average Vehicle 18-Kip and Log-Kip Axle Equivalents Generated by Texas Cargo Vehicles Weighed at 21 Loadometer Stations in 1967, by Vehicle Type

Vehicle Type	Number of Vehicles	Average Vehicle 18 Kip Equivalents	Average Vehicle Log Kip Equivalents[1]
Single Units			
2-Axle, 6-Tire	4,134	0.1749	-1.4118
3-Axle	716	0.3025	-1.0371
Tractor-Semitrailer Combinations			
3-Axle (2-S1)	1,439	0.4462	-0.6672
4-Axle (2-S2)	2,760	0.5363	-0.6608
4-Axle (3-S1)	62	0.5061	-0.6020
5-Axle (3-S2)	9,643	0.5855	-0.5279
Tractor-Semitrailer-Trailer Combinations			
5-Axle (2-S1-2)	126	1.0042	-0.2632
6-Axle (3-S1-2)	103	0.7327	-0.2488
Truck-Trailer Combinations			
3-Axle (2-1)	100	0.3139	-1.5046
4-Axle (2-2)	86	0.2460	-1.2983
5-Axle (3-2)	25	1.1778	-0.1829
Totals			
All Single Units	4,850	0.1937	-1.3565
All Combinations	14,387	0,5670	-0.5737
All Single Units and Combinations	19,237	0.4729	-0.7711

[1]The log kip equivalents for each vehicle are derived by taking the logarithm (to the base 10) fo the total 18 kip (axle) equivalents computed for that vehicle.

APPENDIX A

Table 19

Average and Standard Deviation from the Average of Log-Kip Axle Equivalents Per Vehicle for Cargo Vehicles Weighed at Each of 21 Loadometer Stations in 1967 by Major Vehicle Type

Loadometer Station by Highway System	18-Kip Axle Equivalents Per Vehicle by Vehicle Type											
	2-Axle 6-Tire		3-Axle Single-Unit		2-S1 Multi-Unit		2-S2 Multi-Unit		3-S2 Multi-Unit		All Axle Types[1]	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Interstate Rural												
10-1	-1.343	0.874	-1.354	0.801	-0.913	0.494	-0.754	0.702	-0.560	0.556	-0.773	0.726
10-2	-1.381	0.755	-0.973	0.616	-0.602	0.535	-0.610	0.538	-0.527	0.565	-0.710	0.681
20-1	-1.217	0.726	-1.037	0.712	-0.584	0.491	-0.569	0.583	-0.425	0.545	-0.591	0.648
20-2	-1.386	0.809	-1.316	0.676	-0.595	0.528	-0.689	0.647	-0.534	0.589	-0.748	0.738
20-3	-1.278	0.768	-1.093	0.739	-0.564	0.544	-0.604	0.634	-0.415	0.515	-0.591	0.652
30-1	-1.276	0.774	-0.816	0.686	-0.662	0.635	-0.641	0.682	-0.512	0.524	-0.699	0.685
35-1	-1.370	0.589	-0.818	0.723	-0.624	0.554	-0.513	0.603	-0.547	0.555	-0.783	0.732
37-1	-1.347	0.815	-1.101	0.920	-0.568	0.625	-0.681	0.659	-0.589	0.602	-0.789	0.754
45-2	-1.367	0.728	-0.693	0.603	-0.637	0.483	-0.618	0.611	-0.419	0.568	-0.563	0.655
Other Rural												
7	-1.377	0.831	-1.002	0.735	-0.821	0.554	-0.725	0.543	-0.701	0.583	-0.910	0.713
16	-1.417	0.833	-1.399	0.670	-0.864	0.519	-0.692	0.666	-0.687	0.575	-0.974	0.765
20	-1.367	0.792	-0.690	0.614	-0.881	0.551	-0.749	0.728	-0.545	0.575	-0.754	0.722
42	-1.447	0.714	-1.136	0.507	-0.671	0.496	-0.666	0.705	-0.507	0.559	-0.883	0.769
72	-1.513	0.969	-1.385	0.776	-0.913	0.729	-0.838	0.737	-0.675	0.569	-0.981	0.838
81	-1.513	0.702	-0.696	0.432	-0.594	0.536	-0.579	0.732	-0.481	0.665	-0.726	0.781
88	-1.322	0.805	-0.952	0.932	-0.701	0.702	-0.816	0.695	-0.661	0.656	-0.949	0.801
145	-1.450	0.743	-1.091	0.853	-0.682	0.511	-0.734	0.664	-0.663	0.574	-0.891	0.734
147	-1.268	0.666	-1.058	0.555	-0.441	0.443	-0.641	0.628	-0.411	0.589	-0.717	0.711
149	-1.518	0.691	-1.486	0.690	-0.589	0.498	-0.776	0.683	-0.606	0.575	-0.716	0.662
Urban												
3	-1.734	0.641	-1.366	0.544	-0.790	0.742	-0.707	0.691	-0.698	0.646	-1.316	0.807
4	-1.675	0.753	-0.853	0.913	-1.356	0.330	-0.928	0.609	-1.101	0.576	-1.494	0.792
All Stations	-1.412	0.791	-1.037	0.755	-0.667	0.572	-0.661	0.654	-0.528	0.575	-0.771	0.742

[1]Includes miscellaneous vehicle types.

APPENDIX A

Table 20

Average and Standard Deviation from the Average of 18-Kip Axle Equivalents Per Vehicle for Cargo Vehicles Weighed at Each of 21 Loadometer Stations in 1967 by Major Vehicle Type

Loadometer Station by Highway System	18-Kip Axle Equivalents Per Vehicle by Vehicle Type									
	2-Axle 6-Tire		3-Axle Single-Unit		2-S1 Multi-Unit		2-S2 Multi-Unit		3-S2 Multi-Unit	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Interstate Rural										
10-1	0.254	0.500	0.146	0.202	0.219	0.246	0.441	0.447	0.489	0.388
10-2	0.142	0.221	0.281	0.595	0.506	0.636	0.468	0.514	0.576	0.537
20-1	0.191	0.327	0.304	0.554	0.440	0.413	0.507	0.453	0.650	0.512
20-2	0.185	0.346	0.159	0.297	0.473	0.493	0.505	0.669	0.614	0.659
20-3	0.183	0.303	0.245	0.323	0.498	0.486	0.600	0.814	0.660	0.689
30-1	0.189	0.288	0.396	0.507	0.523	0.670	0.557	0.618	0.535	0.454
35-1	0.157	0.273	0.432	0.553	0.492	0.643	0.646	0.703	0.575	0.610
37-1	0.176	0.280	0.279	0.285	0.585	0.646	0.530	0.687	0.530	0.498
45-2	0.150	0.263	0.388	0.361	0.396	0.405	0.549	0.849	0.722	0.718
Other Rural										
7	0.153	0.261	0.273	0.340	0.350	0.551	0.438	0.874	0.454	0.718
16	0.161	0.274	0.173	0.491	0.258	0.300	0.511	0.579	0.417	0.448
20	0.171	0.323	0.470	0.618	0.246	0.271	0.513	0.696	0.560	0.625
42	0.127	0.270	0.119	0.117	0.373	0.374	0.613	0.785	0.566	0.492
72	0.390	1.001	0.165	0.257	0.363	0.481	0.528	1.196	0.403	0.377
81	0.094	0.159	0.305	0.284	0.477	0.541	0.682	0.708	0.812	0.972
88	0.234	0.480	0.462	0.603	0.653	1.095	0.474	0.648	0.543	0.638
145	0.132	0.231	0.304	0.399	0.378	0.431	0.468	0.556	0.440	0.442
147	0.143	0.246	0.188	0.238	0.546	0.442	0.513	0.565	0.754	1.228
149	0.106	0.193	0.090	0.145	0.441	0.458	0.443	0.541	0.476	0.452
Urban										
3	0.063	0.187	0.088	0.117	0.507	0.751	0.521	0.674	0.513	0.691
4	0.104	0.280	0.609	0.837	0.057	0.042	0.272	0.377	0.244	0.614
All Stations	0.175	0.404	0.303	0.472	0.446	0.547	0.536	0.721	0.586	0.621

Appendix A

Table 21

Average Vehicle 18-Kip and Log-Kip Axle Equivalents Generated by Texas Cargo Vehicles Weighed at 21 Loadometer Stations in 1967, by Vehicle and Body Type

Body Type	Vehicle Type: Average 18-Kip Equivalents					Vehicle Type: Average Log Kip-Equivalents				
	3-S2	2-S2	2-S1	Others[1]	All Vehicles	3-S2	2-S2	2-S1	Others[1]	All Vehicles
Vans and Panels	0.4754	0.4652	0.3880	0.1120	0.4043	-0.5307	-0.5987	-0.6306	-1.2764	-0.7311
Platform, Lumber and Stakes	0.5284	0.5369	0.4192	0.3124	0.4736	-0.6305	-0.7054	-0.8796	-1.4395	-0.8549
Open Tops	0.7646	0.7359	0.7153	0.2898	0.6464	-0.5111	-0.6400	-0.7490	-1.3403	-0.7336
Insulated Vans	0.6440	0.5447	0.3409	0.2321	0.5222	-0.3906	-0.5662	-0.7157	-0.9989	-0.5701
Tank Trucks	0.5776	0.5277	0.7210	0.2359	0.5191	-0.5891	-0.7758	-0.5532	-1.0479	-0.6832
Cattle and Racks	0.5965	0.4336	0.4532	0.1915	0.3554	-0.4910	-0.6997	-0.8240	-1.4992	-1.0085
Automobile Transports	0.3111	0.4765	0.5455	0.5514	0.5035	-0.7169	-0.5951	-0.5667	-0.5616	-0.5902
Bare Chassis and Miscellaneous	0.6133	0.5762	0.5245	0.2240	0.2967	-0.6277	-0.8700	-0.8578	-1.4358	-1.2990
Totals All Vehicles	0.5855	0.5363	0.4462	0.2156	0.4729	-0.5279	-0.6608	-0.6672	-1.3269	-0.7711

1 Contains the following vehicle types: 2-1, 2-2 and 3-2 truck-trailer combinations; 3-S1 tractor - semitrailer combinations; and 2-S1-2 and 3-S1-2 tractor - semitrailer-trailer combinations.

Appendix A

Table 22

Number and Average 18-Kip Axle Equivalents Generated by Texas Cargo Vehicles Weighed at 21 Loadometer Stations in 1967, by Station and Weekdays

Week Day	Loadometer Station																				
	20-1	20-3	30-1	45-2	7	16	20	42	72	81	88	10-1	10-2	145	147	149	20-2	35-1	37-1	3	4
Monday																					
Number of 18-Kip Equivalents	0	271	52	0	37	48	32	15	55	0	26	22	64	47	62	70	252	268	26	14	35
Average of 18-Kip Equivalents	0.00	0.46	0.35	0.00	0.36	0.34	0.24	0.67	0.49	0.00	0.32	0.32	0.38	0.30	0.58	0.39	0.62	0.40	0.31	0.34	0.20
Tuesday																					
Number of 18-Kip Equivalents	210	131	124	533	48	0	149	35	0	81	18	52	128	150	20	66	158	72	86	0	14
Average of 18-Kip Equivalents	0.59	0.64	0.70	0.54	0.42	0.00	0.48	0.44	0.00	0.54	0.59	0.38	0.50	0.36	0.42	0.47	0.52	0.33	0.43	0.00	0.12
Wednesday																					
Number of 18-Kip Equivalents	129	118	212	0	33	71	121	0	160	94	0	31	209	52	0	0	343	322	82	0	1
Average of 18-Kip Equivalents	0.51	0.73	0.54	0.00	0.33	0.41	0.48	0.00	0.75	0.53	0.00	0.49	0.49	0.33	0.00	0.00	0.46	0.46	0.45	0.00	0.05
Thursday																					
Number of 18-Kip Equivalents	299	229	0	403	9	46	0	76	184	150	59	0	48	71	47	59	181	190	100	62	0
Average of 18-Kip Equivalents	0.54	0.62	0.00	0.73	0.20	0.25	0.00	0.37	0.41	0.58	0.48	0.00	0.35	0.51	0.53	0.49	0.43	0.81	0.53	0.25	0.00
Friday																					
Number of 18-Kip Equivalents	103	0	250	296	0	117	137	20	127	52	83	36	53	53	39	17	0	0	31	21	0
Average of 18-Kip Equivalents	0.48	0.00	0.39	0.64	0.00	0.32	0.53	0.41	0.28	1.26	0.44	0.55	0.71	0.39	0.45	0.38	0.00	0.00	0.43	0.18	0.00
All Week Days																					
Number of 18-Kip Equivalents	741	749	638	1232	127	282	439	146	526	377	186	141	502	373	168	212	934	852	325	97	50
Average of 18-Kip Equivalents	0.54	0.56	0.47	0.62	0.35	0.33	0.46	0.41	0.43	0.60	0.44	0.42	0.47	0.37	0.51	0.44	0.50	0.47	0.45	0.24	0.17

Appendix A

Table 23

Number and Average 18-Kip Axle Equivalents Generated by Texas Cargo Vehicles Weighed at 21 Loadometer Stations in 1967, by Station, Fuel Type, Time of Day, and Degree of Load

