*PROCEDURAL GUIDE FOR
ESTIMATING AXLE LOADINGS ON
A STATEWIDE BASIS*

JUNE 1965

NO. 8

*Joint
Highway
Research
Project*

by
R. H. LARSON

*PURDUE UNIVERSITY
LAFAYETTE INDIANA*

Final Report

PROCEDURAL GUIDE FOR ESTIMATING AXLE LOADINGS ON A STATEWIDE BASIS

To: K. B. Woods, Director
Joint Highway Research Project

May 18, 1965

From: H. L. Michael, Associate Director
Joint Highway Research Project

File: 3-3-32
Project: C-36-54FF

The Final Report attached "Procedural Guide for Estimating Axle Loadings on a Statewide Basis" has been prepared by Roy H. Larson, Graduate Assistant on our staff. Professor W. L. Grecco supervised the research and the preparation of the report. Mr. Larson also used the research report as his thesis for the MSCE degree.

The research was approved by the Board on March 6, 1964, under a plan of study titled "Intercity Truck Trips and Axle Loadings on State Highways in Indiana".

The results of this research suggests some changes which should be made by the State Highway Commission in the location of portable truck weighing stations to satisfy the needs of design in estimating axle loads. Professor Grecco has agreed to work with the Highway Planning Survey in discussing these changes and in using the Guide to develop statewide axle loads estimates on a statistical basis.

The report is submitted for the record.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Secretary

HIM:bc

Attachment

Copies:

F. L. Ashbaucher
J. R. Cooper
W. L. Dolch
W. H. Goetz
W. L. Grecco
F. F. Havey
F. S. Hill
G. A. Leonards
J. F. McLaughlin

F. B. Mendenhall
R. D. Miles
R. E. Mills
J. C. Oppenlander
W. P. Privette
M. B. Scott
J. V. Smythe
E. J. Yoder

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by
Roy Hilton Larson
Graduate Assistant

Joint Highway Research Project

File No: 3-3-32

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Purdue University

Lafayette, Indiana

May 18, 1965

ACKNOWLEDGMENTS

The author wishes to express his sincerest appreciation to Dr. William L. Grecco, Associate Professor of Civil Engineering, for his assistance, encouragement, and support throughout the research and writing; to Robert A. McLean of the Statistical Laboratory, for his advice on the statistical design and analysis of the data; to Dr. Harlley E. McKean and Dr. Joseph C. Oppenlander for review of the manuscript; and to the Joint Highway Research Project at Purdue University for its sponsorship of this investigation.

Appreciation is also expressed to the Indiana State Highway Commission and the Bureau of Public Roads for their fine cooperation.

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ABSTRACT

Larson, Roy Hilton, MSCE., Purdue University, June 1965.
Procedural Guide for Estimating Axle Loadings on a Statewide Basis. Major Professor: William L. Grecco.

The number and magnitude of axles passing over a section of highway is an important consideration in the design of the surface course, the base, and the subbase of a highway. The purpose of this research report was to provide a method for estimating the axle loadings on the statewide highway system.

The Procedural Guide which was developed provides a statistical approach to establishing station similarities on a statewide basis. The Guide is composed of five parts. They are:

1. Sections;
2. Data collection;
3. Data analysis;
4. Continuing phase; and
5. Calculation of axle loadings.

Each part contains recommendations for the different phases of a study. The analysis of data is given in a step by step procedure. The analysis provides for the

determination of station similarities by stations or by truck types. Data collected at one station may be used to estimate equivalent axle loadings for all similar stations. Each year, similar stations are to be replaced with additional stations until a statewide coverage is obtained. In the following years only a classification count will have to be performed at the similar stations. The statistical techniques which were used include the Analysis of Variance, the Foster-Burr Test for homogeneity of variance, the Newman-Keuls Sequential Range Test, and the T-Test.

The analysis of the 1963 data indicated that the procedure suggested in the Guide is a feasible approach to the problem of statewide axle loading prediction.

INTRODUCTION

The important role of transportation in the stimulation of the economy of a country has long been known. The development of the United States first took place around seaports; later canals linked the sources of raw materials with the industrial areas and the seaports. However, major expansion of the United States economy took place in the nineteenth century with the development of a transcontinental railroad system. In the twentieth century the introduction of the motor vehicle caused a significant change in the technology of transportation. Today the entire field of transportation accounts for one fifth of the Gross National Product.

The development of a vast highway system was undertaken to meet the demands caused by the motor vehicle. In 1939 the Public Roads Administration recognized the need for a nationwide freeway system. The objectives of the Interstate System were set forth in the Interregional Highway Report of 1944:

"The cities and metropolitan areas of the country are known to include the sources and destinations of much the greater part of the heavy flow of traffic that moves over the Nation's highways. The system of interregional highways proposed, within the limit of the mileage adopted, connects as many as possible of the larger cities and metropolitan areas regionally and interregionally. For this reason, although in miles it represents scarcely over one per cent of the entire highway and street system, it will probably

serve not less than 20 percent of the total street and highway traffic.

"In the selection of all of these systems, one common objective prevailed: To incorporate within each of the several mileage limits adopted, those principal highway routes which would reach to all sections of the country, form within themselves a complete network, and jointly attract and adequately serve a greater traffic volume than any other system of equal extent and condition." (6)*

With the continuation of the trend of urbanization, cities and metropolitan areas will contribute an increasing share of the traffic flow on the nation's highways. The Federal Highway Act of 1956 authorized the Interstate System which exists today. The number of motor vehicles registered in the United States as shown in Figure 1 has risen from 8,000 in 1900 to a total of 81,000,000 in 1963. Eighty percent of all families in the United States own one or more automobiles. Individually and nationally, there is a vital dependence on motor vehicle transportation. One of every seven persons in the United States is employed in highway transport industries while one business in six is dependent on the manufacture, distribution, servicing, and use of motor vehicles. (18) These proportions will increase in the future because of the development of Interstate highways and the increasing highway orientation of the people.(6)

* Numbers in parentheses refer to entries in the List of References.

FIG. 1 GROWTH OF MOTOR VEHICLES
IN THE UNITED STATES
REFERENCE (6)

Importance of Truck Movement of Goods

Since the introduction of the motor vehicle the number of trucks and the amount of goods moved by trucks has increased rapidly. As shown in Figure 2, there were 700 trucks registered in the United States in 1904. There was a moderate increase in the number of trucks until the year 1915. Since that time the number of truck registrations has mushroomed to a total of 13.3 million vehicles. This giant fleet represents 40 percent of the world's trucks.

(2)

Truck travel in 1963 reached 91 billion miles over main rural and local roads and 49 billion miles over urban streets. The total of 140 billion truck miles in and between cities represents an increase of 5 billion miles over the previous year and was triple the 1939 truck mileage. These facts are shown in Figure 3. (2) The total of 140 billion miles represent 17 percent of the total vehicle miles traveled in 1963.

The movement of goods by truck has shown a parallel increase with truck registration and vehicle miles. In 1939, the first year that intercity ton-miles of freight for trucks were recorded, trucks were credited with 53 billion ton-miles. In 1963 trucks were credited with 347.9 billion ton-miles or 23.8 percent of the total ton-miles carried by intercity freight carriers. This

FIG.2 GROWTH IN TRUCK USE IN THE UNITED STATES

FIG. 3 TRUCK VEHICLE MILES
REFERENCE (2)

represents a 101 percent increase in the rate of growth since 1950. (2) Figure 4 shows the percentage breakdown of intercity ton-miles of freight by carrier type.

Trucking is big business in Indiana. The trucking industry represents the largest single source of employment, creating jobs for 248,209 people and an annual payroll of 1.2 million dollars. In Indianapolis alone, there are over 100 common carrier lines serving the city and over twelve major freight lines maintain headquarters there. In the state 86.8 percent of all outbound freight is handled by trucks. Of the 858 post offices in the state of Indiana, 654 or 77 percent receive and send all their mail by motor transport. A total of 1,580 or 49.6 percent of the Indiana communities depend entirely on trucks for all freight transportation. In addition over 90,000 farm trucks are engaged in hauling agricultural products from Indiana farms. (28) With the increase in industries and research and development programs, the motor truck will become an increasingly important part of the state economy.

Truck Weight and Volume Estimation

Because of the increasing volume of intercity freight transported by commercial highway vehicles an estimate of the number of axle load applications and truck volumes on a specific section of a highway is needed by highway engineers, planners, and administrators. This information

FIG.4 TON-MILE DISTRIBUTION
AMONG INTERCITY FREIGHT CARRIERS

REFERENCE (2)

is essential for the determination of design standards, for the systematic classification of highways, and for the development of programs for improvements and maintenance. In addition, the number of axle load applications and total truck volumes are important for the development of highway financing and taxation schedules and for the measurement of the service provided by highway transportation.

A theoretical approach to the prediction of intercity travel is not new. As early as 1889 an Austrian scientist, Edward Lill, proposed a law of travel expressed as $XY = M$. M is a constant which represents the travel value of a particular place, while Y represents the number of travelers going to or beyond a place located at a distance X from a starting point. (25) More recently inter-community traffic models have been used for the following purposes: (16)

1. Highway and road classifications
2. Regional analysis and planning
3. Community analysis and planning
4. Impact studies, and
5. Synthetic origin and destination studies.

The most common inter-community traffic model is the "gravity model." It was first used for classification studies in Illinois, Michigan, and Washington. (16, 19) During 1959 James Burch conducted a study measuring the interactance between five cities in North Carolina. (4) As a result of this study the "gravity model" was applied

on a statewide basis to classify all rural roads into functional systems. At the same time the Automotive Safety Foundation was conducting a statewide study of road and street needs in Iowa. A conceptual model developed by Alan Voorhees was used to produce an index of travel desire rather than the actual number of trips. (16) Although there has been many studies using the gravity model to determine the total travel or travel desire, little work has been done to determine the volume of truck trips between cities. However, a recent study by Magne Helvig at the University of Chicago considered Chicago's sphere of influence as revealed by motor truck movements. A predictive gravity model based on the results of a simple regression analysis was developed. The analysis of the data was performed separately for three different zonal levels. The three levels were from entire states, from counties in the four state area, and from local communities adjoining the Chicago area. Three main hypotheses were formulated on the basis of an existing body of generalizations and theories concerning spatial interaction in general and transportation in particular. Statistical methods were used to test the hypotheses and the results were:

1. It was demonstrated that there is a functional relationship between number of truck trips generated by an area and its structure and magnitude and distance to the area of destination.

2. Truck movements follow general underlying laws of interaction.
3. It was demonstrated that it is possible to develop a generalized model which accounts for the major proportion of areal variations in truck trip generation and this can be applied in the estimation or prediction of interarea truck movements. (9)

Herein lies an approach which may yield adequate prediction of intercity truck volumes for a proposed highway.

A second approach to the prediction of truck volumes and axle loadings is the combined use of two subsystems to weigh axles and to measure truck dimensions. Two types of platform scales are used to weigh vehicles in-motion. When loads are classified into weight groups a broken bridge type scale is the better as it provides discrete weight values. However, the rigid platform type scale was concluded to be the better choice when in-motion measurements are to be made and recorded and no manual manipulation is to be made of the recording. (23) The Franklin Institute is presently conducting research in the evaluation of new or existing equipment for weighing vehicles in-motion. In addition, the Institute is determining the relationship between the static weight of an axle and its dynamic load. (30)

The second subsystem provides a measure of the length of each vehicle by considering both the speed of the vehicle and the amount of time it takes to pass through a photocell beam. A study was conducted by the Port of New York Authority to determine how well vehicle length identifies

type. As shown in Figure 5, the results of the survey reveal that vehicle length is a very good indicator of classification. (5) The Michigan State Highway Department has completed a research project investigating the automatic weighing and dimensional measurement of vehicles in motion. The Department has established operating procedures for use in gathering data for a statistical analysis. Recommendations have been made for a fully automatic system with modifications for improved accuracy as well as automation of operation. The complete automatic system has been recommended for development and testing as part of Michigan Project 52F-26. (17) The use of an automatic data system would provide the engineer with an accurate record of all traffic in terms of volume classifications and weight applications. Such records would be invaluable for future design purposes.