Vehicle Characteristic	Loadometer Station																				
	20-1	20-3	30-1	45-2	7	16	20	42	72	81	88	10-1	10-2	145	147	149	20-2	35-1	37-1	3	4
Fuel Type																					
Diesel																					
Number of 18-Kip Equivalents	588	608	451	955	77	181	349	102	249	258	83	103	364	218	117	171	732	565	188	37	4
Average of 18-Kip Equivalents	0.64	0.66	0.52	0.73	0.45	0.44	0.56	0.55	0.44	0.82	0.59	0.53	0.57	0.45	0.69	0.50	0.61	0.60	0.54	0.45	0.20
Gasoline, Butane, etc.																					
Number of 18-Kip Equivalents	153	141	187	277	50	101	90	44	277	119	103	38	138	155	51	41	202	287	137	60	46
Average of 18-Kip Equivalents	0.34	0.35	0.37	0.40	0.26	0.22	0.27	0.26	0.41	0.38	0.37	0.27	0.32	0.30	0.32	0.29	0.30	0.32	0.37	0.19	0.16
Time of Day																					
Night																					
Number of 18-Kip Equivalents	388	389	305	587	57	70	238	52	125	165	39	74	223	192	57	107	282	439	147	20	3
Average of 18-Kip Equivalents	0.62	0.71	0.55	0.75	0.41	0.41	0.61	0.54	0.42	0.90	0.46	0.52	0.62	0.42	0.54	0.50	0.51	0.67	0.48	0.34	0.10
Day																					
Number of 18-Kip Equivalents	403	360	333	645	70	212	201	94	401	212	147	67	279	181	111	105	652	413	178	77	47
Average of 18-Kip Equivalents	0.49	0.46	0.41	0.53	0.31	0.31	0.35	0.36	0.43	0.48	0.44	0.35	0.40	0.33	0.49	0.38	0.50	0.35	0.42	0.22	0.17
Degree of Load																					
Loaded																					
Number of 18-Kip Equivalents	703	716	607	1182	118	257	405	138	505	362	174	134	474	335	162	199	885	800	307	91	44
Average of 18-Kip Equivalents	0.74	0.76	0.65	0.87	0.50	0.52	0.68	0.57	0.71	0.93	0.74	0.62	0.70	0.57	0.70	0.65	0.75	0.72	0.67	0.39	0.27
Empty																					
Number of 18-Kip Equivalents	38	33	31	50	9	25	34	8	21	15	12	7	28	37	6	13	49	52	18	6	6
Average of 18-Kip Equivalents	0.09	0.09	0.07	0.08	0.07	0.07	0.10	0.07	0.04	0.06	0.06	0.06	0.07	0.09	0.06	0.07	0.07	0.07	0.07	0.03	0.04
All Vehicles of Each Characteristic																					
Number of 18-Kip Equivalents	741	749	638	1232	127	282	439	146	526	377	186	141	502	372	168	212	934	852	325	97	50
Average of 18-Kip Equivalents	0.54	0.56	0.47	0.62	0.35	0.33	0.46	0.41	0.43	0.60	0.44	0.42	0.47	0.37	0.51	0.44	0.50	0.47	0.45	0.24	0.17

APPENDIX A

Table 24

Average and Standard Deviation from the Average of 18-Kip Axle Equivalents Per Tandem Axle for Cargo Vehicles Weighed at Each of 21 Loadometer Stations in 1966-68 by Major Vehicle Type

Loadometer Station by Highway System	18-Kip Axle Equivalents Per Tandem Axle by Vehicle Type							
	3-Axle Single-Unit		2-S2 Multi-Unit		3-S2 Multi-Unit		All Vehicle Types[1]	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Interstate Rural								
10-1	0.081	0.141	0.144	0.205	0.231	0.237	0.215	0.233
10-2	0.208	0.260	0.161	0.251	0.269	0.295	0.253	0.292
20-1	0.263	0.410	0.181	0.260	0.296	0.289	0.283	0.291
20-2	0.176	0.313	0.178	0.322	0.278	0.348	0.265	0.347
20-3	0.184	0.294	0.193	0.300	0.276	0.270	0.262	0.276
30-1	0.185	0.332	0.209	0.295	0.249	0.261	0.241	0.267
35-1	0.296	0.487	0.192	0.256	0.270	0.333	0.282	0.331
37-1	0.179	0.262	0.138	0.205	0.230	0.300	0.214	0.287
45-2	0.268	0.366	0.191	0.258	0.322	0.347	0.306	0.340
Other Rural								
7	0.183	0.267	0.141	0.267	0.190	0.275	0.182	0.273
16	0.149	0.346	0.148	0.200	0.198	0.225	0.188	0.231
20	0.226	0.372	0.140	0.220	0.247	0.319	0.235	0.311
42	0.085	0.153	0.244	0.347	0.261	0.281	0.252	0.297
72	0.138	0.211	0.112	0.183	0.180	0.215	0.169	0.211
81	0.182	0.270	0.287	0.326	0.377	0.467	0.360	0.448
88	0.399	0.580	0.191	0.312	0.294	0.439	0.281	0.430
145	0.214	0.281	0.167	0.233	0.197	0.258	0.197	0.268
147	0.169	0.220	0.097	0.142	0.285	0.247	0.256	0.244
149	0.151	0.216	0.158	0.228	0.212	0.248	0.209	0.245
Urban								
3	0.127	0.245	0.147	0.258	0.249	0.361	0.201	0.321
4	0.452	0.945	0.102	0.274	0.163	0.280	0.236	0.585
All Stations	0.221	0.400	0.175	0.266	0.261	0.306	0.248	0.305

[1]Includes miscellaneous vehicle types.

APPENDIX A

Table 25

Number, Average Weight, and Standard Deviation from Average Weight of Single Axles Weighed at 21 Loadometer Stations During 1966-68, According to Vehicle Type and Location of Station [1]

Vehicle Type	Rural Stations				
	Eight Interstate	Eleven Other[2]	Nineteen Rural	Two Urban Stations	All 21 Stations
2-Axle 6-Tire Single Unit					
Number of Axles	4,625	4,559	9,184	1,358	10,542
Average Axle Weight (Kips)	4.779	4.622	4.701	4.587	4.687
Standard Deviation (Kips)	1.537	1.475	1.509	1.559	1.515
3 axle Single Unit					
Number of Axles	343[3]	1,257	1,600	181	1,781
Average Axle Weight (Kips)	8.085	6.996	7.229	7.240	7.230
Standard Deviation (Kips)	3.428	2.588	2.778	2.371	2.741
2-S1 Combination					
Number of Axles	2,192[4]	1,395	3,587	152	3,739
Average Axle Weight (Kips)	6.281	6.002	6.172	5.457	6.143
Standard Deviation (Kips)	1.804	1.732	1.781	1.716	1.784
2-S2 Combination					
Number of Axles	8,544	6,089	14,633	328	14,961
Average Axle Weight (Kips)	9.279	8.920	9.129	8.535	9.116
Standard Deviation (Kips)	4.056	4.313	4.169	4.206	4.170
3-S2 Combination					
Number of Axles	14,204	9,207	23,411	192	23,603
Average Axle Weight (Kips)	8.727	8.341	8.575	7.140	8.564
Standard Deviation (Kips)	1.579	1.543	1.577	1.859	1.584
Miscellaneous Combinations					
Number of Axles	453[3]	1,721	2,174	54	2,228
Average Axle Weight (Kips)	9.735	8.993	9.148	8.203	9.124
Standard Deviation (Kips)	3.871	3.983	3.971	4.585	3.990
All Vehicle Types					
Number of Axles	31,730	22,859	54,589	2,265	56,854
Average Axle Weight (Kips)	8.132	7.572	7.898	5.731	7.811
Standard Deviation (Kips)	3.073	3.165	3.124	2.806	3.141

[1]Only front axles are represented in this table for those axle types with no tandem axle.
[2]Interstate Station 37-1 is included in this group.
[3]Interstate Stations 45-2 and 35-1 are the only stations in this group; thus the other group has 17 stations.
[4]Interstate Station 10-1 is in the other group made up of 12 stations.

APPENDIX A

Table 26

Number, Average Weight and Standard Deviation from Average Weight of Tandem Axles Weighed at 21 Loadometer Stations During 1966-68 According to Vehicle Type and Location of Station

Vehicle Type	Rural Stations			Two Urban Stations	All 21 Stations
	Eight Interstate	Eleven Other[1]	Nineteen Rural		
3-Axle Single Unit					
Number of Axles	829	764	1,593	180	1,773
Average Axle Weight (Kips)	17.019	15.649	16.362	16.128	16.338
Standard Deviation (Kips)	8.961	8.892	8.954	9.374	8.975
2-S2 Combination					
Number of Axles	4,254	3,032	7,286	164	7,450
Average Axle Weight (Kips)	16.536	15.302	16,022	14.872	15.997
Standard Deviation (Kips)	7.988	8.193	8.098	6.818	8.073
3-S2 Combination					
Number of Axles	28,250	18,359	46,609	384	46,993
Average Axle Weight (Kips)	19.606	17.912	18.939	17.289	18.926
Standard Deviation (Kips)	8.269	8.469	8.390	8.341	8.390
Miscellaneous Combinations					
Number of Axles	366	332	698	14	712
Average Axle Weight (Kips)	17.923	18.072	17.993	18.714	18.007
Standard Deviation (Kips)	7.161	7.328	7.245	5.946	7.215
All Vehicle Types					
Number of Axles	33,699	22,487	56,186	742	56,928
Average Axle Weight (Kips)	19.137	17.486	18.476	16.500	18.451
Standard Deviation (Kips)	8.312	8.484	8.420	8.324	8.422

[1]Interstate Station 37-1 is included in this group.

APPENDIX A

Table 27

Number, Average Weight, and Standard Deviation from Average Weight of Single and Tandem Axles Weighed at 21 Loadometer Stations During 1966-68 According to Vehicle Type and Load Characteristic

Vehicle Type	Single Axles			Tandem Axles		
	Empty	Loaded	All	Empty	Loaded	All
2-axle 6-tire Single Unit						
Number of axles	8,256	12,828	21,084	-	-	-
Average Axle Weight (Kips)	4.913	7.612	6.555	-	-	-
Standard Deviation (Kips)	1.991	4.324	3.830	-	-	-
3-axle Single Unit						
Number of Axles	921	870	1,791	917	856	1,773
Average Axle Weight (Kips)	6.693	7.905	7.282	10.441	22.657	16.338
Standard Deviation (Kips)	2.476	3.112	2.867	5.119	7.907	9.000
2-S1 Combination						
Number of Axles	3,663	7,550	11,213	-	-	-
Average Axle Weight (Kips)	6.475	10.125	8.932	-	-	-
Standard Deviation (Kips)	1.799	4.006	3.846	-	-	-
2-S2 Combination						
Number of Axles	5,809	9,254	15,063	2,876	4,579	7,455
Average Axle Weight (Kips)	6.647	10.671	9.119	8.638	20.622	15.999
Standard Deviation (Kips)	1.746	4.509	4.184	2.388	6.864	8.073
3-S2 Combination						
Number of Axles	7,935	15,677	23,614	15,765	31,231	47,000
Average Axle Weight (Kips)	7.879	8.916	8.567	9.653	23.603	18.928
Standard Deviation (Kips)	1.375	1.594	1.600	2.718	6.075	8.392
2-S1-2 Combination						
Number of Axles	211	1,059	1,270	-	-	-
Average Axle Weight (Kips)	6.498	11.176	10.399	-	-	-
Standard Deviation (Kips)	1.812	3.518	3.727	-	-	-
3-S1-2 Combination						
Number of Axles	70	740	810	25	263	288
Average Axle Weight (Kips)	6.229	10.588	10.211	10.768	17.102	16.552
Standard Deviation (Kips)	2.133	3.006	3.185	3.672	4.663	4.908

APPENDIX A

Table 27

(Continued)

Vehicle Type	Single Axles Empty	Single Axles Loaded	Single Axles All	Tandem Axles Empty	Tandem Axles Loaded	Tandem Axles All
3-S1 & 3-1 Combinations						
Number of Axles	154	252	406	77	126	203
Average Axle Weight (Kips)	7.214	11.299	9.749	13.301	22.892	19.251
Standard Deviation (Kips)	1.458	3.831	3.718	4.390	5.402	6.852
2-3 & 3-2 Combinations						
Number of Axles	41	89	130	29	44	73
Average Axle Weight (Kips)	5.780	10.665	9.123	15.628	26.159	21.973
Standard Deviation (Kips)	3.200	3.772	4.239	4.255	7.459	8.147
3-3 & 3-S3 Combinations						
Number of Axles	83	132	215	24	47	71
Average Axle Weight (Kips)	7.561	12.999	10.902	13.600	24.085	20.535
Standard Deviation (Kips)	3.287	6.275	5.921	10.455	6.806	9.500
2-1 & 2-2 Combinations						
Number of Axles	391	585	976	-	-	-
Average Axle Weight (Kips)	4.516	6.770	5.868	-	-	-
Standard Deviation (Kips)	2.365	5.178	4.415	-	-	-
2-S3 Combination						
Number of Axles	9	9	18	22	44	66
Average Axle Weight (Kips)	7.667	8.333	8.000	9.727	14.091	12.636
Standard Deviation (Kips)	2.962	2.494	2.666	6.938	7.790	7.786
All Vehicle Types						
Number of Axles	27,543	49,045	76,590	19,735	37,190	56,929
Average Axle Weight (Kips)	6.433	9.149	8.172	9.571	23.164	18.451
Standard Deviation (Kips)	2.134	3.822	3.562	2.923	6.326	8.423