The third and most commonly used approach to the prediction of truck volumes and axle loadings is the use of volume classifications and/or loadometer studies. One method requires the computation of equivalent axle applications from loadometer studies made for a given design situation. A second procedure uses loadometer studies to establish factors for vehicles of each type. These factors are then weighted according to the percentage of each truck type determined for a given design problem. The advantage of this method is that it provides an estimate

FIG.5 PLOT OF FREQUENCY DISTRIBUTION BY PERCENT
OF VEHICLE LENGTHS IN ONE FOOT CLASSES
REFERENCE (5)

of loads on the basis of count data from locations where there are no loadometer stations. A third procedure which uses the same data as the previous method is that of computing a weighted mean factor for all truck types. This factor is then multiplied by the number of trucks expected. This latter method requires stability in truck type distributions to obtain reasonable accuracy.

All the methods mentioned previously - theoretical prediction of truck trips; weighing in-motion and classification studies; and loadometer studies and classification counts - are important in the prediction of future truck trips. Each has inherent advantages and disadvantages which the engineer must evaluate when he selects a method to use for predicting present and future truck trips.

Purpose and Scope

The purpose of this research was to develop a Procedural Guide for establishing an estimate of the traffic load pattern for the Indiana State Highway System.

The study included the application of statistical techniques to the analysis of truck weights in the state of Indiana. In particular the study investigated the establishing of station similarities on a statistical basis. The analysis was performed on 1963 loadometer data and recommendations were made concerning future data collection and analysis.

TRUCK WEIGHT AND CLASSIFICATION STUDIES

The Bureau of Public Roads has cooperated with several states in the designing of pilot studies for truck weighing and vehicle classification counting. The states which have conducted pilot studies in truck weighing are:

1. New Hampshire,
2. Wisconsin,
3. North Dakota,
4. South Dakota,
5. Oregon, and
6. Mississippi.

North Dakota and Oregon have conducted pilot studies in vehicle classification. These pilot studies were based on probability procedures so that the reliability of the data collected could be evaluated. The importance of obtaining weight and classification data is emphasized when the design curves developed as a result of the AASHO test road are used.

The sample design used in the pilot truck weight studies is a stratified cluster sample. The highway section or loadometer station within the highway systems and the day of operation were selected on a random basis. In two states

the sampling period for trucks was a 15 minute interval while all other states used an interval of 10 minutes. All vehicles of specified types were scheduled to be weighed only when they approached the weighing location during the selected sampling intervals.

The analysis of the data was based on formulas appropriate to cluster sampling. Each stage of sampling makes a contribution to sampling variability. The Bureau of Public Roads in the analysis of sample design computed the amount of sampling variability contributed by each sampling stage. However, to calculate the standard error of any estimate only a measure of the total sampling variability was needed. Any average, such as average weight in which the denominator is the number of vehicles, is a ratio of two random variables; namely, the weights yielded by clusters and the number of vehicles yielded by clusters. Formulas applicable to ratio estimates applied to cluster samples must be used to compute the standard error of such estimates. (20)

In addition to the analysis of the design of the sampling program the Bureau of Public Roads is performing the following tests:

1. Variation of loading characteristics by truck types between highway systems,
2. A measure of the variation of loading characteristics by vehicle type by 8-hour periods,

3. A comparison of estimates based upon the data collected using statistical principles versus information collected during the preceding two years without the use of statistical techniques, and
4. A comparison of variation in truck weight characteristics by seasons of the year.

The data from the pilot studies is being analyzed and will be completed during 1965.

In 1959 the Bureau of Public Roads in cooperation with the Mississippi State Highway Department performed a statistical analysis of truck weight data in the state of Mississippi. The primary purpose of the study was to investigate the possibility of obtaining mean weights by simplified methods of similar quality to those presently obtained. More specifically, it was hoped that the study would show that a truck weighing schedule could be developed which would provide results which would be representative of axle and vehicle mean weights of both daylight and night operations by daytime sampling only.

A preliminary analysis of vehicle and axle weights was performed to determine if the station mean weights could come from a single statistical population. The assumption was made that weight distribution obeyed the Gaussian Law. The F test which was made on the means indicated whether or not the spread of the normal distribution of

weights obtained at one station differed significantly from the spread of the normal distribution obtained at other stations. The F test is given below. The within station variance is computed as follows:

$$S_w = \left[\sum A_1^2 - \frac{(\sum A_1)^2}{N_1} \right] + \left[\sum A_2^2 - \frac{(\sum A_2)^2}{N_2} \right] + \dots + \left[\sum A_m^2 - \frac{(\sum A_m)^2}{N_m} \right]$$

$$V_w = \frac{S_w}{N_w}$$

The between station variances is computed as follows:

$$S_b = \frac{(\sum A_1)^2}{N_1} + \frac{(\sum A_2)^2}{N_2} + \dots + \frac{(\sum A_m)^2}{N_m} - \frac{(\sum A)^2}{N}$$

$$V_b = \frac{S_b}{n_b}$$

where:

A = individual weight

$\sum A_i$ = total of weights at station i

$\sum A$ = total of weights at all stations

N_i = number of weights at station i

N = total number of weights

n_w = degrees of freedom, within stations

n_b = degrees of freedom, between stations

S_w = squares, within stations

S_b = squares, between stations

V_w = variance within stations

V_b = variance between stations

m = last weight

$F = \frac{\text{Larger variance}}{\text{Smaller variance}}$

The larger variance could be either V_w or V_b .

The results of this test indicated that some truck types such as the 2-axle truck with dual tires (type 13) and the 3-axle motor truck (type 14) could come from single populations while the 2-axle tractors and 2-axle trailers would not be expected to come from the same single population.

Because of the observed population heterogeneity a sample size design criterion was set up using a ± 5 percent standard error of the mean on the 95 percent confidence limit.

Defining the population as all units weighed, the number of units required in the sample was computed according to the design specification. The determination of the required sample size indicated that the variation of axle weights was larger than the variation of vehicle weights; therefore, the minimum number of vehicles to be selected for a sample is indicated by the largest sample requirement of any axle for a given vehicle type. It was the practice in Mississippi to weigh all heavy vehicles passing a weighing station. However, the mean weights of those vehicles were less precise than ± 5 percent error on the 95 percent confidence interval. This indicated that a change in the frequency of weighing or an increase in the number of weighing stations would be necessary if the specified statistical precision was to be obtained. Since the mean weights obtained by existing procedures were acceptable for use by engineers and administrators the study investigated the possibility of further reduction of sample size as long as the precision of the mean weight from still smaller samples would not be significantly different from those actually obtained.

The following statistical tests were used to determine if a smaller sample was representative of the larger sample

or the population. T-Test of significant differences between means is:

$$T = \frac{M_1 - M}{S E}$$

F test of significant differences between variances is:

$$F = \frac{V_1}{V_2}$$

where:

M_1 = mean of the larger sample

M = mean of the smaller sample

SE = standard error of the mean of the smaller sample

V_1 = larger variance

V_2 = smaller variance

The results of the tests of means indicated that the desired information concerning the mean vehicle and axle weights could be obtained during the eight hour period, 2 p.m. to 10 p.m. and those weights would be representative of the 24 hour weighing operations. The 8 a.m. to 4 p.m. period showed some significant differences for total weights of empty vehicles (type 22), for some of the axle loads empty, and for total weights of loaded vehicles of

the same type at weigh stations on rural roads. There was no significance for either test for any vehicle type or any axle during the 8 a.m. to 4 p.m. period in the urban areas.

The results of the F tests for significant differences between variances indicated that 7 stations which could not be identified with the population of the 18 rural stations were all located on the roads of the Interstate System. There were no significant differences of variances at the 12 remaining stations. However, one station located on the Primary state highway showed a significant difference by the T-Test.

(22)

The Wisconsin Highway Department performed an analysis of mean weights for selected vehicle types on weight data collected at 20 Other Main Rural (OMR) loadometer stations in 1963. The specific objective of the analysis was to determine if the mean weights of various types of vehicles from all samples of the 20 Other Main Rural stations were significantly different from the means of other selected samples. The following tests were performed:

1. 3 vs. 4,
2. 3 vs. 2, and
3. 3 vs. 1.

Where

Sample	Hours
1	6 a.m. to 2 p.m.
2	2 p.m. to 10 p.m.
3	all 8 hour shifts (including 10 p.m. to 6 a.m.), and,
4	8 a.m. to 4 p.m.

The statistical test used to determine if significant differences occurred between pairs of means was the T-Test or Least Significant Difference Test.

The results of the study indicated that there was no significant differences between samples 3 and 4 at the level of .01. On the basis of this analysis the Wisconsin Highway Department proposed to reduce their loadometer weighing operations to a 8 a.m. to 4 p.m. shift on all OMR locations.
(27)

It is noted for this analysis that neither the Mississippi study nor the Wisconsin study collected their weight data on a true probability sampling basis. In Mississippi, all heavy vehicles passing the weigh station were weighed. In Wisconsin, some effort was made to acquire a random sample by selecting vehicles to be weighed in approximate proportion to the total number of vehicles of each type as opposed to the total number of all trucks in the traffic stream at high volume locations.

At the present time the Michigan Highway Department is conducting a research project, entitled "State Wide

Determination of Highway Loadings and Conversions to 18 Kip Single Axle Load Equivalence." The objective of this study is to obtain information on traffic volumes and loadings so that a traffic axle load pattern for the state highway system can be established. Some of the individual items which are being investigated are:

1. A general relationship or several individual relationships between the frequency of axle load magnitude and each truck type.
2. The number of truck classification surveys needed to cover the state highway system.
3. The determination of hourly, daily and monthly factors to expand loadometer or truck classification counts into weekly, monthly, or annual periods.
4. The accuracy of average daily traffic and percent commercial data obtained by representative sampling of truck traffic.
5. A systematic classification of pavements by type and magnitude of truck traffic to provide information on statewide traffic load trends.

Data for this project is being collected at the present time.

HISTORY OF LOADOMETER STUDIES IN INDIANA

The loadometer studies were first started in 1939 by the Indiana Highway Department. At that time approximately 90 locations were considered as possible sites for the weighing operations. On the basis of the opinion of their staff 20 locations were selected which would be representative of the state highway system. Some additional considerations on the location of the stations were adequate truck volumes to obtain a large amount of weight data and the minimization of disruption to the traffic stream while the loadometer stations were in operation. The number of stations to be operated was based on the number that could be operated during a one month period when only one station is operated each day. More recently the Indiana Highway Department has added two loadometer stations in urban areas at the request of the Bureau of Public Roads. In addition one or two stations have been operated for specific purposes. The present locations of the 22 loadometer stations are shown in Figure 6. The location description for each station is given in Table 1. Under present plans of the Interstate System, there will be seven permanent scales available for truck weighing in the approximate locations shown in Figure 7.

FIG.6 LOCATION OF PRESENT LOADOMETER STATIONS

TABLE 1
LOCATIONS OF PRESENT LOADOMETER STATIONS
IN THE STATE OF INDIANA

<u>Station</u>	<u>Location</u>
2	On U.S. 20, 0.60 mile W. of the Jct. of S.R.2. (Laporte Co.)
4	On U.S. 31, 1000' S. of the Jct. of U.S. 6. (Marshall Co.)
5	On U.S. 30, 130 miles E. of E. city limits of Bourbon. (Marshall Co.)
9	At State Police Pit Scale No. (3-13), located on U.S. 24 and 35, 0.40 miles E. of the Jct. of U.S. 24 and 35. (Cass Co.)
12	On U.S. 24 and 52, 2.25 miles W. of Jct. of U.S. 41 and 52 in Kentland, (Newton Co.)
14	On U.S. 41, 0.5 miles S. of the N. Jct. of S.R. 2. (Lake Co.)
15	At State Police Pit Scale No. (1-2), located on U.S. 30 between S.R. 55 and S.R. 53. (Lake Co.)
16	At State Police Pit Scale No. (1-3), located on U.S. 6, 3.0 miles W. of Jct. of S.R. 49. (Porter Co.)
23	On U.S. 20, 0.50 miles E. of the Jct. of S.R. 15. (Elkhart Co.)
27	On S.R. 9, 950' S. of the Jct. of S.R. 218. (Huntington Co.)
29	On S.R. 9, (State St.) in Greenfield, between Pa. RR and Osage St. (Hancock Co.)
33	On U.S. 24, 0.30 miles W. of the Jct. of S.R. 14. (Allen Co.)
34	On S.R. 22, (Sycamore St.) in Kokomo, between Phillips and McCann St. (Howard Co.)