APPENDIX B

SUPPORTING CHARTS

APPENDIX B

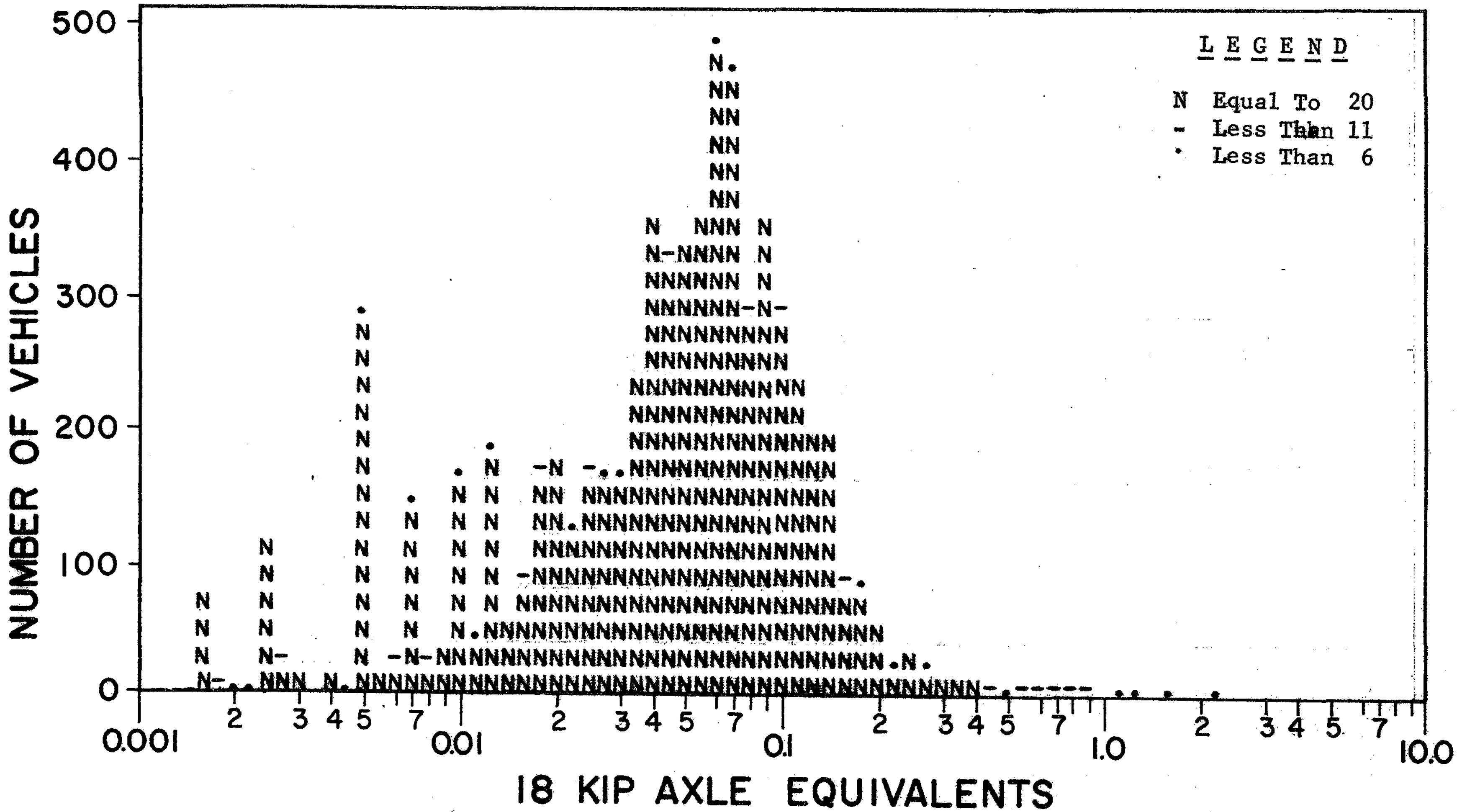

Figure 1. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all empty cargo vehicles studied from the 1967 loadometer weighings.

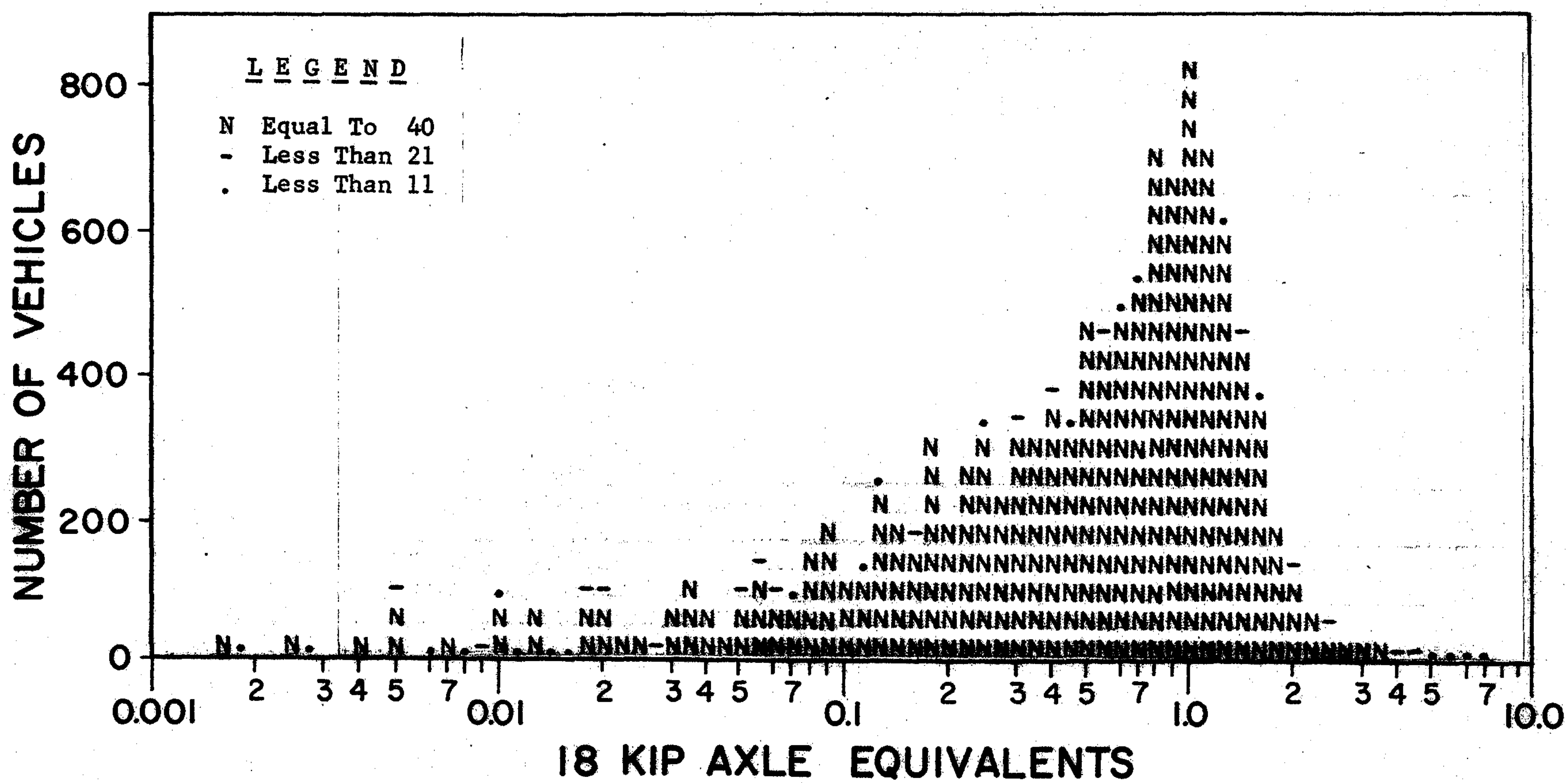

Figure 2. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all loaded cargo vehicles studied from the 1967 loadometer weighings.

APPENDIX B

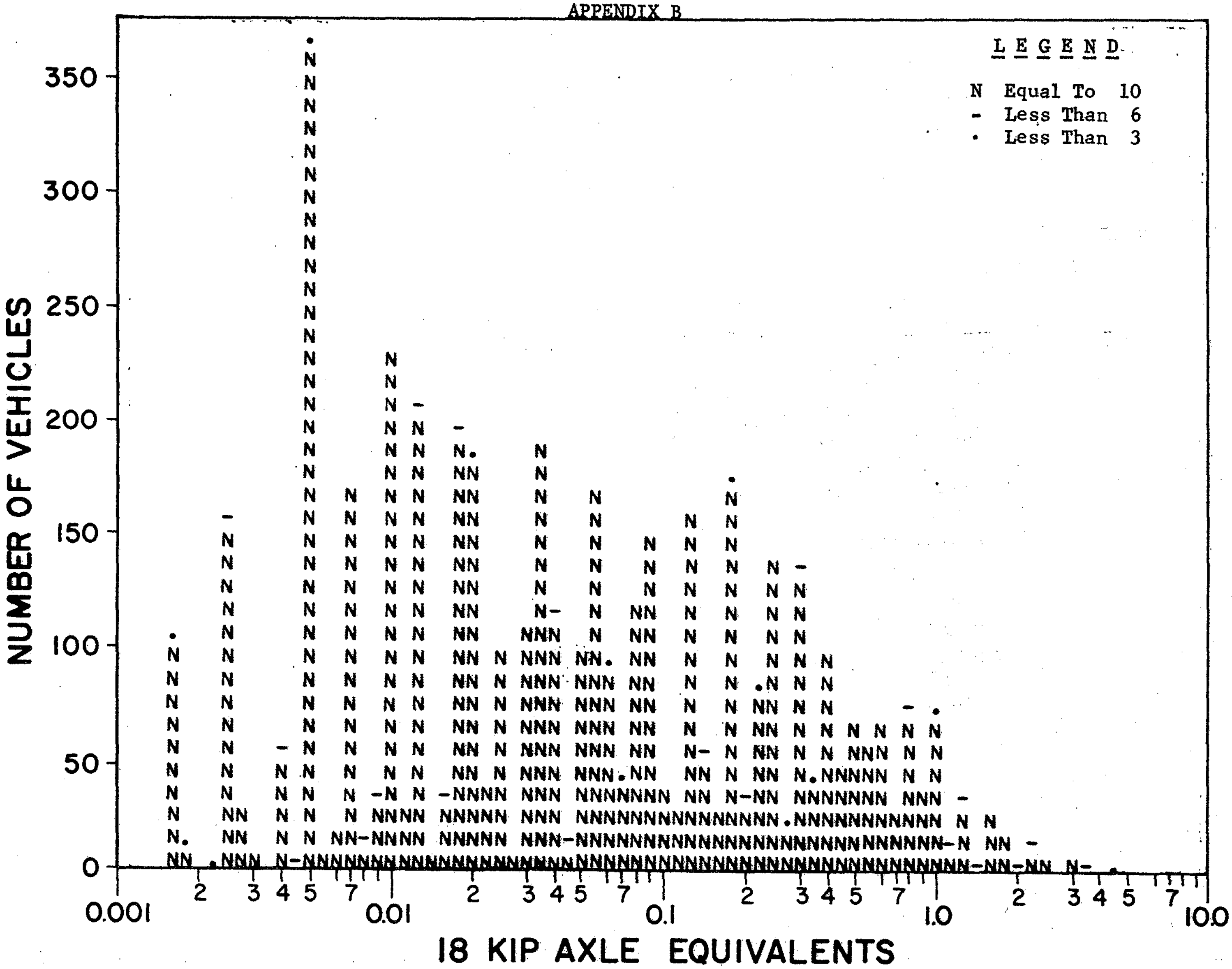

Figure 3. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all single unit cargo vehicles studied from the 1967 loadometer weighings.

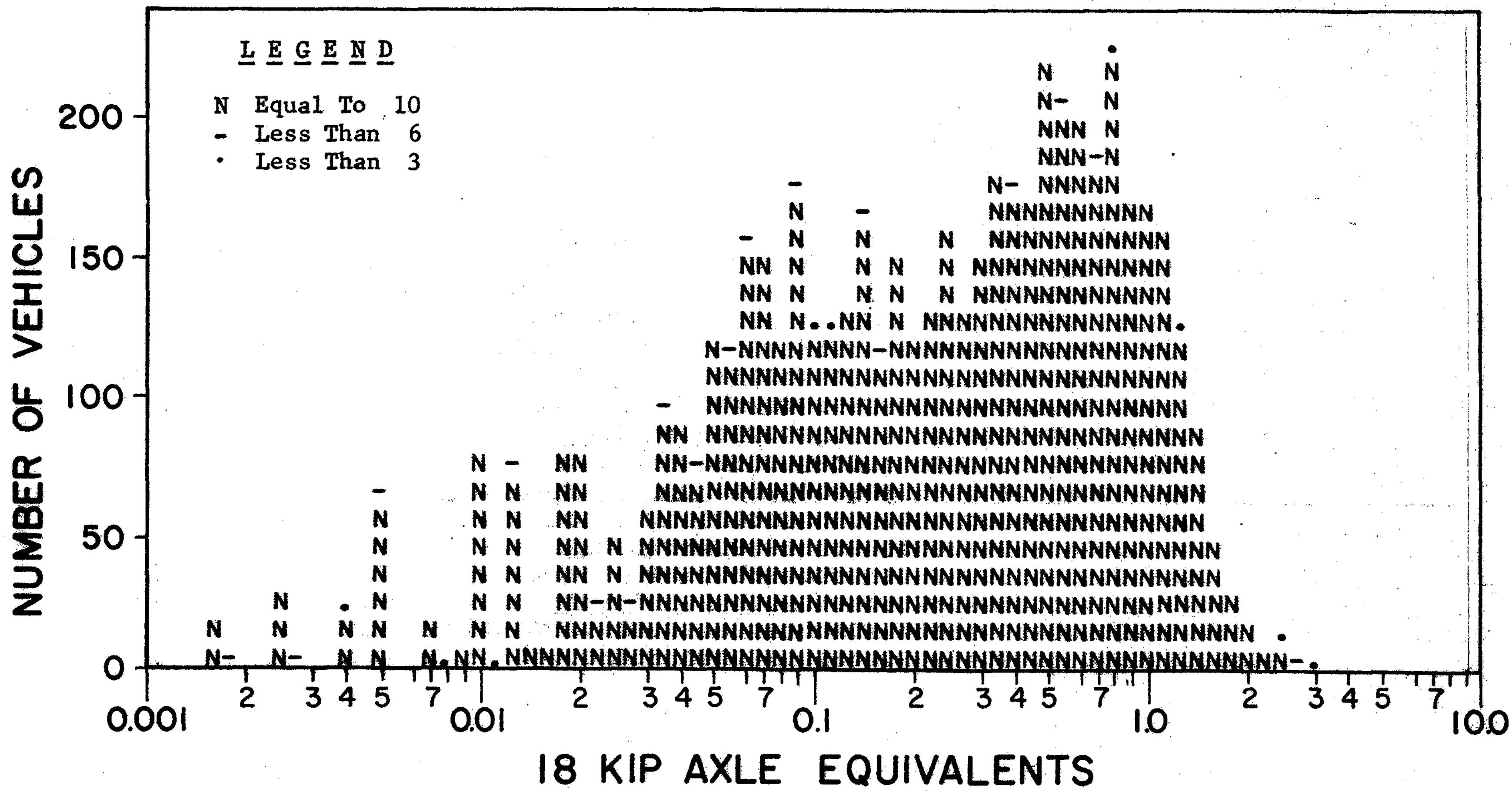

Figure 4. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all van (except insulated vans) and panel cargo vehicles studied from the 1967 loadometer weighings.

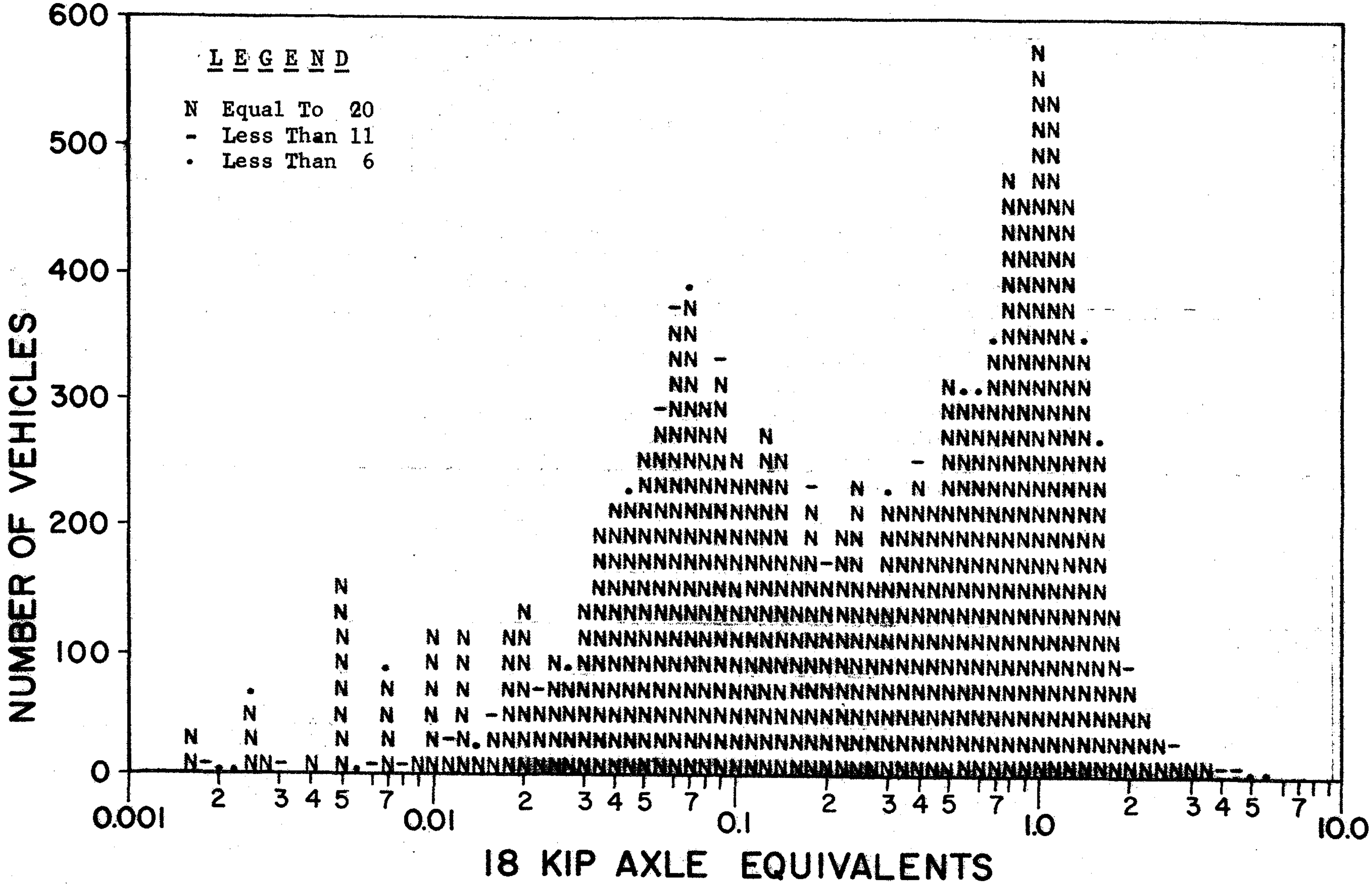

Figure 5. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles studied from the 1967 weighings at loadometer stations on rural interstate roads.

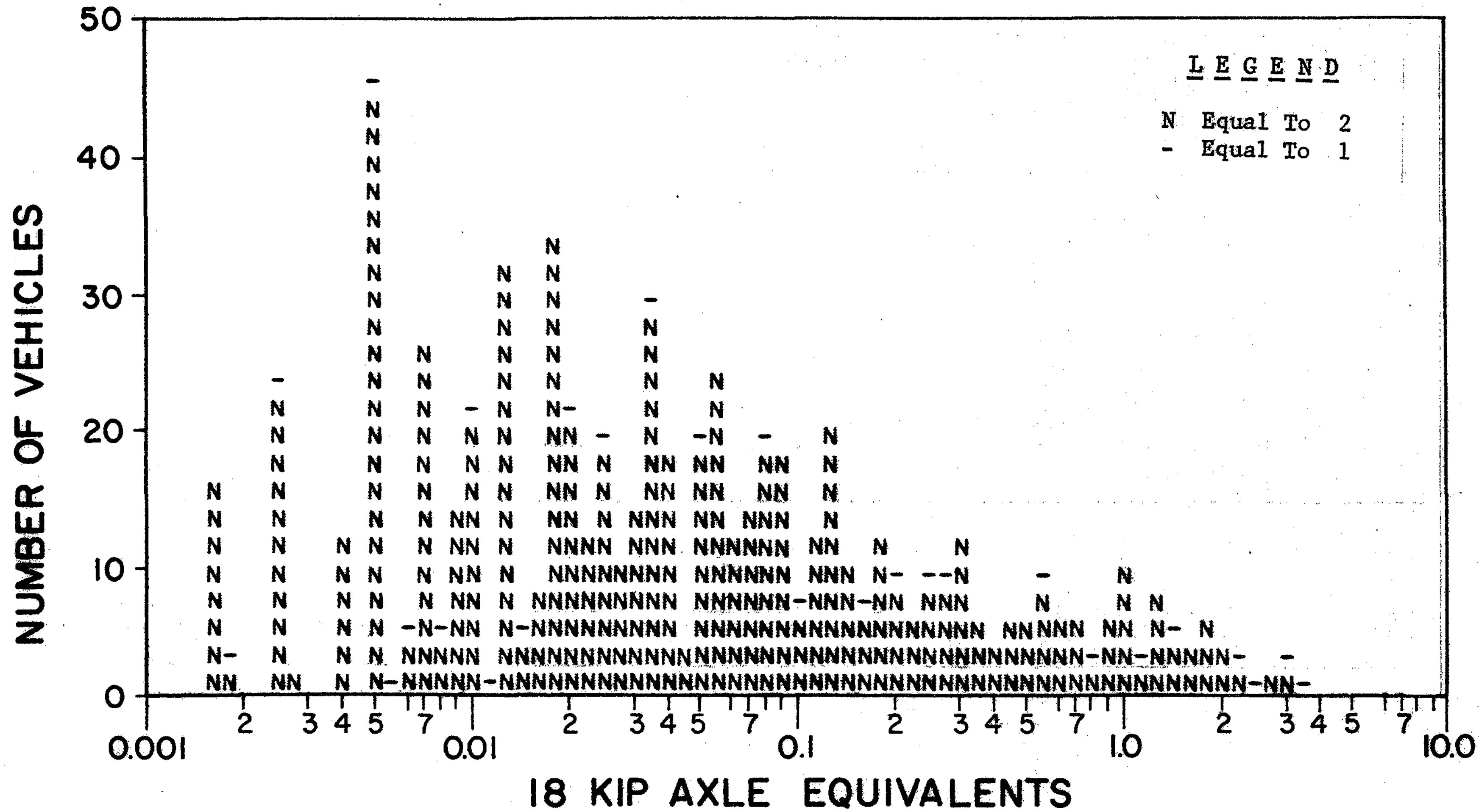

Figure 6. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles studied from the 1967 weighings at loadometer stations on urban roads.

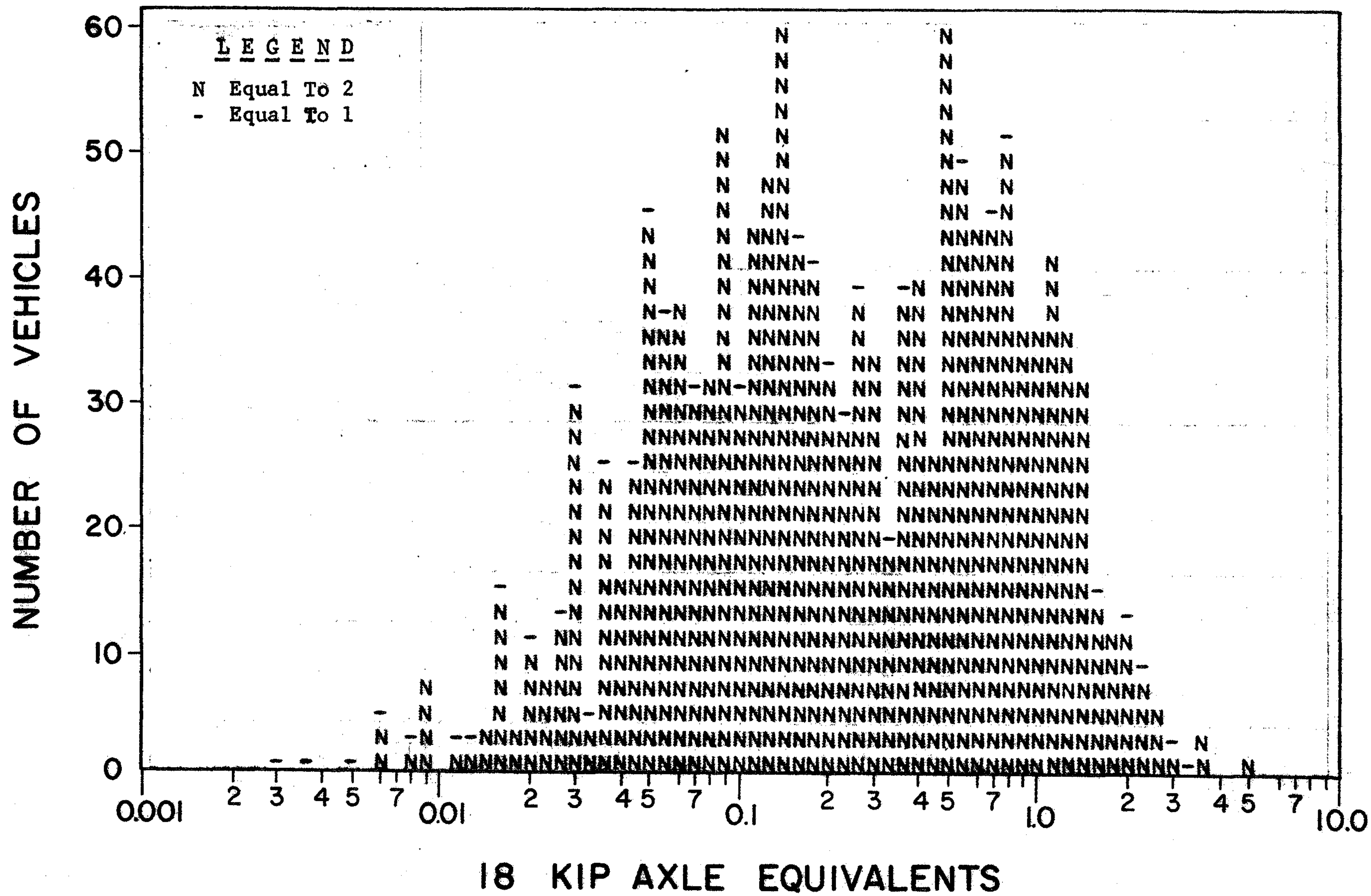

Figure 7. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles of the 2-S1 axle type from the 1967 loadometer weighings.

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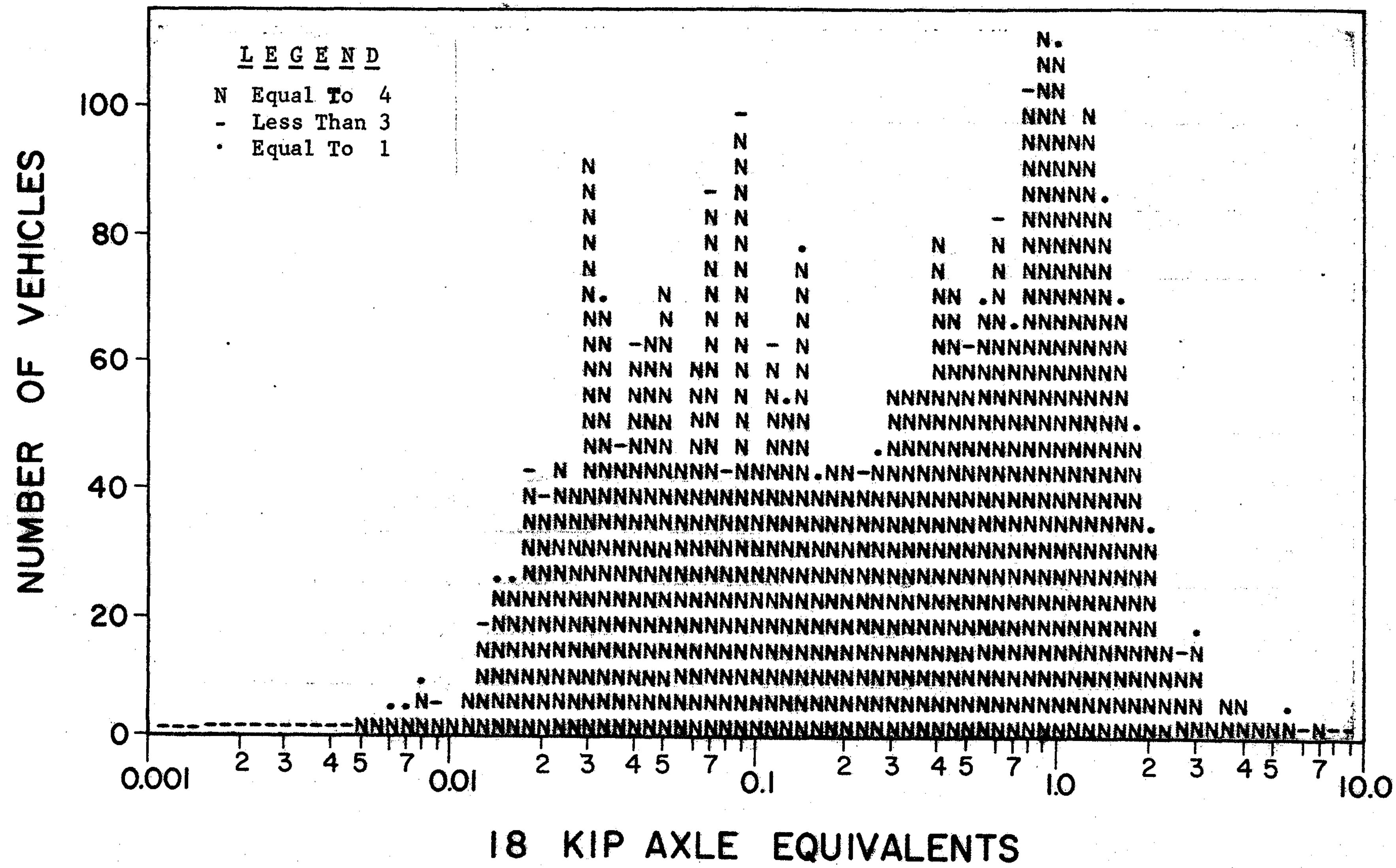

Figure 8. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles of the 2-S2 axle type from the 1967 loadometer weighings.