TABLE 1 (continued)

Station	<u>Location</u>
42	On U.S. 52 - 600' S.E. of N. Jct. of S.R. 28. (Tippecanoe Co.)
45B	On S.R. 67, 1.00 mile S.W. of Muncie. (Delaware Co.)
58B	On U.S. 31, 2000' S. of the Jct. with the Southport Rd. (Marion Co.)
61	On U.S. 52, 1.30 miles S.E. of the Jct. of U.S. 52 and S.R. 3, S. of Rushville. (Rush Co.)
63	At State Police Pit Scale No. (6-4), located on U.S. 35 and U.S. 40, 1.50 miles E. of Richmond. (Wayne Co.)
68	On U.S. 50, 1.25 miles W. of W. Corp. limits of Aurora. (Dearborn Co.)
75	On U.S. 41, 0.25 miles S. of the Jct. of U.S. 41 business route (Vigo Co.)
81	On U.S. 150, 0.30 miles E. of Jct. S.R. 56. (Orange Co.)
83	At State Police Pit Scale No. (8-1), located on U.S. 41, 0.50 miles N. of Jct. of S.R. 57. (Vanderburg Co.)

FIG.7 INTERSTATE WEIGH STATION LOCATIONS
REFERENCE (31)

At the present time the weighing operations are conducted in the eight hour period from 8 a.m. to 4 p.m. Classification counts are made at the same time for the eight hour period. Classification counts for the other two eight hour periods are conducted within one month before or after the loadometer study. A general sampling program for the selection of trucks to be weighed is followed. The first five empty trucks along with the loaded trucks of a given type are weighed. When possible a constant backlog of approximately 10 vehicles are held for weighing. Almost all semi-trailer trucks are weighed. In addition all trucks with uncommon axle configurations are weighed.

In the past the results of loadometer studies have been used by the highway department engineers for the design of pavements and the testing of subgrade soils. More recently the highway department is using the results of the loadometer studies in pavement life studies.

PROCEDURAL GUIDE

The purpose of this interim guide is to provide a procedure for making estimates of the traffic axle load patterns based on the traffic volume counting program and the loadometer study program in Indiana.

The traffic volume counting program has been an established program for many years. Following the recommendations made in the "Guide for Traffic Volume Counting Manual" which was based on statistical analysis and experience in the application of statistically controlled procedures in over thirty states, the standard deviation of the errors of the estimate is reduced to $\pm$ ten percent for roads carrying approximately 500 average daily traffic (ADT) or more.

The application of statistical analysis and statistically controlled procedures to the loadometer study program is relatively new. It is expected that the guide will be reviewed and revised as may be found necessary through practice and further research. On the basis of existing information and the analysis of 1963 loadometer study data the following guide was developed. The analysis portion of the guide relies heavily on the use of Statistical Laboratory Library Programs and the IBM 7094 computer

installation at Purdue University. The use of these programs and the computer facility reduces the amount of work considerably. However, the importance of having some knowledge of the mathematical theory of statistics, an acquaintance with the statistical techniques used, the limitations and advantages of each, the assumptions upon which they are based, the place each occupies in a logical analysis of the data, and the interpretation which can be made from them cannot be over emphasized.

Sections

The highway systems under consideration should include the Federal Aid Secondary in addition to the Interstate, Federal Aid Primary and Urban systems. The roads in the four systems are to be divided into sections of varying length based on the following criteria:

1. There is at least one location within the section suitable for conducting loadometer operations.
2. The weight distribution is relatively constant throughout the section.

The first criteria provides for the safety of the weighing party and the general public. It also minimizes the disruption to the traffic stream. The second criteria insures that the distribution of weights obtained at the weighing location is similar to the distribution of weights anywhere else within the road section. Since the second

criteria requires a knowledge of the local road characteristics it may be desirable to do a portion of work at the district level. However, it may be highly impractical to end all sections at district boundaries. Some review of the sections may be necessary at a higher level in the highway department.

In addition to considering the four systems the Bureau of Public Roads and the State Highway Commission have indicated a need for axle load and frequency data on urban arterials in major cities and on county roads. A urban arterial which would provide a large amount of truck weight data is South Street from East Street to West Street in Indianapolis. This street is a major intra-city truck route which carries approximately 80 percent trucks.

Data Collection

No additional data will be needed other than that data collected under normal truck weight study operations. The standard instructions issued by the Bureau of Public Roads in the Instructional Memorandum for the Truck Weight Study should be followed.

Vehicle Classification

The classification of vehicles will be consistent with past practices. However, a 24 hour classification count is requested at each station on the same day that trucks are

weighed at the station. This requirement is necessary to give a more accurate estimate of the proportion of a given truck type in the traffic stream during the 24 hour periods.

When each truck is weighed the vehicle should be classified as loaded or empty. All trucks carrying any amount of cargo should be classified as loaded except those vehicles containing small amounts of liquid or dry commodities which were not discharged when the vehicle was unloaded. A vehicle that is carrying empty drums, pallets, crates, bins or other than truck load size containers should be classified as loaded. For trucks that are making "containerization" shipments where the container is so large that only a single container is carried, the vehicle should be classified as empty if the container is empty. Containers include removable van type bodies which are designed for transfer to rail cars or ships, truck load size rubberized collapsible containers used for hauling liquid commodities in van or flat bed bodies, large refuse containers transported by vehicles designed to lift them, and other similar apparatus. If the vehicle is carrying more than one collapsible container, or if it is carrying cargo in addition to a collapsed container, it should be classified as loaded. (12)

Weighing Vehicles

Since the reliability of the data and its analysis is dependent upon the care exercised in the weighing of the vehicles, the operation of the loadometers should be consistent with approved practices. All wheels of the truck or combination should be on the same horizontal plane with brakes released at the time of weighing. If the brakes must be set when weighing with loadometers, the brakes should be released after the vehicle has been stopped on the loadometers and then reset. (12)

Sampling from the Traffic Stream

An important assumption in the analysis and interpretation of the results in the proposed program is that a representative sample of each vehicle type be obtained at each station. The equivalent axle load distribution and the percentages of loaded vehicles of each type are determined from the sample of vehicles selected for weighing. For this reason a probability sampling procedure must be used.

The sampling procedure recommended is that which the Bureau of Public Roads in cooperation with several highway departments developed and tested in its truck weight and classification studies. This procedure assures probability sampling at locations where volumes are so great that all passing trucks cannot be weighed. The weighing period is

divided into ten minute intervals. A given vehicle type is assigned intervals on a pre-determined sampling rate with a random start. A vehicle of a given type is weighed if it arrives in a designated interval. If the vehicle arrives during an undesignated interval, the vehicle is allowed to bypass the loadometers. All infrequently occurring vehicle types and all vehicles with uncommon axle configurations and spacings are weighed. At the lower volume stations it may be desirable to sample 100 percent of all semi-trailer combinations. At locations where volumes are extremely high, it may be necessary to reduce sampling rates so that all vehicles of given types that arrive during an interval are weighed in that interval. Table 2 shows the sampling rates which appear feasible on the basis of the number of vehicles weighed and counted in 1963 for the Indiana loadometer study in 1965. The stations have been grouped into three classes on the basis of their ADT. Tables 3, 4, and 5 show the schedule for weighing vehicles during the first two hours. The extension to the remaining two hour periods is a repeat of the given schedules. It is requested that the 10 minute interval in which the individual truck is weighed be recorded.

If the state highway commission desires to weigh trucks passing the loadometer scale which were not designated to be weighed on the probability sampling basis, a record should be kept so that these trucks can be omitted from the data used in the subsequent analysis.

TABLE 2
SAMPLING RATES

A.D.T.	Vehicle Type					All Others
	2 axle 4 tires	2 axle 6 tires	3 axle	2S1	2S2	3S2
5,000	1/2	1/2	1/1	1/1	3/4	1/1
5,000-10,000	1/4	1/2	1/1	3/4	1/2	1/1
10,000	1/4	1/4	1/2	1/2	1/4	1/1

TABLE 3

INDIANA LOADOMETER STUDY INTERVAL SCHEDULE

Schedule for weighing vehicles during
first two hours at stations having
ADT less than 5,000

(Values are in units of 10-minute intervals)

Station	2 Axle 4 Tires	2 Axle 6 Tires	3 Axles	2S1	2S2	3S2
12	1,3,5,7,9,11	2,4,6,8,10,12	All	All	1,3,4,5,7,8,9,11,12	All
23	1,3,5,7,9,11	2,4,6,8,10,12	All	All	1,3,4,5,7,8,9,11,12	All
61	1,3,5,7,9,11	2,4,6,8,10,12	All	All	1,3,4,5,7,8,9,11,12	All
81	2,4,6,8,10,12	1,3,5,7,9,11	All	All	2,3,4,6,7,8,10,11,12	All
29	1,3,5,7,9,11	2,4,6,8,10,12	All	All	1,3,4,5,7,8,9,11,12	All
34	2,5,6,8,10,12	1,3,5,7,9,11	All	All	2,3,4,6,7,8,10,11,12	All

TABLE 4

INDIANA LOADOMETER STUDY INTERVAL SCHEDULE

Schedule for weighing vehicles during
first two hours at stations having

ADT of 5,000 to 10,000 VPH

(Values are in units of 10-minute intervals)

Station	2 Axle 4 Tire	2 Axle 6 Tire	3 Axles	2S1	2S2	2S3
2	4,8,12	1,3,5,7,9,11	All	2,3,4,6,7,8,10,11,12	1,3,5,7,9,11	2,4,6,8,10,12
4	1,5,9	2,4,6,8,10,12	All	1,3,4,5,7,8,9,11,12	2,4,6,8,10,12	1,3,5,7,9,11
5	1,5,9	2,4,6,8,10,12	All	1,3,4,5,7,8,9,11,12	2,4,6,8,10,12	1,3,5,7,9,11
16	4,8,12	1,3,5,7,9,11	All	2,3,4,6,7,8,10,11,12	1,3,5,7,9,11	2,4,6,8,10,12
27	2,6,10	1,3,5,7,9,11	All	2,3,4,6,7,8,10,11,12	1,3,5,7,9,11	2,4,6,8,10,12
45	1,5,9	2,4,6,8,10,12	All	1,3,4,5,7,8,9,11,12	2,4,6,8,10,12	1,3,5,7,9,11
68	3,7,11	2,4,6,8,10,12	All	1,3,4,5,7,8,9,11,12	2,4,6,8,10,12	1,3,5,7,9,11

TABLE 5

INDIANA LOADOMETER STUDY INTERVAL SCHEDULE

Schedule for weighing vehicles during
first two hours at stations having
ADT greater than 10,000
(Values are in units of 10-minute intervals)

Station	2 Axle 4 Tire	2 Axle 6 Tire	3 Axle	2S1	2S3	3S2
9	4,8,12	1,5,9	1,3,5,7,9,11	2,4,6,8,10,12	2,6,10	3,6,9,12
14	1,5,9	2,6,10	2,4,6,8,10,12	1,3,5,7,9,11	3,7,11	1,4,7,10
15	4,8,12	1,5,9	1,3,5,7,9,11	2,4,6,8,10,12	2,6,10	3,6,9,12
33	2,6,10	3,7,11	1,3,5,7,9,11	2,4,6,8,10,12	4,8,12	2,5,8,11
42	4,8,12	1,5,9	1,3,5,7,9,11	2,4,6,8,10,12	2,6,10	3,6,9,12
58	4,8,12	1,5,9	1,3,5,7,9,11	2,4,6,8,10,12	2,6,10	3,6,9,12
63	4,8,12	1,5,9	1,3,5,7,9,11	2,4,6,8,10,12	2,6,10	3,6,9,12
75	1,5,9	2,6,10	2,4,6,8,10,12	1,3,5,7,9,11	3,7,11	1,4,7,10
83	3,7,11	4,8,12	2,4,6,8,10,12	1,3,5,7,9,11	1,5,9	2,5,8,11

If so many vehicles arrive in a time interval that vehicles have to be passed without weighing, the record should indicate the station number, the vehicle type, and the 10 minute interval. This information will be used to re-evaluate the sampling rate for future studies. Vehicles should be by-passed without bias to truck type or loaded condition.

The procedure of selecting vehicles for weighing from one directional flow of traffic for four hours and then changing to the opposite direction should be continued. However, the initial direction of flow which will be sampled has been assigned on a random basis to eliminate any possible bias. The station number and the randomly assigned direction of flow to be sampled during the first four hour period is given in Table 6.