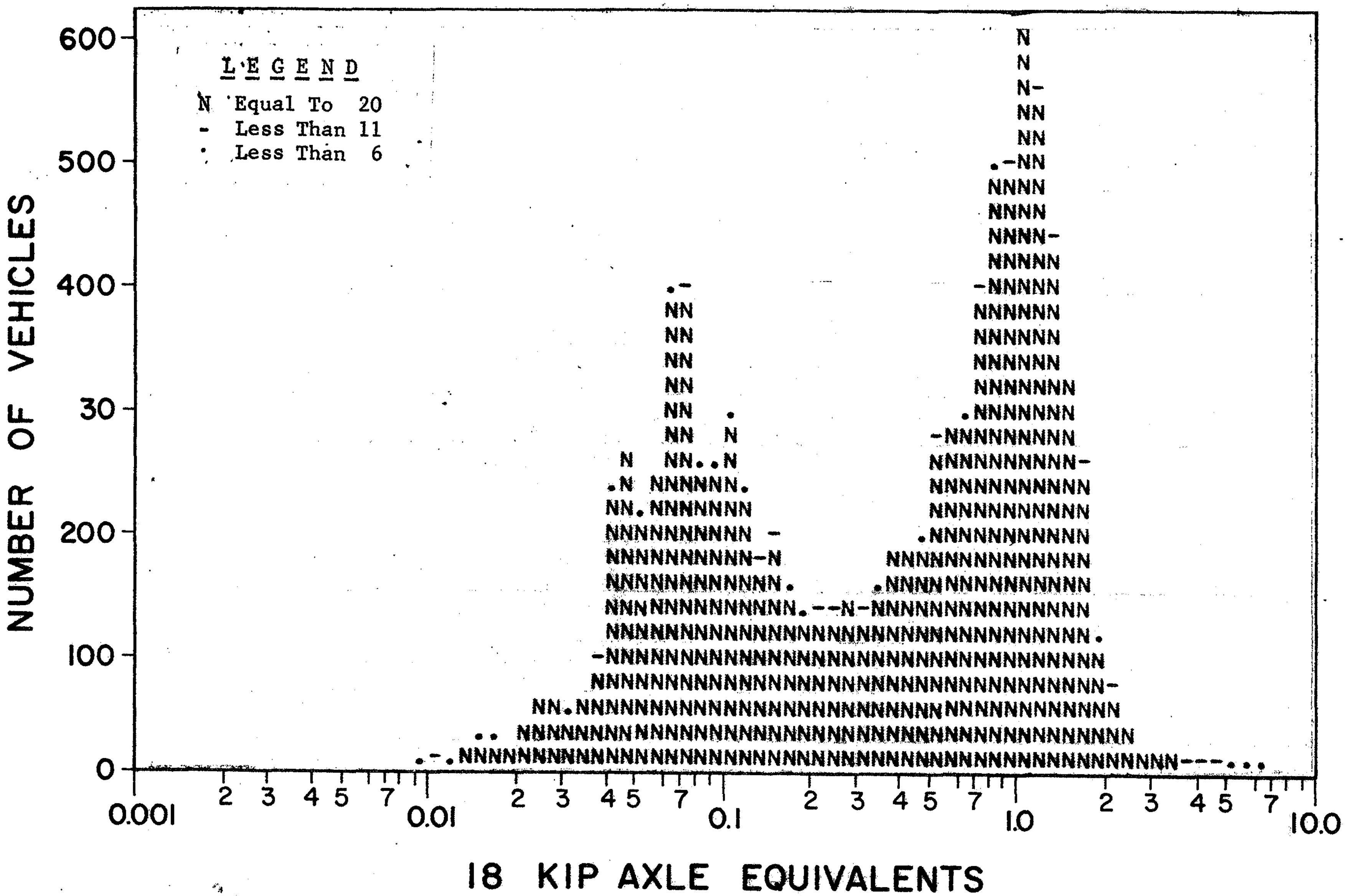

Figure 9. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles of the 3-S2 axle type from the 1967 loadometer weighings.

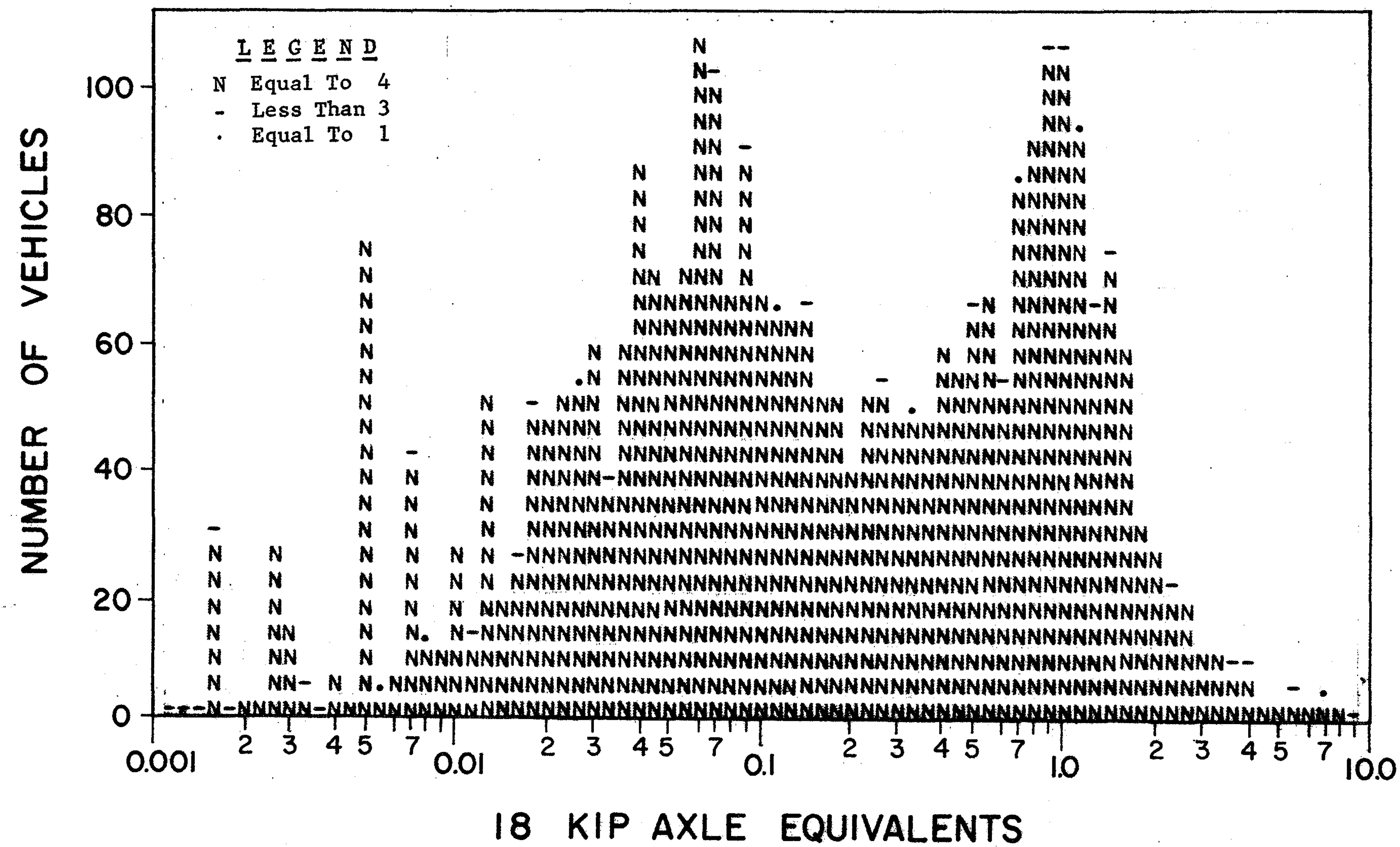

Figure 40. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles of the oil or platform body type studied from the 1967 loadometer weighings.

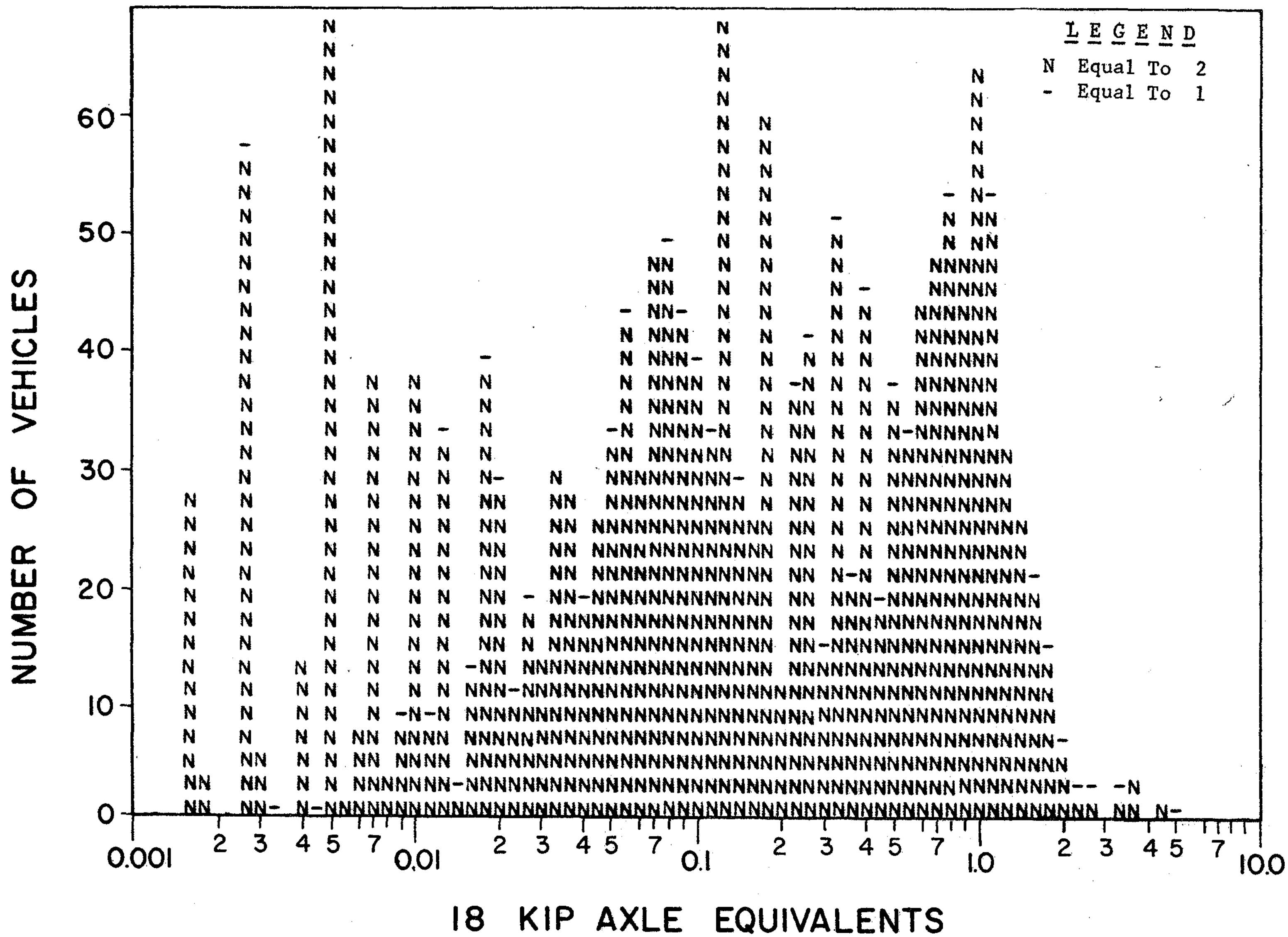

Figure 11. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles of the cattle or rack body type studied from the 1967 loadometer weighings.

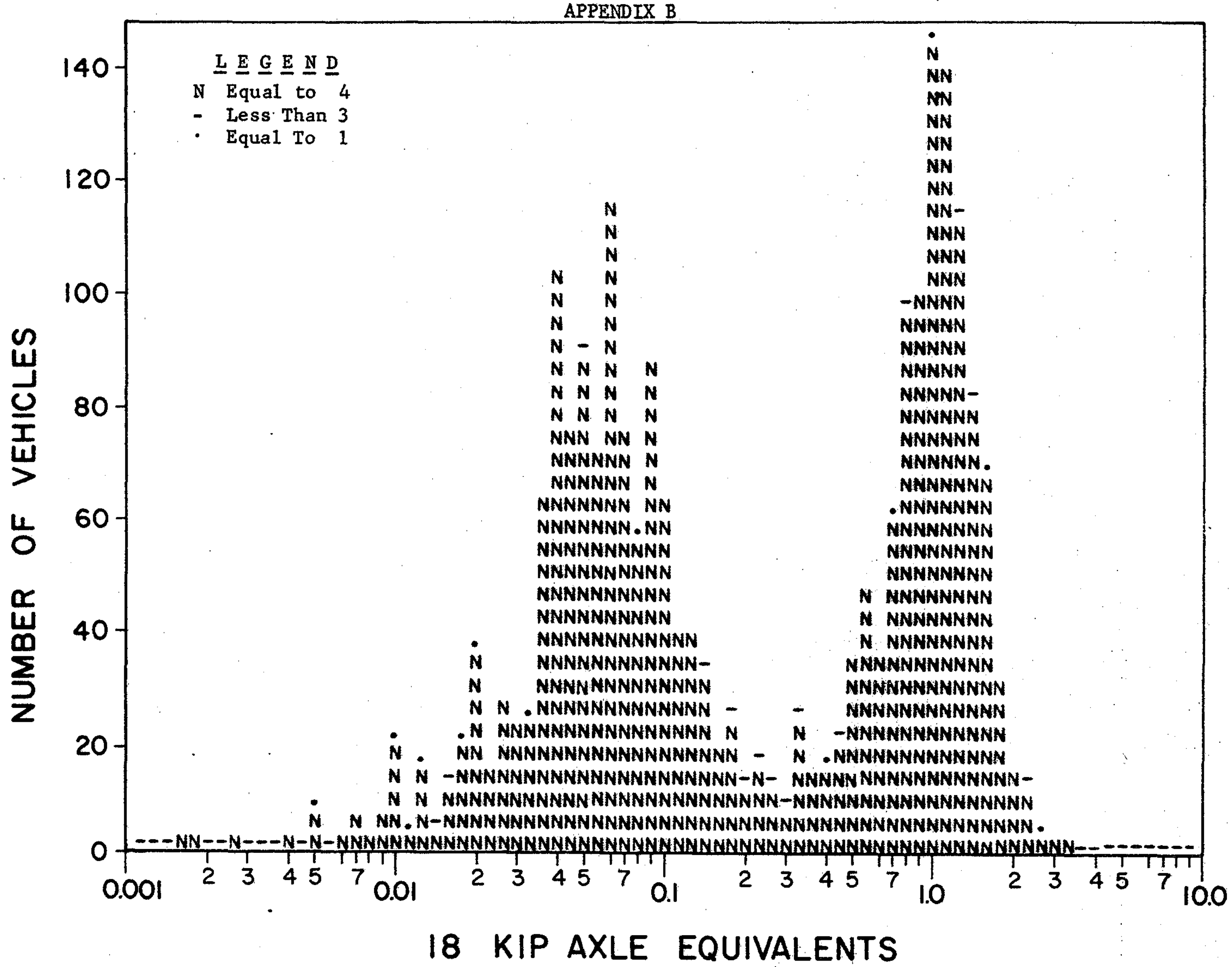

Figure 12. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles of the tank body type studied from the 1967 loadometer weighings.

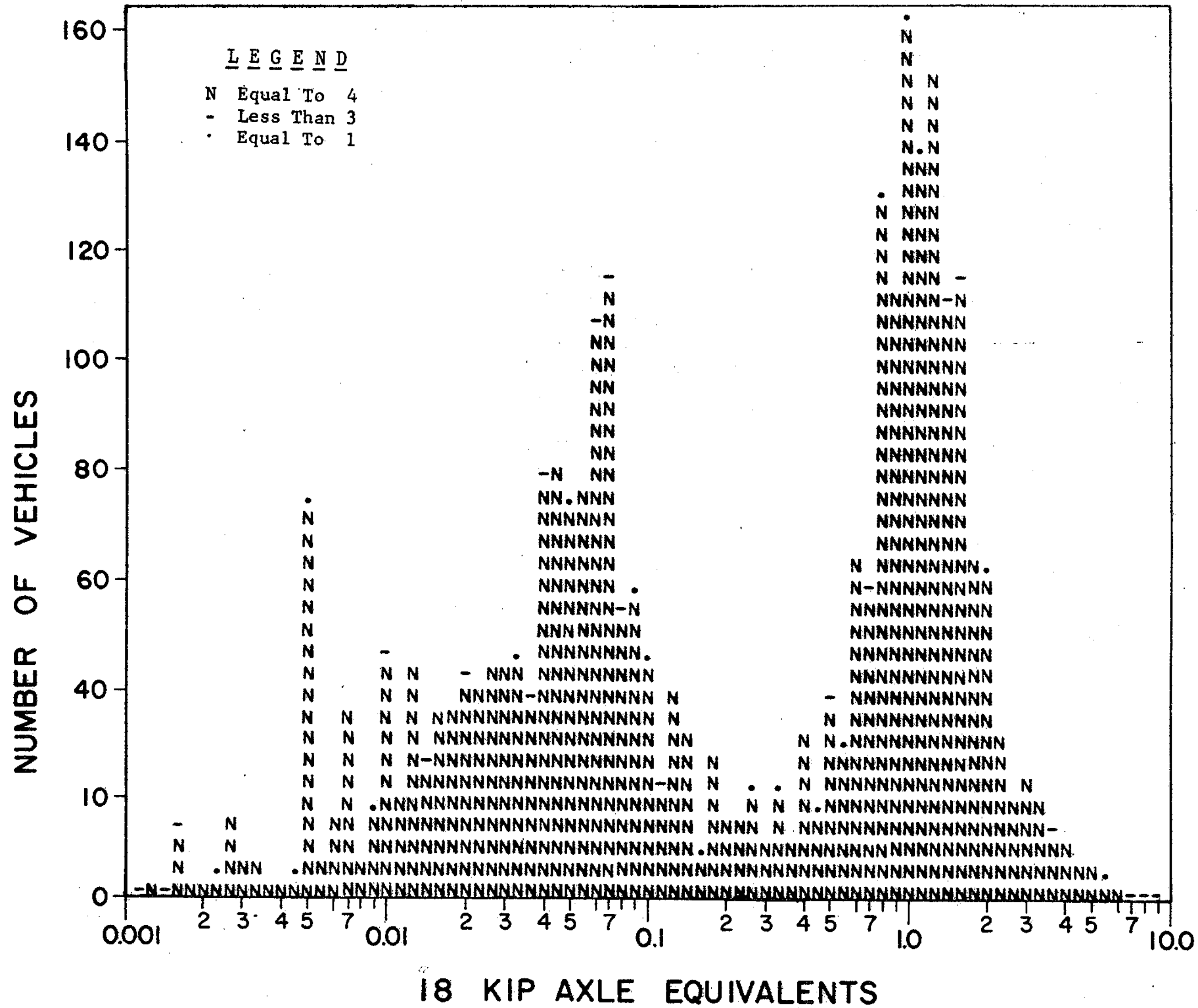

Figure 13. Chart showing frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles of the open top body type studied from the 1967 loadometer weighings.

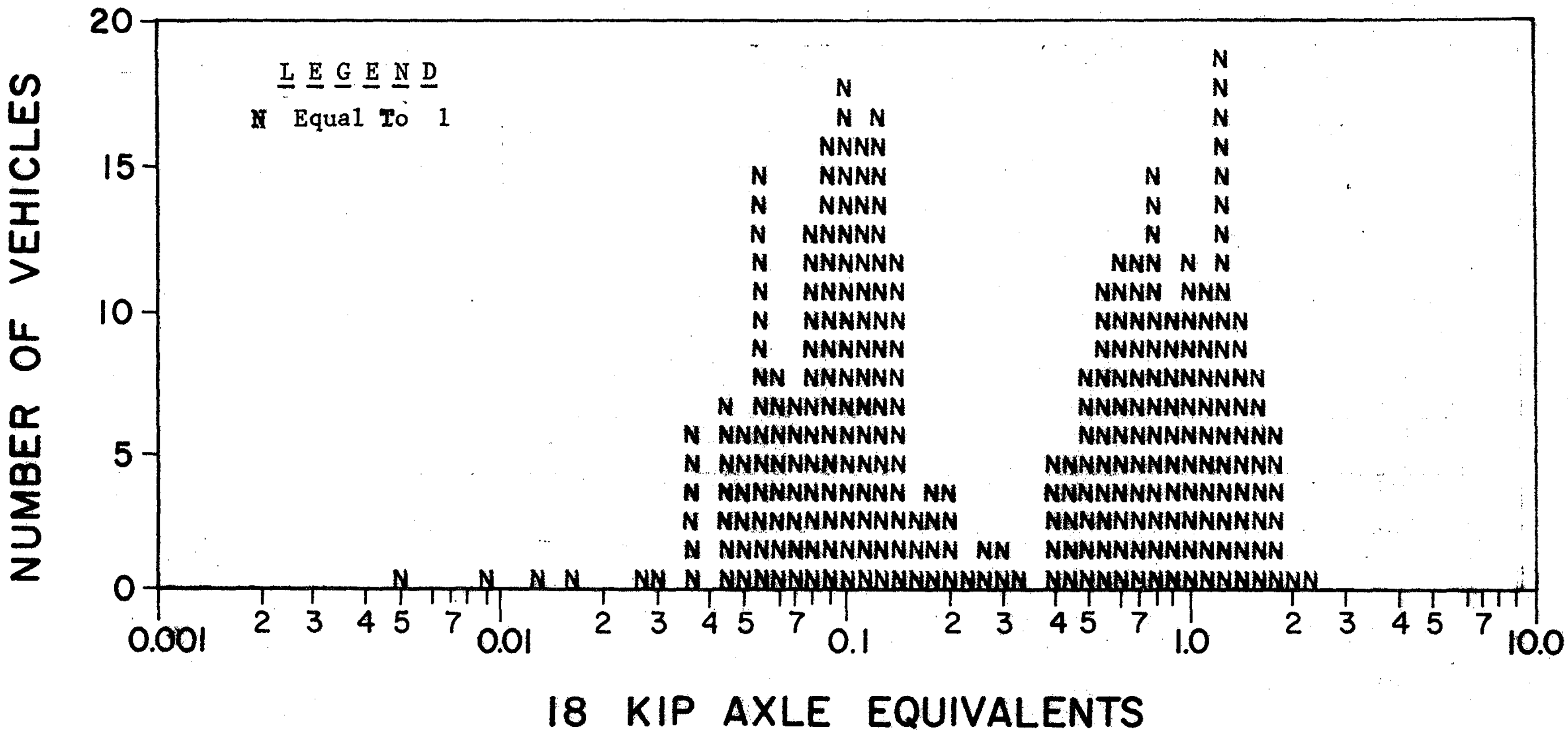

Figure 14. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles of the auto transport type studied from the 1967 loadometer weighings.

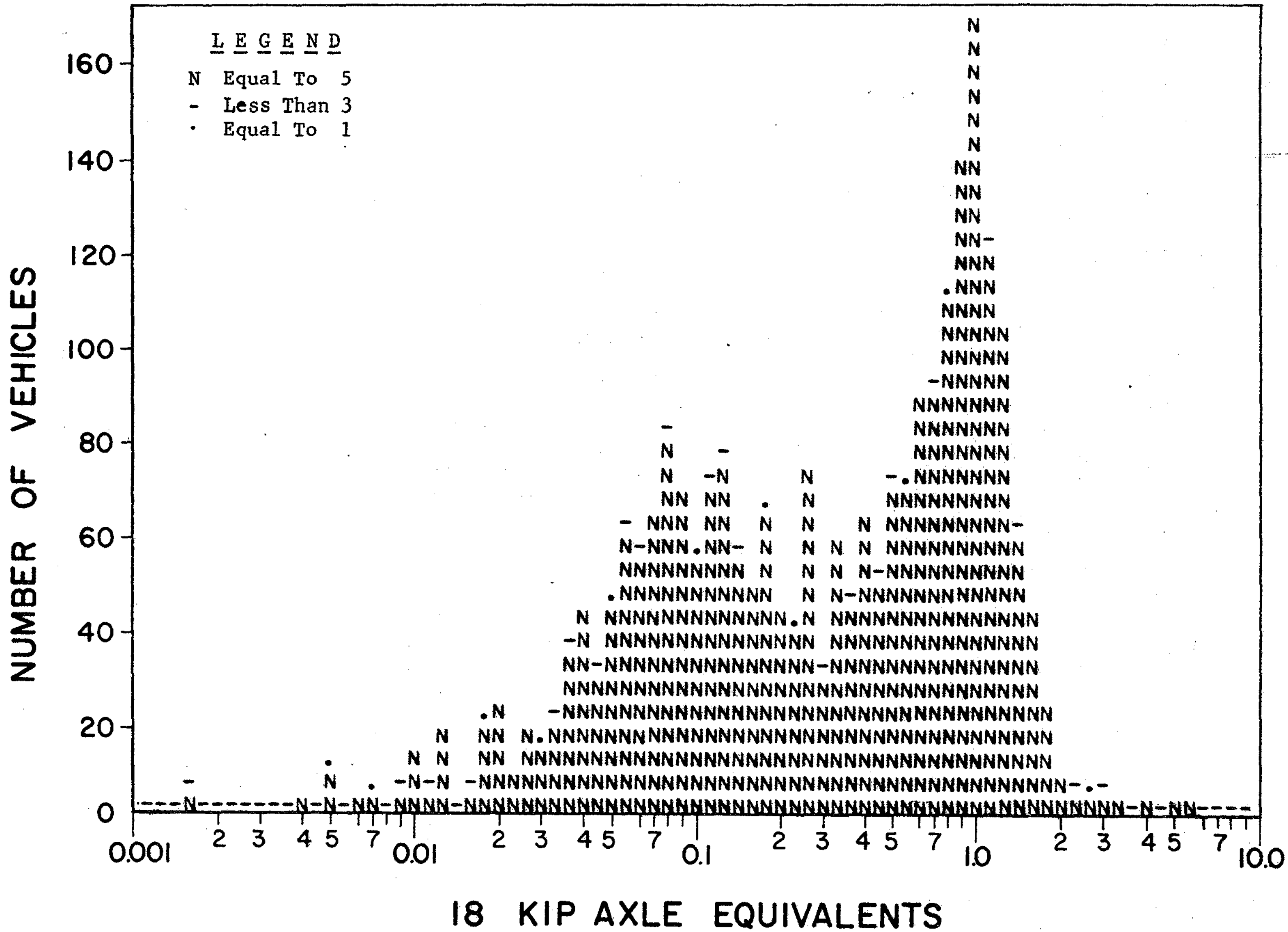

Figure 15. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles of the insulated van body type studied from the 1967 loadometer weighings.