An additional consideration in the collection of data is the scheduling of the field operations on a probability basis. The purpose of this scheduling is to reduce the possibility of bias which could arise from weighing of a station on a given day of the week or from weighing stations in a fixed order.

There are three restrictions which must be satisfied in making the assignment. They are:

1. The distance traveled between stations must be limited.
2. The loadometer stations are not to be operated on the Friday previous to or the Tuesday and Friday following a holiday.

TABLE 6
SCHEDULE OF OPERATIONS
FOR 1965 LOADOMETER SURVEY

Date	Day	Station	Direction of Flow to be Sampled in first four hour period
Aug. 23	Monday	58	N
Aug. 24	Tuesday	61	NW
Aug. 25	Wednesday	29	N
Aug. 26	Thursday	63	E
Aug. 27	Friday	68	W
Aug. 30	Monday	58	N
Aug. 31	Tuesday	81	E
Sept. 1	Wednesday	83	S
Sept. 2	Thursday	75	N
Sept. 8	Wednesday	42	SE
Sept. 9	Thursday	45	N
Sept. 13	Monday	23	E
Sept. 14	Tuesday	5	E
Sept. 15	Wednesday	4	N
Sept. 16	Thursday	33	S
Sept. 17	Friday	27	S
Sept. 20	Monday	12	W
Sept. 21	Tuesday	16	W
Sept. 22	Wednesday	2	W
Sept. 23	Thursday	15	W
Sept. 24	Friday	14	N
Sept. 27	Monday	34	E
Sept. 28	Tuesday	9	E

3. A practice session will be held on the first Monday at Loadometer Station No. 58.

A procedure with limited modifications which will meet the restrictions is to stratify the stations on the basis of geographic location and then randomly assign the groups and the stations within groups. Upon examination of the groupings by geographic area it was found that the distances between stations in Southern Indiana prevented the scheduling within the group on a purely random basis. The stations 75, 83, and 81 must be scheduled in that order or the reverse order. With this consideration the loadometer stations must be scheduled for the operation of four stations in each of two weeks, five stations in each of two weeks and two stations during the Labor Day week. The remaining stations are to be operated in the sixth week. Two stations were selected at random from the third group and were scheduled to be operated during the Labor Day week. The remaining stations were assigned at random in the sixth week. The schedule developed on this basis is shown in Figure 6. If it becomes impossible to operate the station on the scheduled day because of rain, the first available day after the end of the scheduled operations may be substituted.

The schedule of operations for the loadometer stations is presented for the State Highway Commission's convenience. Any program developed by the state on a random basis would be equally satisfactory. However, the adoption of any

schedule based on a random assignment will result in additional travel time and inconvenience for the field crew as well as additional cost for the state. An appropriate member of the Indiana Highway Commission must make the decision whether the additional cost is justified in view of overall analysis.

Data Analysis

The statistical analysis is designed to investigate the significant differences in equivalent axle weights for the following categories:

1. Stations;
2. Truck types,
 - a. Loaded and unloaded separately,
 - b. Loaded and unloaded combined; and
3. Highway Systems

The four statistical techniques which are used to test for the significant differences are the Analysis of Variances, the Foster-Burr Homogeneity of Variance Test, the Newman-Keuls Sequential Range Test, and the T-Test. The general description of each statistical test, where the calculations are done by the use of computer, is given in Appendix B. A general description and the computational procedures for those statistical tests that are performed by hand computation are given in Appendix C.

In step 1, a portion of the analysis is performed first with each truck type classified as loaded and unloaded. Secondly, a portion of the analysis is performed on the truck types independent of the loaded or unloaded condition. The same data deck produced in Step 1 is used. However, the data must be rearranged for the second portion of the analysis to eliminate the effect of the loaded and unloaded condition.

All statistical tests are performed at the 95 percent confidence level. The theoretical distribution values for the Chi-square (χ^2), F, and T-Test can be found in most statistical textbooks (21).

The following is a step-by-step procedure for the analysis of data.

Step 1

Convert the weight data collected in the loadometer studies to one observation for each truck using the computer program in Appendix A.

The computer program in Appendix A converts the individual axle weight to an equivalent 18 kip single axle load and sums the equivalent axle loads over all axles to give an equivalent 18 kip axle load for each truck. These data are punched into a data card along with the station number, the truck type, and the loading classification. The equivalence factors are for flexible pavement with a serviceability index (P_t) of 2.5 and a structural number (SN) of 5. These

factors are taken from the AASHO Interim Guide for the Design of Flexible Pavement Structures. The computer program interpolates linearly the values in the table to the second decimal place.

The equivalent 18 kip axle load factors for flexible pavement of $P_t = 2.5$ and $SN = 5$ were used for convenience. Any other set of equivalence factors could be used. The equivalence factors were used to give a measure of the axle weights of a truck with one independent observation. The data are assumed to be normally distributed.

Step 2

Check for homogeneity of variance using the Foster-Burr Test in Appendix B.1. Use the χ^2 statistic if there are more than ten observations per subrouping and the Q statistic if there is ten or less observations per subgroup.

If there are ten or fewer observations per subgroup and the Q-statistic exceeds those in Table 20, go to Step 3, otherwise go to Step 4. If there are more than ten observations per subgroup and the χ^2 statistic exceeds those in a χ^2 table, go to step 3, otherwise go to Step 4.

The data are analyzed by highway system. Each system makes up a data set. Each truck type at a given station represents a subgroup. For example, if there are six truck types and six stations on the Interstate System, there would be 36 subgroups in that data set.

The mean equivalent 18 kip single axle weight for all truck types should be examined. If the mean equivalent

value for any truck type is consistently zero, the truck type should be eliminated from the analysis and the homogeneity of variance test should be performed again excluding those truck types. Only the small single unit trucks will have a zero mean equivalent 18 kip axle weight.

Step 3

A transformation of the data is performed using the computer program in Appendix B.1. The computer program will perform the transgeneration by selecting the proper option. The square root and log transformation are recommended. A homogeneity of variance test is performed again on the transformed data in accordance with Step 2. If homogeneity of variance exists in accordance with the test performed in Step 2, go to Step 4, if not go to Step 6.

Step 4

Using the computer program in Appendix B.2, perform a two way analysis of variance selecting the options of proportional weights and non-additive model. The proportional weights option is recommended because it assigns weights proportional to the number of observations at each level. A non-additive model was selected in order to test the significance of the truck type by station interaction. If the tabular value of F is greater than the calculated F value, continue with Step 4, otherwise go to Step 5.

Tests are made for significant difference between station means. If the tabular value of F is greater than the calculated F value, all station means are not significantly different from each other. It can then be concluded that any station can be used to represent all other stations. If significant differences exist, go to Step 7.

Step 5

For each truck type, test for homogeneity of variance over all stations within each system using the Foster-Burr Test given in Appendix B.1. If homogeneity of variance exists, go to Step 6. If homogeneity of variance does not exist, transform the data in accordance with Step 3. Repeat the test for homogeneity of variance on the transformed data. If homogeneity of variance exists, go to Step 6, otherwise go to Step 8.

The data are analyzed by truck type for each highway system. Given three highway systems and six different truck types, the analysis for homogeneity of variance would be performed 18 times. Each truck type makes up a data set. Each truck type at a given station represents a subgroup. For example, if there are six stations on the Interstate system, there would be six subgroups in the data set.

Step 6

Using the one way analysis of variance program in Appendix B.3, test for significant differences between the mean 18 kip equivalent axle weights per vehicle. If transformation of the data was required to obtain homogeneity of variance, the analysis of variance test is performed on the transformed data. If the tabular value of F is greater than the calculated F value the mean 18 kip equivalent axle weight for the given truck type is not significantly different for the stations tested and no further calculations are required. If the calculated F value is greater, go to Step 8. Repeat for all truck types within a highway system.

Step 7

Perform the Newman-Keuls Sequential Range Test given in Appendix C.1 for individual comparisons of pairs of the station's mean equivalent 18 kip axle weights. The test for significant differences is made in accordance with the instructions for hand computations in Appendix C.1. The results of this test is a list of those stations for which the mean equivalent 18 kip axle weights are significantly different. These results are summarized in Step 10.

Step 8

Perform the Newman-Keuls Sequential Range Test given in Appendix C.1 for individual comparisons of pairs of mean equivalent 18 kip axle weight within each truck type between stations. The test for significant differences is made in accordance with the instructions for hand computations in Appendix C.1. The result of this test is a list of those truck types for which the mean equivalent 18 kip axle weights are significantly different. These results are summarized in Step 10.

Step 9

Perform the T-Test given in Appendix C.2 for individual comparisons of pairs of mean equivalent 18 kip axle weights within each truck type between stations. The test for significant differences is made in accordance with the instructions for hand computations in Appendix C.2. The T-Test is repeated until tests of all possible pairs of means are completed. The result of these tests is a list of the truck types which are significantly different. These results are summarized in Step 10.

Step 10

Summarize the results of the Analysis of Variance, Newman-Keuls, and the T-Test in a triangular table.

(Example Table 18). The table shows by station the truck types that are significantly different.

Upon completion of Step 10, the portion of the analysis of each truck type classified as loaded and unloaded and the portion of the analysis of each truck type independent of the loading classification are complete. A decision should be made as to which approach will be used in future analysis.

The analysis of each truck type independent of loading classification is the preferred method since it eliminates the need for estimating the percent of trucks which are loaded for a given type. However, the combined classification could result in a large number of non-homogeneity truck types. The only statistical test applicable in this case is the T-Test. The separate classification is preferred when the problem of non-homogeneity of variance arises in the combined classification.

If the analysis of each truck type classified as loaded and unloaded is chosen, perform the Contingency Table Analysis given in Appendix C.3. The contingency table analysis tests for equal proportions of loaded trucks for a given truck type within a system. If the tabular χ^2 value exceeds the calculated χ^2 value use the average percent loaded from the table as the best estimate. If the calculated χ^2 is larger, use the average percent loaded for each individual station as the best estimate.

Step 11

In order to establish which stations are similar, the triangular table is evaluated on the basis of truck type and the number of truck types that have similar weight characteristics for the several stations. Choose at least ten stations which will be operated in the following year. to represent the 22 existing loadometer stations including at least one from each highway system.

Step 12

The preceding analysis did not test for station similarities between highway systems. In analyzing future data, it may be advantageous to make this test.

An analysis of differences between highway systems by truck types can be performed with the T-Test. A homogeneity test as given in Appendix B.1 is performed to test for homogeneity of variance among highway systems for a given truck type. Each system is a subgroup. All systems will make up a data set. If homogeneity of variance exists, the following T-Test is used:

$$T = \frac{\bar{X}_i - \bar{X}_j}{\sqrt{\frac{\sum (x_i - \bar{X}_i)^2 + \sum (x_j - \bar{X}_j)^2}{N_i + N_j - 2}}}$$

FIG.8 FLOW CHART FOR DATA ANALYSIS

where:

$\bar{x}_i$ and $\bar{x}_j$ are the respective mean equivalent axle weight for the given truck type.

$\sum (x_i - \bar{x}_i)^2$ and $\sum (x_j - \bar{x}_j)^2$ are the respective sum of squares values. (These values are obtained from the output of the homogeneity test.)

N_i and N_j are the respective number of observations for the given truck types.

If homogeneity of variance does not exist, use the T-Test procedure given in Appendix C.2.

Continuing Phase

The ten or more stations which were selected as being representative of the 22 stations that were operated the first year should be continued indefinitely. These stations will be operated as long as it is important to provide information on long range trends. The stations which will be represented by these ten or more stations are to be discontinued. Each year new locations for the temporary location of the loadometer stations are to be selected at random from the remaining sections. The sampling program should be continued with all phases based on probability considerations. The state may wish to stratify their sections to assure that they operate a loadometer station in

each geographic area and in each highway system. If the analysis of the data indicates that a temporary loadometer station cannot be represented by the original ten or more loadometer stations, this station should be operated along with the permanent stations. After a period of four or five years the state should have an estimate of the axle load pattern on all highway systems throughout the state. The state can then reduce their loadometer operations to the minimum necessary to assure detection of trends.

Calculation of Axle Loadings

An estimate of the axle loadings on a given section can be computed as follows:

ADT x percent (Truck Type) x average equivalent 18 kip axle weight equals the total 18 kip axle weight equivalents due to that specific truck type in one year.

Where:

ADT is obtained from the volume count program.