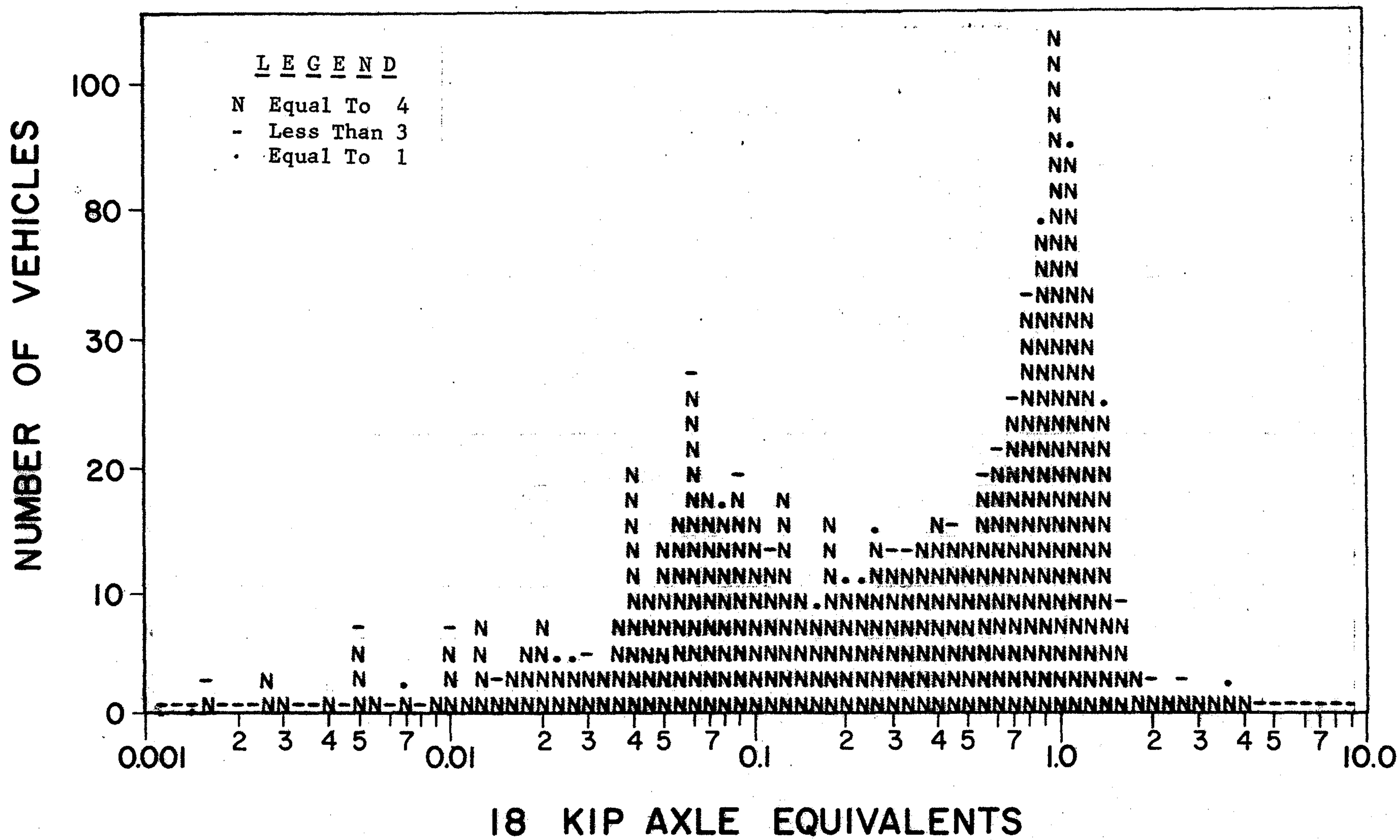

Figure 16. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles studied from the 1967 weighings at Loadometer Station 20-1.

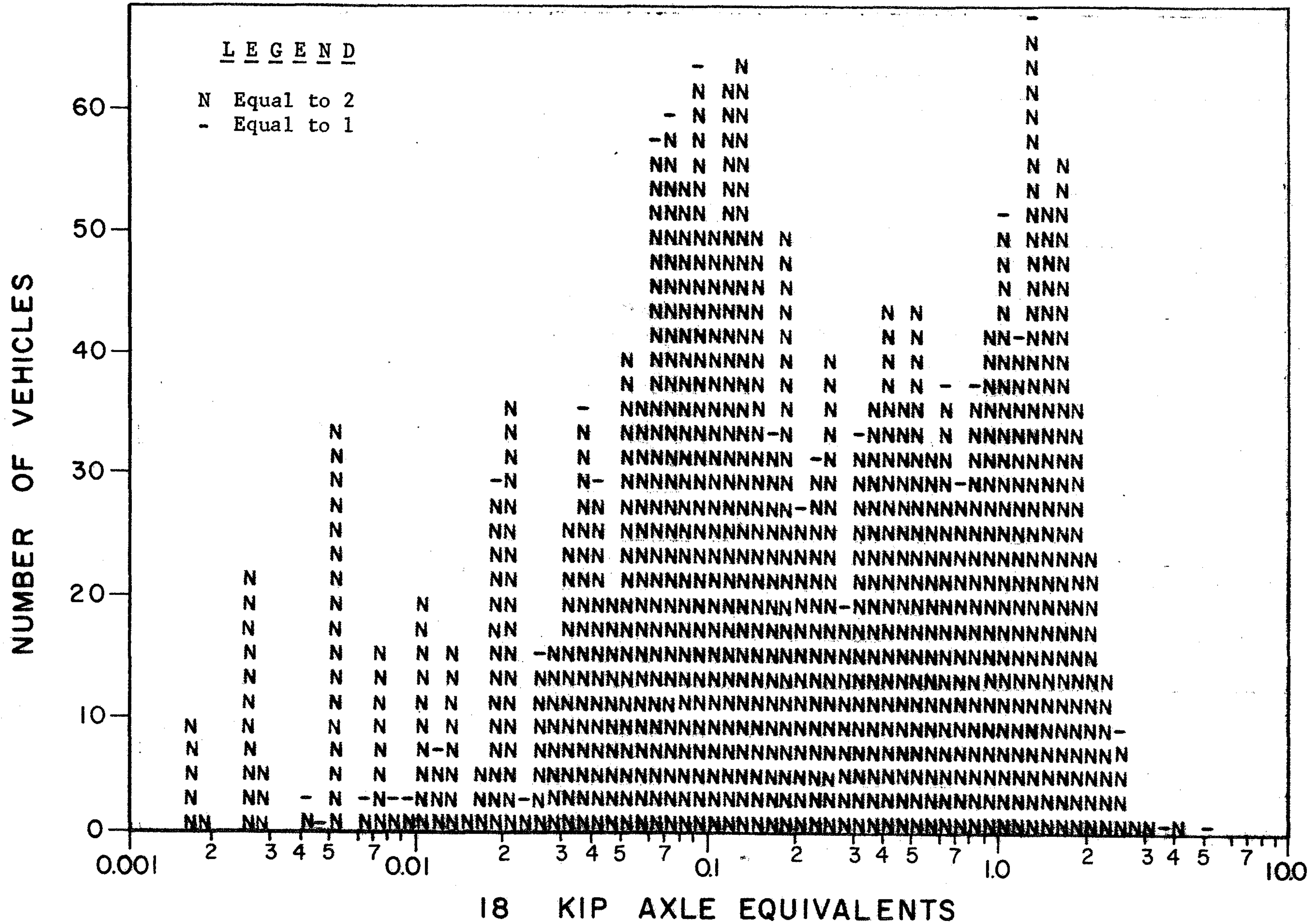

Figure 17. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles studied from the 1967 conventional loadometer weighings at Station 35-1.

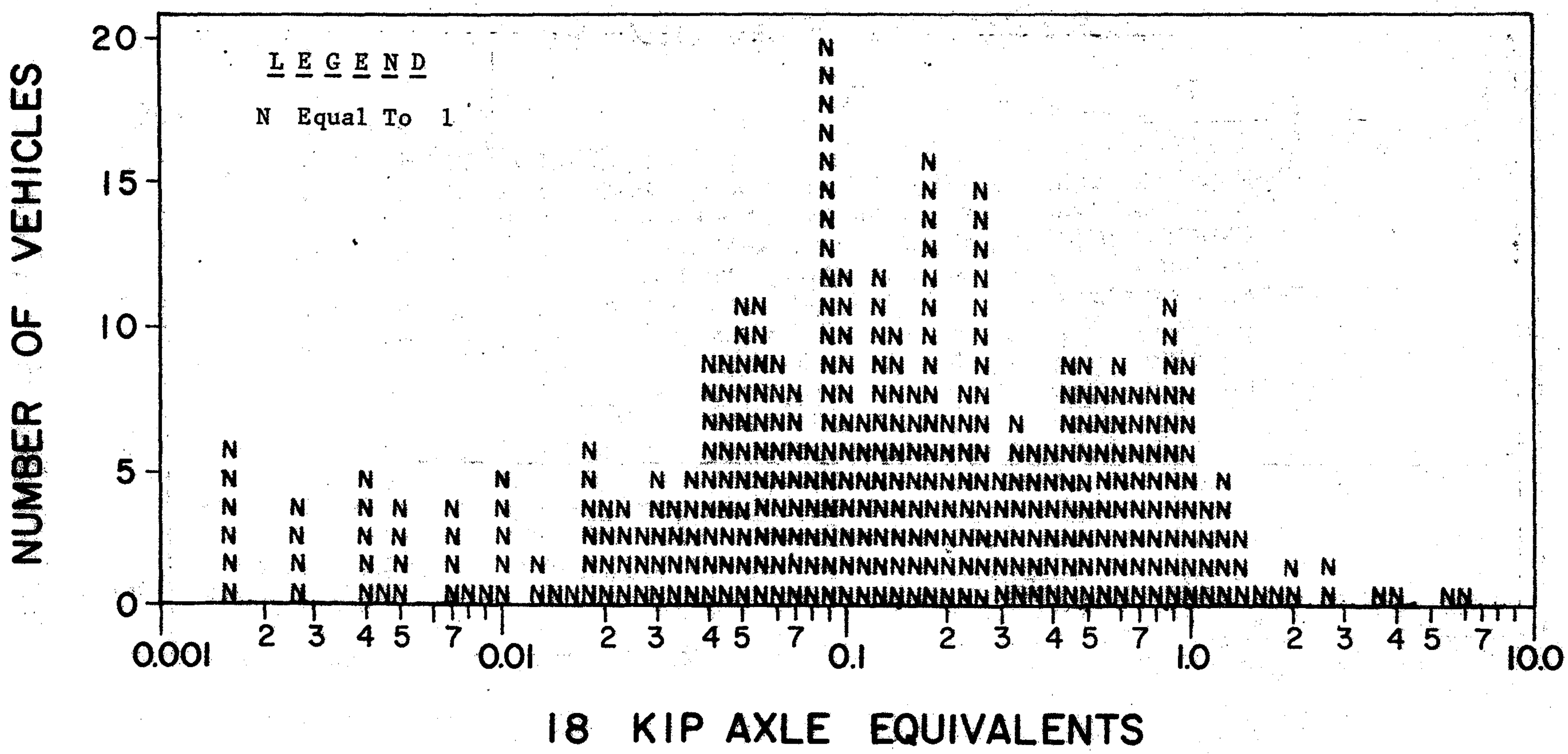

Figure 18. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles studied from the 1967 weighings at Loadometer Station 7.

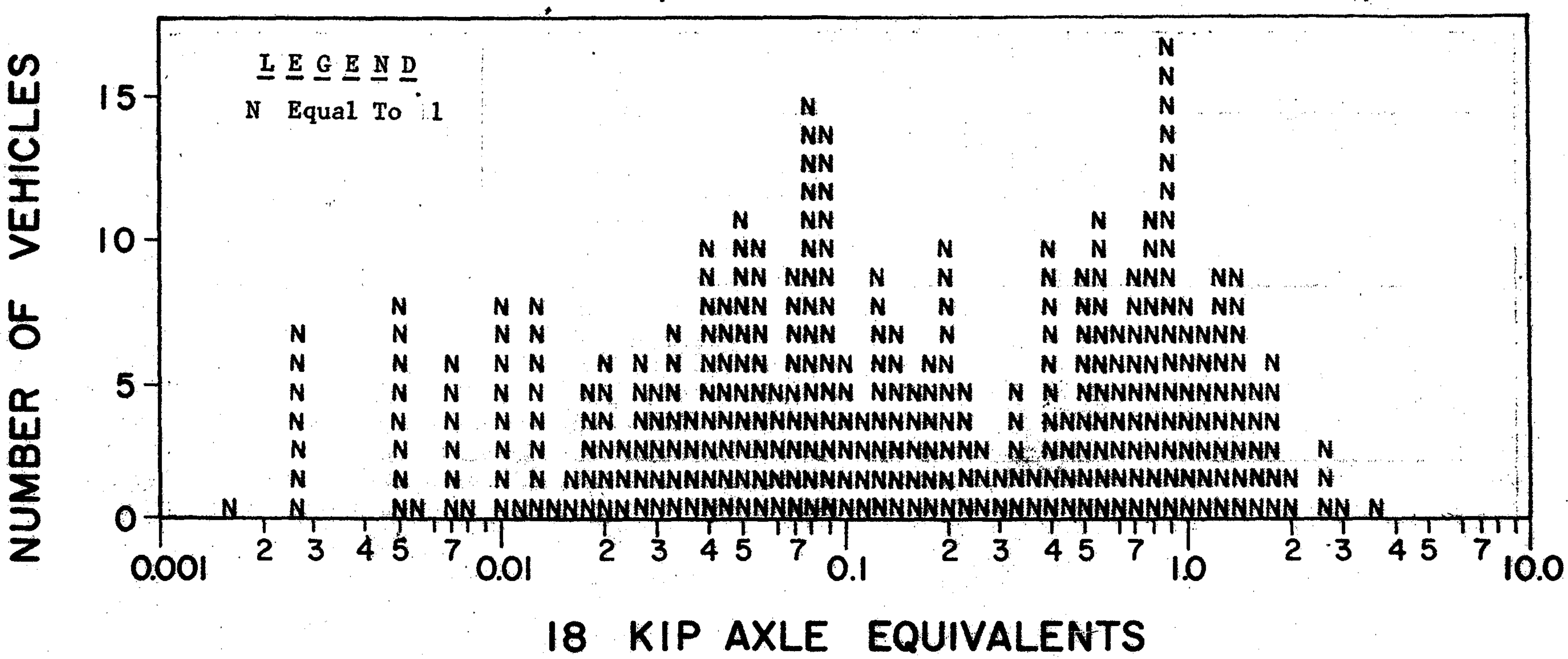

Figure 19. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles studied from the 1967 weighings at Loadometer Station 42.

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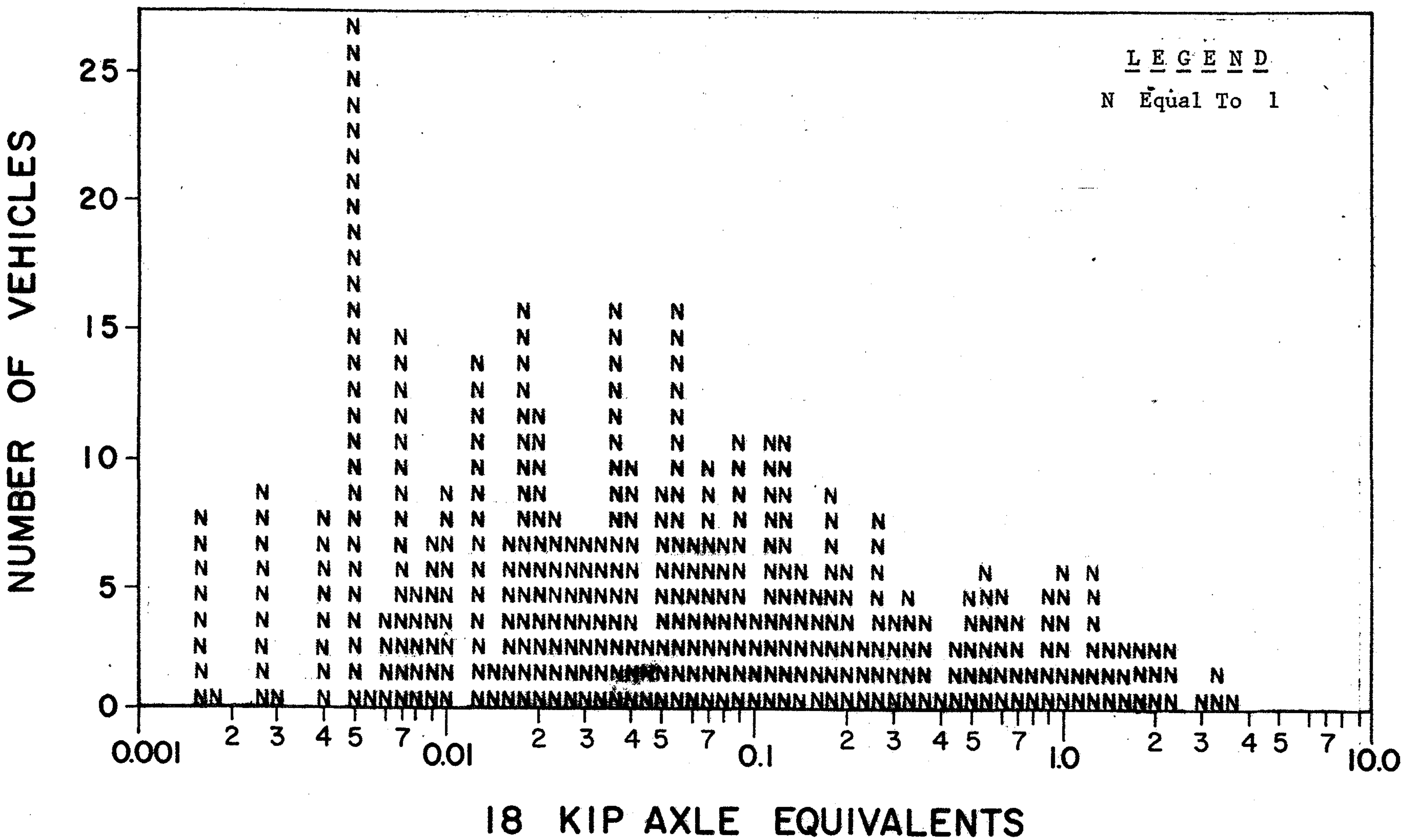

Figure 20. Chart showing a frequency distribution of flexible pavement log-kip axle equivalents for all cargo vehicles studied from the 1967 weighings at Loadometer Station 3.

APPENDIX C

COMPUTER PROGRAMS

APPENDIX C

COMPUTER PROGRAMS

The following computer programs, written in FORTRAN IV subroutines which were run on an IBM 360/65, are included to define the 18-kip axle equivalents used in the regression models, either as the dependent variable or as an argument to the ALOG10 function which was used as the dependent variable.

SUBROUTINE AXLE (Figure 1) was used to group individual axle weights (from array AW) into single or tandem axle groups (into array LOAD) using the "Policy on Maximum Dimensions and Weights of Motor Vehicles to be operated Over the Highways of the United States", officially adopted by AASHO in December of 1964.[1] If axles are spaced less than 40 inches apart (spacing in array AD), their weights are combined and considered as a single axle load. Individual axle weights of a tandem axle group are added together, but the sign is changed to negative to flag the weight as a tandem axle load.

Functions FKIP (Figure 2) and RKIP (Figure 3) were used to calculate the flexible or rigid 18-kip equivalents respectively with the argument the axle loads which were returned in array LOAD from SUBROUTINE AXLE.

The functions were initialized using an extension of FORTRAN IV, the ENTRY statement. If this extension is unavailable, equivalent

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[1]U. S. Department of Transportation Instructional Memorandum 50-4-66(4), June 14, 1967, page 18.

coding may be programmed by initializing the constants in COMMON which adds considerably to the computational speed as compared with a method which uses structural number, initial serviceability and terminal serviceability on each function call.

Kip equivalents used for this study were calculated using the AASHO Road Test formulas[2] with SN=3.0, CO=4.2, and P=2.5 with flexible pavement and with D=8.0, CO=4.5, and P=2.5 with rigid pavement, but results using different values would be very similar unless extreme values are selected. The example coding below will calculate the logarithm of the 18-kip equivalents for a vehicle on flexible pavement and place in variable LKIP.

```
      INTEGER AW, AD
      DIMENSION AW (8), AD(7), LOAD(8)
      DUMMY = FLEXIN (3.0, 4.2, 2.5)
            .
            .
      Read in data NA, AW, and AD
      TKIP = 0.0
      CALL AXLE (NA, AW, AD, LOAD, NL, NTL, N3, NTSL, NE)
      IF (NE.NE.0) GO TO 3
      DO 2 I = 1, NL
2     TKIP = TKIP + FKIP (FLOAT (LOAD (I))
      LKIP = ALOG10 (TKIP)
            .
            .
3     STOP
      END
```

[2]AASHO Road Test, Highway Research Board Special Report No. 73, pages 432-438.

Appendix C
Figure 1

SUBROUTINE AXLE
Page 1 of 2

```
      SUBROUTINE AXLE (NA, AW, AD, LOAD, NL, NTL, N3, NTSL, NE)
C A SUBROUTINE TO DETERMINE THE NUMBER AND WT. OF SINGLE AND TANDEM
C     AXLES OF A VEHICLE USING AASHO DECISION RULES ADOPTED DECEMBER 7,
C     1964.
C  REFERENCE . . .
C     U.S. DEPT. OF TRANS. INSTRUCTIONAL MEMORANDUM 50-4-66(4) OF JUNE
C        14, 1967, PGE 18.
C
C     NA = NUMBER OF AXLE WTS.
C     AW = ORIGINAL ARRAY OF INDIVIDUAL AXLE WTS.
C     AD = ORIGINAL ARRAY OF DISTANCES BETWEEN AXLES IN INCHES
C
C
C     LOAD = ARRAY OF AXLE LOADS WHERE THE AXLE MAY BE A SINGLE AXLE
C            AND THE LOAD THE SAME AS AXLE WEIGHT OR OR IT MAY BE THE
C            LOAD ON A TANDEM AXLE(THE COMBINED WEIGHT OF TWO AXLES)
C            THE SIGN OF A TANDEM AXLE LOAD IS CHANGED TO NEGATIVE
C
      INTEGER AW(1), LOAD(1), AD(1)
C  INITIALIZATION
C
C NL =   NUMBER OF AXLE LOADS
      NL = 1
C NTSL = NUMBER OF TIMES CONSECUTIVE AXLE WTS COMBINED INTO A SINGLE
C        LOAD ( AXLES CLOSER THAN 40 INCHES )
      NTSL = 0
C M = LOAD COUNTER
      M = 1
C N = AXLE COUNTER
      N = 1
C NTL =  NUMBER OF TANDEM LOADS
      NTL = 0
C N3 =   NUMBER OF 3 AXLE GROUPS - ONE TANDEM AND ONE SINGLE LOAD EACH
      N3 = 0
C NE = NUMERIC CODE SET NONZERO IF ERROR DETECTED
C     1 = WT. ERROR
C     2 = DISTANCE ERROR
C     3 OR GREATER = COMBINATION OF 1 & 2 OR A LOGIC ERROR
      NE = 0
C
      LOAD(M) = AW(N)
 1    IF ( N .GE. NA ) GO TO 2
      IF ( AD(N) .GE. 0 ) GO TO 111
         NE = NE + 2
         GO TO 2
111   N = N + 1
      IF( AW(N) .GT. 0 ) GO TO 121
         NE = NE + 1
         GO TO 2
121   CONTINUE
```

Appendix C
Figure 1

SUBROUTINE AXLE
Page 2 of 2

```
      IF ( AD(N-1) .GE. 40 ) GO TO 131
           LOAD(M) = LOAD (M) + AW(N)
 11        CONTINUE
           NTSL = NTSL + 1
           GO TO 1
131   M = M + 1
      LOAD(M) = LOAD(M) + AW(N)
      IF ( N .GE. NA ) TO TO 2
      IF ( AD(N) .GT. 8 ) GO TO 1
7     CONTINUE
      IF ( AD(N) .LT. 40 ) GO TO 1
      N = N + 1
      IF ( N .GT. NA ) GO TO 2
      LOAD(M) = LOAD(M) + AW(N)
      IF ( N .LT. NA ) GO TO 161
C
C     TANDEM AXLE
 151  NTL = NTL + 1
      LOAD(M) = - LOAD(M)
      GO TO 1
C
 161  IF ( AD(N) .GT. 96 ) GO TO 151
C
C     THREE AXLE GROUP
      N3 = N3 + 1
      IF ( AD(N) .GE. AD(N-1) ) GO TO 1
      LOAD(M)  = LOAD(M) - AW(N)
      M = M + 1
      LOAD(M) = LOAD(M) + AW(N)
      GO TO 7
 2    CONTINUE
      NL = M
      IWTOT = 0
      DO 15  II = 1, NA
 15   IWTOT = IWTOT + AW(II)
      DO 16 II = 1, NL
 16   IWTOT = IWTOT - IABS( LOAD(II) )
      IF ( IWTOT .EQ. 0 ) GO TO 17
         NE = NE + 3
 17   RETURN
      END
```

Appendix C
Figure 2

FUNCTION FKIP

```
      FUNCTION FKIP( AXLEL )
C   A FUNCTION TO CALCULATE THE 18 AXLE KIP EQUIVALENTS OF FLEXIBLE
C     PAVEMENT GIVEN  'AXLEL' THE LOAD ON AN AXLE OR ON A TANDEM AXLE
C     GROUP.  THE SIGN OF AXLEL IS IS NEGATIVE TO SIGNIFY A TANDEM AXLE.
C     THIS FUNCTION IS INITIALIZED USING THE ENTRY POINT FLEXIN AS ...
C     DUMMY = FLEXIN(3.0, 4.2, 2.5)
C
C REFERENCES...
C     HIGHWAY RESEARCH BOARD SPECIAL REPORT NO. 73, AASHO ROAD TEST.
C        PAGES 432-438
C     TEXAS HIGHWAY DEPT., PROGRAM ROTEST, SUBROUTINE TF
C
      REAL L1
      L1 = ABS(AXLEL) / 1000.
      IF( AXLEL .LT. 0.0) GO TO 10
C*** CALCULATION FOR SINGLE AXLE
      B = 0.4 +BD1081 * (L1 + 1.0)**3.23
      FKIP = (L1+1.0)**4.79 / T2 * T4 / 10.0**(GT/B)
      RETURN
C
C*** CALCULATION FOR TANDEM AXLE
 10   B = 0.4 +BD2081 * (L1 + 2.0)**3.23
      FKIP = (L1+2.0)**4.79 / T2 / T3 * T4 / 10.0**(GT/B)
      RETURN
C
      ENTRY FLEXIN( SN, CO, P )
C
C   AN ENTRY TO INITIALIZE CONSTANTS FROM GIVEN VALUES OF SN, CO, AND P
C     SN IS THE STRUCTURAL NUMBER ( NOMINALLY 3.0 IN TEXAS)
C     CO IS THE INITIAL SERVICIBILITY INDEX ( NOMINALLY 4.2 IN TEXAS)
C     P IS THE SERVICIBILITY AT THE END OF THE PERIOD
C        ( 2.5 IN TEXAS)
C
C        CONSTANT FOR BETA WITH SINGLE AXLE
      BD1081 = 0.081 / (SN+1.0)**5.19
C        CONSTANT FOR BETA WITH TANDEM AXLES
      BD2081 = 0.081 /     (   (SN+1.0)**5.19 * 2.0**3.23   )
C        BETA OF 18 KIP AXLE USED FOR EQUIVALENT
      B18 = 0.4 + (18.0 + 1.0)**3.23 * BD1081
      GT = ALOG10( (CO-P) / (CO-1.5) )
      T2 = (18.0 + 1.0)**4.79
      T3 = 2.0**4.33
      T4 = 10.0**(GT/B18)
      FLEXIN = 0.0
      RETURN
      END
```