The percent (truck type) is the best estimate of the percent composition of the traffic stream obtained from the 24 hour classification count for that truck type. If the analysis indicated that the loaded and unloaded trucks are treated separately, there will be an additional factor

to correct for percent loaded and unloaded. The 8 hour classification of vehicles as to loaded condition during the loadometer study will be considered as the best estimate.

Average equivalent 18 kip axle weight is the calculated average equivalent 18 kip axle weight for that truck type and the existing conditions at that station.

It is important to note that the analysis indicates which stations have similar truck axle weight characteristics. This does not mean that the axle weights have the same effect at all stations. The results of the AASHO Road Test were used in the analysis. However, any equivalent applications concept can be used in evaluating the number of axle applications to which the section is subjected. The above calculation is repeated for each truck type and then summed over all truck types to give an estimate of the total 18 kip equivalent axle loadings on that section.

If axle loadings and frequencies are desired, the data collected during the loadometer study will serve as the best estimate at that station and all other stations which are not significantly different.

The primary use of the data obtained from the analysis is in pavement design and/or road design. The design of subbase, base, and surface course is dependent on the magnitude of the axle load applications and the order in which they are applied. The need for more accurate truck

weight data should be evaluated against the size of the error that will cause a major change in pavement or road design. Only then can a decision be made on additional accuracy needed in truck weight studies.

ANALYSIS OF 1963 LOADOMETER DATA

The 1963 loadometer data from the 20 loadometer stations was analyzed to provide a check on the feasibility of the analysis as proposed in the Procedural Guide. The analysis also makes possible the comparison of the results of data collected on a non-probability basis as opposed to that data which will be collected under probability considerations.

The data was obtained from the Indiana Highway Commission on IBM data cards. A computer program was written which computed the mean, the variance, and the standard deviation for each axle for a given station, truck type, and loaded condition. While the information calculated in the program indicated above was not used, it did give an indication of the magnitude of the problem if the analysis was to be performed on each axle for a given truck type and loaded condition. The requirement of independent observations in forthcoming statistical analysis suggested another approach. The computer program in Appendix A was used to convert the individual axle weight to an equivalent 18 kip single axle load. The equivalent axle loads were then summed to give an equivalent 18 kip single axle load for each truck. The data was then punched into a data card along

with the station number, truck type, and loading classification. Truck types eleven and twelve were combined into one truck type. The conversion of the axle weight data to equivalent 18 kip axle weights resulted in a new data deck which was used in the analysis.

A test for homogeneity of variance was performed on the new data which had been grouped by station, truck type and load classification on the card sorter. The homogeneity test for truck type by station was performed separately on each highway system. The homogeneity of variance test was repeated with each of the following changes:

1. Truck type eleven and twelve were eliminated from the analysis. Their mean equivalent axle weight was consistently zero.
2. The data was transformed using a square root function.
3. The data was transformed using a natural log function. It was necessary to add 1.00 to each observation before transformation since some of the observations were zero.

In each case the calculated χ^2 value exceeds the tabular χ^2 value.

The homogeneity of variance test was then applied with a square root transformation to truck types within a highway system. Truck types eleven and twelve were again excluded from the analysis. The trucks classified as loaded and

unloaded in a given truck type were analyzed separately. All truck types with loaded classification in the Primary and Interstate system had equal cell variance; however, in the unloaded classification, truck types 13 and 24 in the Primary system and 13, 21, 22, and 24 in the Interstate system had non-homogeneous variances.

A one-way analysis of variance was performed on all truck types having homogeneity of variance. The analysis indicated that the following truck types were not significantly different over all stations in the Primary highway system:

1. Truck type 21, loaded;
2. Truck type 22, loaded;
3. Truck type 14, unloaded;
4. Truck type 21, unloaded; and
5. Truck type 22, unloaded.

The truck types which were not significantly different on the Interstate System were:

1. Truck type 13, loaded;
2. Truck type 14, loaded;
3. Truck type 21, loaded;
4. Truck type 22, loaded; and
5. Truck type 14, unloaded.

The Newman-Keuls Sequential Range Test was performed on all truck types that had homogeneity of variance and whose means were declared significantly different in the

one-way analysis of variance test as given in Appendix C.1. The results of individual comparisons of pairs of station means using this test are shown in Tables 7, 8, 9, 10, and 13. The T-Test was performed on all truck types lacking homogeneity of variance. The theoretical and calculated values for the individual comparison of station means are given in Tables 11, 12, 14, 15, 16, and 17. The station means by truck type which have been declared significantly different by the Newman-Keuls test and the T-Test were summarized in Tables 18 and 19.

An important consideration in the interpretation of Tables 18 and 19 is the error that will be produced in making a decision on what stations are representative of others. The magnitude of the mean equivalent 18 kip axle load for a given truck type and the number of trucks that appear in the traffic stream are major factors. Upon examination of the station means for a given truck type it was found that for truck types with an unloaded classification the difference in the stations highest and lowest mean equivalent axle weight did not exceed 0.07. The only exception to this was truck type 21 on the Interstate System in which the mean 18 kip equivalent axle weight ranged from 0.03 to 0.18. Several of the mean equivalent axle weights, for given truck types with the unloaded classification, were declared significantly different. In the author's opinion the differences are not sufficient to

be of concern at this stage of development of truck weight studies. One additional consideration is the number of trucks of type 14 which were observed. A relatively small error would result in assuming that the equivalent axle weights for this truck type were equal on all stations of the Primary System.

From Table 19, it can be concluded that station 63, on the Interstate System is significantly different from the other five stations. Any one of the other five stations can be used to represent the remaining stations.

With the considerations previously mentioned, the problem of selecting stations with similar truck characteristics on the Primary System is reduced to truck types 22 and 24. From the analysis of the 1963 data, it can be concluded that stations 75, 9, and 4 should be operated independently. Station 2 can represent stations 83, 81, 68, 61, 45, and 23. Station 15 can represent stations 16, 5, and 12. There are many possible combinations which are practical. For example, Station 15 could represent 11 stations within the statistical limits established for this study. Stations 75, 9, and 4 are statistically different from many other stations. A member of the Indiana State Highway Commission who is familiar with the local conditions may be able to explain this statistical difference.

The above recommendations should only serve as a guide and final recommendations should be based on analysis of data collected in the 1965 loadometer studies.

The analysis of the data with trucks classified as loaded and unloaded combined was not performed because the data were not collected on a probability basis. A significant difference in station means for a given truck type could be due to a significant difference in equivalent axle weights or because the selection of vehicles by truck type that were weighed was not a true proportion of the loaded or unloaded vehicles in the traffic stream.

TABLE 7
SIGNIFICANT DIFFERENCES BY NEWMAN-KEULS TEST FOR
TRUCK TYPE 13, LOADED, PRIMARY SYSTEM

STA	45	2	5	12	15	61	16	75	4	9	23	83	68
81	4.94 8.87	4.88 7.71	4.81 7.23	4.73 7.11	4.65 6.38	4.55 6.14	4.49 5.86	4.31 5.37	4.16 5.32	3.98 5.26	3.74 4.87	3.40 4.13	2.83 4.11
68													
63													
23													
9													
4													
75													
16													
61													
15													
12													
5													
2													

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 8
SIGNIFICANT DIFFERENCES BY NEWMAN-KEULS TEST FOR
TRUCK TYPE 14, LOADED PRIMARY SYSTEM

STA	81	16	45	61	15	2	5	75	23	9	68	12	82
4	5.43 18.05	5.35 15.37	5.27 14.68	5.17 11.02	5.07 10.87	4.96 7.77	4.83 7.55	4.67 7.55	4.49 6.36	4.28 4.50	4.00 4.25	3.61 3.50	
83	5.35 14.71	5.27 12.03	5.17 11.34	5.07 7.69	4.96 7.30	4.83 4.43							
12	5.27 14.54	5.17 11.86	5.07 11.18	4.96 7.52	4.83 7.36								
68	5.17 13.79	5.07 11.12	4.96 10.42	4.83 4.77	4.67 6.61								
9	5.07 13.45	4.96 10.87	4.83 10.17	4.67 6.51	4.49 6.36								
23	4.96 11.69	4.83 9.01	4.67 8.32	4.49 4.66	4.28 4.51								
75	4.83 10.50	4.67 7.82	4.49 7.13	4.28 3.47									
5	4.67 10.50	4.49 7.82	4.28 7.13										
2	4.49 10.28	4.28 7.61	--- ---										
15	4.28 7.18	4.00 4.50	3.61 3.81										
61	4.00 7.02	3.61 4.35	2.97 3.66										
45	3.61 3.37												
16													

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 9
SIGNIFICANT DIFFERENCES BY NEWMAN-KEULS TEST FOR
TRUCK TYPE 22, LOADED, PRIMARY SYSTEM

STA	9	23	4	2	45	15	83	16	81	68	5	12	61
75	4.92 12.81	4.86 12.32	4.79 11.62	4.71 11.26	4.63 10.07	4.53 9.70	4.42 9.38	4.30 9.24	4.15 8.59	3.97 7.70	3.73 6.86	3.39 6.34	2.83 5.68
61	4.86 7.13	4.79 6.64	4.71 5.92	4.63 5.58	4.53 4.39								
12	4.79 6.47	4.71 5.99	4.63 5.28	4.53 4.92									
5	4.71 5.94	4.63 5.46	4.53 4.76	4.42 4.40									
68	4.63 5.11	4.53 4.63	4.42 3.92										
81	4.53 4.21												
16													
83													
15													
45													
2													
4													
23													

The upper entry is the theoretical value and the lower entry is the calculated entry.

TABLE 10
SIGNIFICANT DIFFERENCES BY NEWMAN-KEULS TEST FOR
TRUCK TYPE 24, LOADED, PRIMARY SYSTEM

STA	9	16	15	45	61	2	23	83	12	5	81	68	4
75	4.94	4.88	4.81	4.72	4.65	4.55	4.44	4.31	4.16	3.98	3.74	3.40	2.83
4	9.17	7.72	7.03	6.85	6.09	5.90	5.77	5.45	4.23	4.22	4.09	2.92	2.23
	4.88	4.81	4.73	4.65									
68	6.94	5.49	4.81	4.62									
	4.81	4.73	4.65										
81	6.25	4.80	4.12										
	4.73	4.65											
5	5.07	3.62											
	4.65	4.55											
12	4.96	3.50											
	4.55												
83	4.94												
	4.44												
23	3.72												
2													
61													
45													
15													
16													

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 11
SIGNIFICANT DIFFERENCES BY T-TEST FOR
TRUCK TYPE 13, UNLOADED, PRIMARY SYSTEM

STA	83	81	75	68	61	45	23	16	15	12	9	5	4
2	2.09	2.12	2.10	2.11	2.12	2.10	2.13	2.30	2.09	2.10	2.07	2.12	2.10
4	0.31	0.94	1.32	1.33	0.01	0.82	0.50	1.24	1.58	1.58	1.64	0.21	1.06
	1.62	2.07	2.07	2.09	2.09	2.07	2.09	3.19	2.07	2.07	2.05	2.09	
5	0.90	2.14	0.10	0.40	1.14	0.32	1.67	0.41	0.54	0.60	0.61	0.95	
	2.07	2.11	2.09	2.10	2.12	2.08	2.12	2.31	2.08	2.47	1.82		
9	0.11	1.41	1.23	1.24	0.24	0.68	0.83	1.14	1.51	1.50	1.57		
	2.04	2.04	2.05	2.07	2.06	2.05	2.06	2.23	2.05	2.06			
12	1.54	2.71	0.59	0.16	1.74	0.96	2.52	0.20	0.08	0.00			
	2.07	2.08	2.08	2.09	2.09	2.07	2.08	2.23	2.08				
15	1.47	2.54	0.59	0.18	1.66	0.94	2.13	0.21	0.99				
	2.06	2.07	2.07	2.09	2.08	2.07	2.08	2.25					
16	1.48	2.68	0.51	0.90	1.69	0.89	2.21	0.13					
	2.30	2.34	2.29	2.24	2.31	1.85	2.33						
23	1.11	2.10	0.34	0.39	1.30	0.63	1.70						
	2.07	2.10	2.09	2.11	2.14	2.08							
45	1.00	0.55	2.15	1.83	0.55	1.49							
	2.05	2.06	2.06	2.09	2.09								
61	0.62	2.06	0.48	0.70	0.90								
	2.08	2.10	2.09	2.11									
68	0.36	1.07	1.46	1.40									
	2.09	2.10	2.09										
75	1.20	2.20	0.36										
	2.05	2.06											
81	1.20	2.86											
	2.02												
	1.68												

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 12
SIGNIFICANT DIFFERENCES BY T-TEST FOR
TRUCK TYPE 24, UNLOADED, PRIMARY SECTION

STA	83	81	75	68	61	45	23	16	15	12	9	5	4
2	2.06	2.20	2.16	20.61	4.26	2.11	2.68	2.06	2.07	2.19	2.06	2.05	2.09
	3.18	1.31	0.12	0.18	0.38	0.12	0.58	1.48	1.80	2.21	2.81	1.15	0.01
4	2.13	2.21	2.18	2.09	4.41	2.13	2.69	2.11	2.12	2.18	2.11	2.06	
	3.00	1.18	0.11	0.16	0.38	1.11	0.58	1.43	1.72	2.17	2.65	1.09	
5	2.07	2.19	2.14	2.06	4.26	2.10	2.66	2.06	2.06	2.16	2.05		
	4.22	0.48	0.81	0.95	0.15	0.76	1.19	2.51	2.87	1.48	3.90		
9	2.11	2.21	2.18	2.08	4.28	2.12	26.82	2.10	2.10	2.19			
	0.54	2.72	2.18	2.90	0.84	2.05	0.68	0.97	0.83	3.70			
12	2.20	2.20	2.20	2.35	4.13	2.18	2.51	2.19	2.20				
	3.93	0.81	1.94	2.09	0.35	1.88	2.07	3.04	3.23				
15	2.11	2.21	2.17	2.09	4.28	2.13	2.70	2.10					
	1.26	2.23	1.51	1.93	0.71	1.43	0.31	0.20					
16	2.12	2.21	2.17	2.09	4.26	2.12	2.54						
	1.36	2.07	1.29	1.61	0.67	1.23	2.06						
23	2.51	2.54	2.65	2.68	4.14	2.59							
	0.87	1.34	0.60	0.67	0.57	0.60							
45	2.13	2.20	2.15	2.11	4.20								
	2.32	0.98	0.01	0.02	0.35								
61	3.16	4.13	4.22	4.27									
	2.87	0.12	0.35	0.35									
68	2.09	2.20	2.16										
	3.26	1.09	0.03										
75	2.19	2.22											
	2.47	1.01											
81	2.22												
	2.93												

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 13
SIGNIFICANT DIFFERENCES BY NEWMAN-KEULS TEST FOR
TRUCK TYPE 24, UNLOADED, INTERSTATE SYSTEM

STA	63	42	33	58	14
27	4.16 5.29	3.98 2.83			
14	3.98 4.54				
58	3.74 3.71				
33					
42					

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 14
SIGNIFICANT DIFFERENCES BY T-TEST FOR
TRUCK TYPE 13, UNLOADED, INTERSTATE SYSTEM

STA	63	58	42	33	27
14	2.75 0.39	2.77 0.95	3.12 0.47	3.12 1.39	3.08 1.14
27	2.13 2.63	2.07 0.00	2.55 1.27	2.19 0.54	
33	2.13 2.97	2.07 0.31	2.64 1.83		
42	2.26 1.78	2.23 0.78			
58	2.09 2.07				

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 15
SIGNIFICANT DIFFERENCES BY T-TEST FOR
TRUCK TYPE 21, UNLOADED, INTERSTATE SYSTEM

STA	63	58	42	33	27
14	2.35 0.27	2.21 1.23	2.30 1.10	3.10 0.98	2.31 0.48
27	2.26 0.27	2.20 1.10	2.25 0.81	3.12 0.80	
33	3.14 0.90	2.54 0.42	3.00 0.34		
42	2.27 1.00	2.21 0.75			
58	2.204 1.17				

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 16
SIGNIFICANT DIFFERENCES BY T-TEST FOR
TRUCK TYPE 22, UNLOADED, INTERSTATE SYSTEM

STA	63	58	42	33	27
14	2.05	2.05	2.03	2.08	2.05
	2.53	0.90	0.28	0.88	1.50
27	2.07	2.07	2.05	2.09	
	1.05	0.59	1.74	1.71	
33	2.09	2.09	2.09		
	2.31	1.38	0.72		
42	2.04	2.04			
	2.74	1.15			
58	2.06				
	1.62				

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 17
SIGNIFICANT DIFFERENCES BY T-TEST FOR
TRUCK TYPE 24, UNLOADED, INTERSTATE SYSTEM

STA	63	58	42	33	27
14	2.09	2.09	2.05	2.51	2.18
	2.03	1.02	0.09	1.99	1.02
27	2.20	2.19	2.19	2.31	
	1.95	1.53	0.99	2.05	
33	2.60	2.46	2.54		
	0.42	0.89	2.13		
42	2.10	2.10			
	2.23	1.13			
58	2.13				
	0.64				

The upper entry is the theoretical value and the lower entry is the calculated value.

TABLE 18

**SUMMARY OF SIGNIFICANT DIFFERENCES
FOR ALL TRUCK TYPES WITH THE NEWMAN-KEULS
AND T-TEST ON PRIMARY SYSTEM
(U - Unloaded, L - Loaded)**

[illegible]

TABLE 19

SUMMARY OF SIGNIFICANT DIFFERENCES FOR ALL
TRUCK TYPES WITH THE NEWMAN-KEULS AND T-TEST ON INTERSTATE SYSTEM
(U - Unloaded, L - Loaded)

STA	63	58	42	33	27
14	22U 24L				
27	13U 24L				
33	13U 22U				
42	22U 24U				
58					

CONCLUSIONS AND RECOMMENDATIONS

On the basis of an analysis of the 1963 data using the prescribed Procedural Guide, it can be concluded that:

1. With the use of statistical techniques six selected stations could provide information representative of the truck weight characteristics of the 20 loadometer stations operated in 1963. However, to determine long range trends a minimum of ten stations are to be operated.
2. The approach suggested for selection of stations which are representative of other stations is feasible.
3. On the basis of the feasibility of the Procedural Guide, the loadometer data collected for 1965 and the ensuing years should be analyzed to establish representative stations. Each year study stations are deleted, additional stations should be added until statewide coverage is obtained.

RECOMMENDATIONS FOR ADDITIONAL RESEARCH

Additional research in truck weight studies is recommended in four general areas:

1. The development of a statistical sampling program for classification counts.
2. To determine season variations in weight and classification data.
3. The development and testing of automatic data recording equipment for weighing-in-motion and classification of main stream traffic.
4. The extent of overloading above legal tolerance limits.

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APPENDICES

APPENDIX A
COMPUTER PROGRAM FOR CONVERSION TO 18 KIP
EQUIVALENT AXLE WEIGHT

APPENDIX A

Computer Program for Conversion to 18 KipEquivalent Axle Weight

(FORTRAN IV Coding for IBM 7094)

\$EXECUTE IBJOB

\$IBJOB

\$IBFTC MAIN

C CONVERSION OF INDIVIDUAL AXLE WEIGHTS TO EQUIVALENT AXLE
C WEIGHT FOR EACH INDIVIDUAL TRUCK USING EQUIVALENCE FACTORS
C FOR FLEXIBLE PAVEMENT P=2.5 SN=5 SOURCE, AASHO INTERIM
C GUIDE FOR THE DESIGN OF FLEXIBLE PAVEMENT STRUCTURES, 1961
C ASSIGN VALUES TO I, J, K TO FACILITATE INCREMENTING OF
C SUBSCRIPTS
C TRUCK TYPES LISTED ARE NOT INCLUDED IN THE ANALYSIS (15
C 23, 32, 34, 52)
C PRINT OUT OF UNCOMMON TRUCK TYPES WITH STATION NUMBER AND
C LOADING CODE
C I SUBSCRIPTS STATIONS 1-14 ARE PRIMARY ROAD STATIONS 2, 4,
C 5, 9, 12, 15, 16, 23, 45, 61, 68, 83, RESPECTIVELY.
C I SUBSCRIPTS STATIONS 15-20 ARE INTERSTATE ROAD STATIONS
C 14, 27, 33, 42, 58, 63, RESPECTIVELY.
C 13, 14, 21, 22, 24, RESPECTIVELY. NOTE THAT TRUCK TYPES

C 11 AND 12 HAVE BEEN COMBINED.
 C K SUBSCRIPTS LOAD CLASSIFICATIONS, UNLOADED 1,2,3,
 C 2 LOADED 4,5,6,7,8,9 RESPECTIVELY.
 C DEFINITIONS
 C KK = STATION NUMBER
 C MM = TRUCK TYPE
 C NN = LOAD CLASSIFICATION
 C AXSPCD = AXLE SPACING BETWEEN 3RD AND 4TH AXLE
 C AXSPDE = AXLE SPACING BETWEEN 4TH AND 5TH AXLE
 C AWA' = FIRST AXLE ON TRUCK OR TRUCK COMBINATION
 C AWB = SECOND AXLE ON TRUCK OR TRUCK COMBINATION
 C AWC = THIRD AXLE ON TRUCK OR TRUCK COMBINATION
 C AWD = FOURTH AXLE ON TRUCK OR TRUCK COMBINATION
 C AWE = FIFTH AXLE ON TRUCK OR TRUCK COMBINATION
 C AWF = SIXTH AXLE ON TRUCK OR TRUCK COMBINATION
 C AWG = SEVENTH AXLE ON TRUCK OR TRUCK COMBINATION
 C TAWF = FIRST TANDEM AXLE GROUP ON TRUCK OR TRUCK
 C COMBINATION
 C TAWS = SECOND TANDEM AXLE GROUP ON TRUCK OR TRUCK
 C COMBINATION
 C EQIVS(AWX) = SUBROUTINE FOR CONVERSION OF OBSERVED
 C SINGLE AXLE WEIGHT TO AN 18 KIP EQUIVALENT
 C AXLE WEIGHT
 C EQIVT(TAWX)= SUBROUTINE FOR CONVERSION OF OBSERVED
 C TANDEM AXLE WEIGHT TO AN 18 KIP EQUIVALENT
 C AXLE WEIGHT
 DIMENSION I(83),J(52),K(9),EQAXS(30),EQAX(42)

```
COMMON /ABC/ I,J,K,EQAXS,EQAXT

1 READ(5,5) KK, MM, NN, AXSPCD,AXSPDE,AWA,AWB,AWC,AWD,
  LAWE,AWF,AWG,TAWF,TAWS

5 FORMAT(12,11X,12,6X,11,6X,2F3.1,9X,9F3.1)

  KK = I(KK)
  MM = J(MM)
  NN = K(NN)

  IF (MM.EQ.1) GO TO 10
  IF (MM.EQ.2) GO TO 10
  IF (MM.EQ.3) GO TO 12
  IF (MM.EQ.4) GO TO 14
  IF (MM.EQ.5) GO TO 16
  IF (MM.EQ.6) GO TO 18

500 WRITE (6,501) KK,MM,NN
  GO TO 1

501 FORMAT (1H0,13HERROR INPUT =,3I3)

10 CALL EQIVS(AWA)
  CALL EQIVS(AWB)
  EQAXW=AWA+AWB
  GO TO 1000

12 CALL EQIVS(AWA)
  CALL EQIVT(TAWF)
  EQAXW = AWA + TAWF
  GO TO 1000

14 CALL EQIVS(AWA)
  CALL EQIVS(AWB)
```

```
CALL EQIVS(AWC)

EQAXW = AWA + AWB + AWC

GO TO 1000

16 IF (AXSPCD.GE.8.0) GO TO 17

CALL EQIVS(AWA)

CALL EQIVS(AWB)

CALL EQIVT(TAWF)

EQAXW = AWA + AWB + TAWF

GO TO 1000

17 CALL EQIVS(AWA)

CALL EQIVS(AWB)

CALL EQIVS(AWC)

CALL EQIVS(AWD)

EQAXW = AWA + AWB + AWC + AWD

GO TO 1000

18 IF (AXSPDE.GE.8.0) GO TO 19

CALL EQIVS(AWA)

CALL EQIVT(TAWF)

CALL EQIVT(TAWS)

EQAXW = AWA + TAWF + TAWS

GO TO 1000

19 CALL EQIVS(AWA)

CALL EQIVT(TAWF)

CALL EQIVS(AWD)

CALL EQIVS(AWE)

EQAXW = AWA + TAWF + AWD + AWE

GO TO 1000
```

1000 CONTINUE

PUNCH 1001, KK,MM,NN,EQAXW

1001 FORMAT (12,1X,12,1X,12,1X,F5.2)

GO TO 1

END

C INPUT STATION, TRUCK TYPE, AND LOAD CLASSIFICATION DATA

\$IBFTC MAIN2

BLOCK DATA

DIMENSION I(83), J(52),K(9),EQAXT(42)

COMMON / ABC/ I,J,K,EQAXS,EQAXT

DATA I/0, 1,0,2,3,3*0,4,2*0,5,0,15,6,7,6*0,8,

1 3*0,16,5*0,17,8*0,18,2*0,9,12*0,19,2*0,10,0,20,4*0,11,6*0,

2 12,5*0,13,0,14/

DATA J/10*0,1,1,2,3,15,5*0,4,5,0,6,25,26,5*0,32,0,34,

1 17*0,52/

DATA K/3*1,6*2/

C INPUT EQUIVALENT AXLE WEIGHT DATA TABLE

C SINGLE AXLE EQAXS(AWX)

DATA EQAXS/5*0,00,0.01,0.02,0.03,0.06,0.09,

1 0.14,0.19,0.27,0.36,0.49,0.62,0.81,1.00,1.24,1.51,1.83,

2 2.18,2.58,3.03,3.56,4.09,4.79,5.39,6.18,6.97/

C TANDEM AXLE EQAXT(TAWX)

DATA EQAXT/9*0.00,3*0.01,0.02,0.03,0.04,0.05,0.06,

1 0.08,0.10,0.12,0.15,0.18,0.22,0.26,0.31,0.36,0.42,0.50,

2 0.58,0.66,0.76,0.86,0.97,1.09,1.23,1.38,1.53,1.70,1.89,

3 2.08,2.29,2.51/

END

C SUBROUTINE CONVERTS SINGLE AXLE TO EQUIVALENT AXLE WEIGHT.

\$IBFTC SUBA

SUBROUTINE EQIVS(AWX)

DIMENSION I(83),J(52), K(9), EQAXS(30),EQAXT(42)

COMMON /ABC/ I,J,K,EQAXS,EQAXT

KEYXL = IFIX (AWX)

AWXL = EQAXS(KEYXL)

KEYXH = KEYXL + 1

AWXH = EQAXS(KEYXH)

AWXD = AWXH - AWXL

AWXF = FLOAT (KEYXL)

EXCESS = AWX - AWXF

AWX = AWXL + EXCESS*AWXD

RETURN

END

C SUBROUTINE CONVERTS TANDEM AXLES TO EQUIVALENT AXLE WEIGHT.

\$IBFTC SUBB

SUBROUTINE EQIVT(TAWX)

DIMENSION I(83), J(52), K(9), EQAXS(30),EQAXT(42)

COMMON /ABC/ I,J,K,EQAX,EQAXT

KEYXL = IFIX (TAWX)

AWXL = EQAXT(KEYXL)

```
KEYXH = KEYXL + 1  
AWXH = EQAXT(KEYXH)  
AWXD = AWHX - AWXL  
AWXF = FLOAT (KEYXL)  
EXCESS = TAWX - AWXF  
TAWX = AWXL + EXCESS*AWXD  
RETURN  
END
```

APPENDIX B
GENERAL DESCRIPTIONS OF COMPUTER PROGRAMS
FROM THE STATISTICAL LABORATORY LIBRARY

APPENDIX B.1

Data Summarization with Homogeneity Tests

General Description

This program is designed to compute various statistics listed below for a maximum of 60 variables in each data set. A problem consists of a set of data divided into one or more sub-groups. With a data set, the same variables will be analyzed on each sub-group; i.e., one format card describes the variables to be analyzed in each sub-group. A new problem begins when a new data set is read in.

There need not be the same number of observations from sub-group to sub-group. If there are missing data values (blanks), they will be ignored in the computations for that particular variable.

If desired, either the Foster-Burr^{*} or Bartlett's test for homogeneity of variance may be run for each variable within a data set. For the Foster-Burr test, a χ^2 value is printed if there are more than 10 observations per group. For variables with 10 or fewer observations per group,

* Note: For a description of the Foster-Burr Test, see the attached write-up.

compare the Q statistic with the values in the attached table. Additional options include transgeneration of the input data as described in section 4, and the listing of all or part of the data analyzed.

The Q -Test for Equality of Variances
by
Louis A. Foster and Irving W. Burr

This brief summary of the Q -test is based on a Ph.D. thesis submitted to Purdue University by Louis A. Foster working under the supervision of Irving W. Burr.

Introduction

The Q -test for equality of variances is based on a statistic which is a monotone function of the coefficient of variation of the sample variances.¹ As such it offers promise as a preliminary test for the assumption of homogeneity of population variances which is needed in the analysis of variance technique.² Although the Q -test is not a so-called quick test, the test statistic is sufficiently simple to permit calculation of its value on a desk calculator (in contrast to the logarithmic transformation required in

¹ Equivalent tests have been proposed by Brandt and Stevens, but in a form depending solely on an asymptotic distribution for the test statistics.

² This statement is based on the role of the coefficient of variation of the population variances in measuring the disruption to the F -ratio in the analysis of variance technique, as set forth by G. E. P. Box in Ann. Math. Stat., Vol. 25, Page 240 and page 484 (1954).

Bartlett's test). A sample variance taking the value zero does not disrupt this test (as it does to Bartlett's and Hartley's tests). Finally, a table of critical values permits the use of this test for small sample sizes where the use of an asymptotic distribution would not be appropriate.

The Q-statistic

For equal sample sizes, n , from each of p parent populations, let s_j^2 (for $j = 1, \dots, p$) denote the j th sample variance. Denoting the value of the test statistic Q by q , we have:

$$q = (s_1^4 + \dots + s_p^4) / (s_1^2 + \dots + s_p^2)^2 .$$

For unequal sample sizes we specify that each sample variance, s_j^2 , be calculated by dividing by the degrees of freedom, v_j , rather than by the sample size, n_j (where $v_j = n_j - 1$, for $j = 1, \dots, p$). Let $\bar{v}$ denote the arithmetic average of the degrees of freedom. In this case we have:

$$q = \bar{v}(v_1 s_1^4 + \dots + v_p s_p^4) / (v_1 s_1^2 + \dots + v_p s_p^2)^2 .$$

The Q-test

Large values of Q lead to rejection of the hypothesis of equal population variances. The critical values are given in the attached table for various numbers of parent populations, p , and various possibilities for equal degrees

of freedom, v (where $v = n - 1$), from one to ten. This table can be used directly for equal degrees of freedom. For unequal degrees of freedom, q is calculated as indicated above, but $\bar{v}$ is to be substituted for v in the attached table, provided that $\bar{v}$ and the harmonic mean of the v_j 's do not differ greatly. For large sample sizes ($v > 10$), we note that $p\bar{v}(pQ - 1)/2$ is asymptotically chi-square with $(p - 1)$ degrees of freedom. (34)

TABLE 20

THE 95th PERCENTILE OF Q FOR EQUAL DEGREES OF
FREEDOM AND EQUAL POPULATION VARIANCES

p	1	2	3	4	5	6	7	8	9	10
2	.999	.951	.886	.829	.785	.750	.722	.700	.681	.666
3	.923	.747	.658	.594	.548	.520	.497	.479	.464	.453
4	.814	.612	.517	.485	.422	.396	.377	.362	.350	.341
5	.708	.510	.421	.371	.339	.318	.302	.290	.280	.272
6	.622	.433	.353	.310	.283	.264	.251	.241	.233	.225
8	.495	.331	.266	.232	.211	.197	.187	.179	.173	.168
9	.449	.295	.236	.206	.187	.175	.166	.159	.153	.149
10	.410	.266	.212	.184	.168	.156	.148	.142	.138	.134
12	.348	.221	.176	.153	.139	.129	.123	.118	.114	.111
16	.264	.164	.130	.113	.103	.0958	.0910	.0874	.0845	.0823
27	.155	.0944	.0747	.0650	.0592	.0554	.0527	.0507	.0492	.0479
32	.129	.0787	.0623	.0543	.0495	.0464	.0442	.0425	.0413	.0402
64	.0613	.0375	.0299	.0262	.0240	.0226	.0216	.0208	.0202	.0197

Note: Use χ^2 test when there are more than 10 observations per sample.

APPENDIX B.2

Two-Way Unequal Cell Anova

General Description

The program is designed for a two-way analysis of variance problem with unequal numbers of observations in the cells. The program will also perform the analysis for a problem with equal numbers of observations in the cells.

The program will handle from 2 to 50 levels of each variable, and from 1 to 999 observations in any cell. It does require that every cell have at least one observation in it. Some transformations are provided for the input data. The user has the option of obtaining an analysis with or without the assumption of additivity (no interaction). Another option that is available is the testing of contrasts among the main effects by the S-Method if nonadditivity is assumed. This is not complete in that the user has to look up the constant S , but the program does give PSI , its variance and standard deviation for any contrast requested. Any number of contrasts may be performed with the restriction that the sum of the contrast coefficients for each contrast be equal to zero.

The analysis is based upon section 4.4 of Henry Scheffe: The Analysis of Variance and thus assumes either of the following fixed models:

1. Additive model: $Y_{ijk} = \mu + \alpha_i + \beta_j + \epsilon_{(ij)k}$
2. Non-additive model: $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{(ij)k}$

The last option provided by the program is that the user can exercise a choice of weights for estimating and testing main effects. The choice of weights for each main effect is unlimited with the restriction that the weights sum to one for each main effect. Referring to the nonadditivity model (Model 2 above), the weights on the main effects imply a set of weights to be interaction, however, the interaction sum of squares is independent of these weights. The $(\hat{\alpha\beta})_{ij}$'s computed by the program are dependent upon the set of weights assumed. The assignment of weights for the model assuming additivity (Model 1 above) imposes the following restrictions:

$$\sum_i w_i \alpha_i = \sum_j v_j \beta_j = 0 ,$$

where

w_i = weight assigned to the i th level of the A main effect

v_j = weight assigned to the j th level of the B
main effect, and

$$\sum_i w_i = \sum_j v_j = 1; \quad i = 1, \dots \text{no. of levels of A}; \\ j = 1, \dots \text{no. of levels of B}.$$

The assignment of weights for the model assuming non-additivity
(Model 2 above) imposes the following restrictions:

$$\sum_i w_i a_i = \sum_j v_j \beta_j = \sum_i w_i (a\beta)_{ij} \\ = \sum_j v_j (a\beta)_{ij} = 0$$

Finally, for the assumption of non-additivity, the main
effect sums of squares given by the program are adjusted for
each other and the interaction; the interaction sum of
squares is adjusted for the main effects. (35)

APPENDIX B.3

Analysis of Variance for One-Way Design

General Description

This program computes an analysis of variance for one-way classification, with unequal group sample sizes. The output includes group or treatment means and standard deviations as well as an anova table with the following:(33)

1. within groups, between groups, and total sum of squares.
2. within groups, between groups, and total degrees of freedom.
3. with groups and between groups mean squares.
4. the F ratio (for $H_0: \mu_1 = \mu_2 = \dots = \mu_k$)

APPENDIX C
GENERAL DESCRIPTIONS AND COMPUTATIONAL PROCEDURES
FOR HAND COMPUTATIONS

APPENDIX C.1

Newman-Keuls Sequential Range Test

General Description

The Newman-Keuls Sequential Range Test is a statistical test used in making multiple, non-independent significance tests on differences among individual means in an analysis of variance. The Newman-Keuls test has the characteristic of "keeping its power up" and still gives good protection against a Type I error on the largest difference. (3)

Notation:

k = total number of means, $\bar{Y}_i$, among which contrasts are to be made

* n_i = the number of observations on which $\bar{Y}_i$ is based

s^2 = unbiased estimate of error variance (usually the error MS appropriate for the F-test of the effect represented by the k means)

* In this application of Newman-Keuls test n_i is replaced by n (the largest number of observations on which $\bar{Y}_i$ is based. This has the effect of raising the α level = .05 to an unknown level).

df = degrees of freedom on which s^2 is based

$$s_{\bar{Y}_1} = \sqrt{\frac{s^2}{n_1}} = \text{estimated standard error of } \bar{Y}_1$$

Procedure

Arrange observed means in decreasing order of magnitude, and let index i refer to the rank position of the corresponding mean:

$$\bar{Y}_1 > \bar{Y}_2 \quad . . . > \bar{Y}_k$$

Prepare triangular table of calculated values.

Rank index	k	k-1		3	2
1	$\frac{\bar{Y}_1 - \bar{Y}_k}{s_{\bar{Y}_i}}$	$\frac{\bar{Y}_1 - \bar{Y}_{k-1}}{s_{\bar{Y}_i}}$		$\frac{\bar{Y}_1 - \bar{Y}_3}{s_{\bar{Y}_i}}$	$\frac{\bar{Y}_1 - \bar{Y}_2}{s_{\bar{Y}_i}}$
2	$\frac{\bar{Y}_2 - \bar{Y}_k}{s_{\bar{Y}_i}}$	$\frac{\bar{Y}_2 - \bar{Y}_{k-1}}{s_{\bar{Y}_i}}$		$\frac{\bar{Y}_2 - \bar{Y}_3}{s_{\bar{Y}_i}}$	
.	.	.		.	
.	.	.		.	
.	.	.		.	
k-2	$\frac{\bar{Y}_{k-2} - \bar{Y}_k}{s_{\bar{Y}_i}}$	$\frac{\bar{Y}_{k-2} - \bar{Y}_{k-1}}{s_{\bar{Y}_i}}$			
k-1	$\frac{\bar{Y}_{k-1} - \bar{Y}_k}{s_{\bar{Y}_i}}$				

Prepare a list of upper 5 percent points of the Studentized Range q from Table 21 as follows (these may not all be needed so they may be obtained from the table as needed):

$qQ(k, df)$ = means the entry in Table 21 for the proper combination of k and df .

$qQ(k-1, df)$

.

.

.

$qQ(3, df)$

$qQ(2, df)$

The test proceeds sequentially, by rows, as follows:

Starting with row 1:

Declare $\frac{\bar{Y}_1 - \bar{Y}_k}{s_{\bar{Y}_i}}$ significant if it is greater than

$qQ(k, df)$. If not, stop. If so, proceed.

Declare $\frac{\bar{Y}_1 - \bar{Y}_{k-1}}{s_{\bar{Y}_i}}$ significant if greater than

$qQ(k-1, df)$. If not, stop, If so, proceed.

Declare $\frac{\bar{Y}_1 - \bar{Y}_{k-2}}{s_{\bar{Y}_i}}$ significant if greater than

$qQ(k-2, df)$. If not, stop. If so, proceed.

Continue in this way until the first non-significant difference occurs in row 1. All differences to the right of this first non-significant difference in row 1 are then also declared differences in row 1, i.e., those differences in the same columns, are also declared non-significant.

Now start with row 2, but consider only those columns whose row 1 differences were declared significant:

Declare $\frac{\bar{Y}_2 - \bar{Y}_k}{s_{\bar{Y}_i}}$ significant if greater than $q\alpha(k-1,df)$.

If not, stop. If so, proceed.

Declare $\frac{\bar{Y}_2 - \bar{Y}_{k-1}}{s_{\bar{Y}_i}}$ significant if greater than $q\alpha(k-2,df)$

If not, stop. If so, proceed.

Continue in this way until the first non-significant difference occurs in row 2. All differences to the right of this in row 2 are then also declared non-significant. All differences below these non-significant differences in row 2, in the same columns, are also declared non-significant.

Now start with row 3, considering only those columns whose row 2 entry (and therefore also their row 1 entry) was significant:

Declare $\frac{\bar{Y}_3 - \bar{Y}_k}{s_{\bar{Y}_i}}$ significant if greater than $qQ(k-2, df)$.

If not, stop. If so, proceed.

Continue the test sequentially in the same manner as already illustrated.

In general, $\frac{\bar{Y}_i - \bar{Y}_j}{s_{\bar{Y}_i}}$ is declared significant if greater than $qQ(j-1+1, df)$; and all differences to the right of, and/or below a non-significant difference are also non-significant.

TABLE 21
UPPER 5 PERCENT POINTS OF THE STUDENTIZED RANGE q *

df	k	2	3	4	5	6	7	8	9	10
1		18.0	26.7	32.8	37.2	40.5	43.1	45.4	47.3	49.1
2		6.09	8.28	9.80	10.89	11.73	12.43	13.03	13.54	13.99
3		4.50	5.88	6.83	7.51	8.04	8.47	8.85	9.18	9.46
4		3.93	5.00	5.76	6.31	6.73	7.06	7.35	7.60	7.83
5		3.61	4.54	5.18	5.64	5.99	6.28	6.52	6.74	6.93
6		3.46	4.34	4.90	5.31	5.63	5.89	6.12	6.32	6.49
7		3.34	4.16	4.68	5.06	5.35	5.59	5.80	5.99	6.15
8		3.26	4.04	4.53	4.89	5.17	5.40	5.60	5.77	5.92
9		3.20	3.95	4.42	4.76	5.02	5.24	5.43	5.60	5.74
10		3.15	3.88	4.33	4.66	4.91	5.12	5.30	5.46	5.60
11		3.11	3.82	4.26	4.58	4.82	5.03	5.20	5.35	5.49
12		3.08	3.77	4.20	4.51	4.75	4.95	5.12	5.27	5.40
13		3.06	3.73	4.15	4.46	4.69	4.88	5.05	5.19	5.32
14		3.03	3.70	4.11	4.41	4.64	4.83	4.99	5.13	5.25
15		3.01	3.67	4.08	4.37	4.59	4.78	4.94	5.08	5.20
16		3.00	3.65	4.05	4.34	4.56	4.74	4.90	5.03	5.15
17		2.98	3.62	4.02	4.31	4.52	4.70	4.86	4.99	5.11
18		2.97	3.61	4.00	4.28	4.49	4.67	4.83	4.96	5.07
19		2.96	3.59	3.98	4.26	4.47	4.64	4.79	4.92	5.04
20		2.95	3.58	3.96	4.24	4.45	4.62	4.77	4.90	5.01
24		2.92	3.53	3.90	4.17	4.37	4.54	4.68	4.81	4.92
30		2.89	3.48	3.84	4.11	4.30	4.46	4.60	4.72	4.83
40		2.86	3.44	3.79	4.04	4.23	4.39	4.52	4.63	4.74
60		2.83	3.40	3.74	3.98	4.16	4.31	4.44	4.55	4.65
120		2.80	3.36	3.69	3.92	4.10	4.24	4.36	4.47	4.56
		2.77	3.32	3.63	3.86	4.03	4.17	4.29	4.39	4.47

k is the number of quantities (e.g. means) whose range is involved.

df is the degrees of freedom in the error estimate

* From "Extended and corrected tables of the Upper Percentage Points of the Studentized Range" by Joyce M. May, Biometrika, Vo. 39, pp. 192-3

TABLE 21 (Continued)

df	11	12	13	14	15	16	17	18	19	20
1	50.6	51.9	53.2	54.3	55.4	56.3	57.2	58.0	58.8	59.6
2	14.39	14.75	15.08	15.38	15.65	15.91	16.14	16.36	16.57	16.77
3	9.72	9.95	10.16	10.35	10.52	10.69	10.84	10.98	11.12	11.24
4	8.03	8.21	8.37	8.52	8.67	8.80	8.92	9.03	9.14	9.24
5	7.10	7.25	7.39	7.52	7.64	7.75	7.86	7.95	8.04	8.13
6	6.65	6.79	6.92	7.04	7.14	7.24	7.34	7.43	7.51	7.59
7	6.29	6.42	6.54	6.65	6.75	6.84	6.93	7.01	7.08	7.16
8	6.05	6.18	6.29	6.39	6.48	6.57	6.65	6.73	6.80	6.87
9	5.87	5.98	6.09	6.19	6.28	6.36	6.44	6.51	6.58	6.65
10	5.72	5.83	5.93	6.03	6.12	6.20	6.27	6.34	6.41	6.47
11	5.61	5.71	5.81	5.90	5.98	6.06	6.14	6.20	6.27	6.33
12	5.51	5.61	5.71	5.80	5.88	5.95	6.02	6.09	6.15	6.21
13	5.43	5.53	5.63	5.71	5.79	5.86	5.93	6.00	6.06	6.11
14	5.36	5.46	5.56	5.64	5.72	5.79	5.86	5.92	5.98	6.03
15	5.31	5.40	5.49	5.57	5.65	5.72	5.79	5.85	5.91	5.96
16	5.26	5.35	5.44	5.52	5.59	5.66	5.73	5.79	5.84	5.90
17	5.21	5.31	5.39	5.47	5.55	5.61	5.68	5.74	5.79	5.84
18	5.17	5.27	5.35	5.43	5.50	5.57	5.63	5.69	5.74	5.79
19	5.14	5.23	5.32	5.39	5.46	5.53	5.59	5.65	5.70	5.75
20	5.11	5.20	5.28	5.36	5.43	5.50	5.66	5.61	5.66	5.71
24	5.01	5.10	5.18	5.25	5.32	5.38	5.44	5.50	5.55	5.59
30	4.92	5.00	5.08	5.15	5.21	5.27	5.33	5.38	5.43	5.48
40	4.82	4.90	4.98	5.05	5.11	5.17	5.22	5.27	5.32	5.36
60	4.73	4.81	4.88	5.94	5.00	5.06	5.11	5.15	5.20	5.24
120	4.64	4.71	4.78	4.84	4.90	4.95	5.00	5.04	5.09	5.13
	4.55	4.62	4.68	4.74	4.80	4.84	4.89	4.93	4.97	5.01

APPENDIX C.2

T-Test

General Description

The T-Test is a statistical test commonly used to test the hypothesis of equal means $H_0: \mu_i = \mu_j$. The test is commonly applied to the situation where the population variances are assumed equal. The specific application of the test in this data analysis occurred only when the population variance were not assumed equal. A reasonably good approximation in this case is given. (21)

Procedure

Compute

$$t' = (\bar{X}_1 - \bar{X}_2) / (s_1^2/n_1 + s_2^2/n_2)^{1/2}$$

and reject if

$$t' \leq - (w_1 t_1 + w_2 t_2) / (w_1 + w_2)$$

or if

$$t' \geq (w_1 t_1 + w_2 t_2) / (w_1 + w_2)$$

where

$$w_1 = s_1^2/n_1$$

$$w_2 = s_s^2/n_2$$

$$t_1 = t_{(1 - \alpha/2)(n_1 - 1)}$$

$$t_2 = t_{(1 - \alpha/2)(n_2 - 1)} \cdot$$

The above test is repeated for all combinations of means.

APPENDIX C.3

Contingency Table Analysis

The Contingency Table Analysis is a statistical test which can be used to test the hypothesis that all trucks of a given type are from the same population. The test statistic is: (21)

$$\chi^2 = \sum \frac{(F - f)^2}{f}$$

where

F is the observed number of loaded trucks of a given type at a station.

f is the expected percent loaded and is estimated by the total number of all loaded trucks observed, divided by the total number of all trucks (of a given type) times the number of all trucks of the given type at a station.

The test statistic is calculated for each station and summed over all stations to give a calculated χ^2 value.

If the calculated χ^2 value exceeds the theoretical χ^2 for N minus one degrees of freedom, the trucks of a given type do not come from the same population. The number of stations over which the test is applied is N.

APPENDIX D

Coding for Vehicle Types (12)

Code	Symbol	Tandem Axles	Description
11	2P	None	2-axle light motor truck, single passenger car type, rear wheels and tires, including panel, and pickup, other light bodies of less than 1-ton rated capacity, except multistop or standup delivery trucks.
12	2S	None	2-axle motor truck or bus, single truck type rear wheels and tires, other, including all 4-tire vehicles of 1-ton or greater rated capacity and all 4-tire multistop or standup delivery trucks.
13	2D	None	2-axle motor truck or bus, dual rear tires.
14	3A	BC	3-axle motor truck or bus.
15	4A	AB, CD	4-axle (or more) motor truck or bus.
21	2S1	None	2-axle tractor, 1-axle semitrailer (5th wheel coupling).
22	2S2	CD	2-axle tractor, 2-axle semitrailer
24	3S2	BC, DE	3-axle tractor, 2-axle semitrailer
32	2-2	None or CD	2-axle truck and 2-axle full trailer

34	3-2	BC	3-axle truck and 2-axle full trailer
52	2S1-2	None or DE	2-axle tractor, 1-axle semi-trailer, 2-axle full trailer