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16. Abstract

In recent years, maximum legal truck size and weight limits have become major issues in the United States. The assessment of impacts due to changes in maximum limits is an ongoing dynamic problem faced by many highway departments and State legislatures. It has been difficult to predict future truck weight distribution patterns as affected by an alternative legislation governing truck weight. Consequently, it has become implausible to try to forecast precisely the benefits and costs associated with changes in weight limits.

In the past, various methodologies for projecting truck weight distribution patterns have been developed. Each methodology makes some contributions to the assessment of changes in truck weight patterns. However, the precision of projection and the application of each methodology can yet be improved.

In June 1977, the Texas SDHPT contracted the Center for Transportation Research to conduct a study into the truck size and weight issue. As a part of the truck study, a shifting methodology has been developed for the projection of future truck weight distribution patterns. This methodology can be applied either manually or by using a series of computer programs. It can be used to predict both gross vehicle weight and axle weight distributions.

In this report, a brief review of available methodologies and a detailed discussion of the new methodology are presented. Illustrative applications of predicting gross vehicle weight and axle weight distributions as a result of changes in weight limits are presented in the text. Comparison of prediction results generated by all the available shifting methodologies is also included.

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TRUCK WEIGHT SHIFTING METHODOLOGY FOR PREDICTING HIGHWAY LOADS

by

C. Michael Walton
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Paul Ng

Research Report Number 241-5

Truck Use of Highways in Texas
Research Study Number 3-18-78-241

conducted for

Texas State Department of Highways and Public Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

April 1983

PREFACE

This is an interim report on Research Project 3-18-78-241, "Truck Use of Highways in Texas." This report represents one element of an ongoing study to assess the various issues and effects of an increase in truck size and weight on rural highways in Texas. Various joint interim reports,

231 "Effects of Heavy Trucks on Texas Highways,"
241-2 "An Assessment of Changes in Truck Dimensions on Highway Geometric Design Principles and Practices,"
241-3 "Operational Issues of Truck Terminals,"
241-4 "An Assessment of Recent State Truck Size and Weight Studies,"
and 241-6F "An Assessment of the Enforcement of Truck Size and Weight Limitations in Texas."

have been published in the past or will be published in the very near future.

The authors would like to express appreciation to the following for their assistance: Ben Barton, H. D. Butler, and Robert L. Mikulin of SDHPT; Perry Kent of FHWA; and the people at CTR who made various contributions to the preparation of this report.

Additionally, the authors would like to acknowledge the guidance, direction, and support given to the study by the Size and Weights Committee of SDHPT. That Committee is composed of the following members:

Chairman, Byron C. Blaschke, Chief Engineer, Maintenance and Operations
R. L. Lewis, Chief Engineer, Highway Design
Wayne Henneberger, Bridge Engineer
Phillip L. Wilson, State Planning Engineer, Transportation
Robert W. Townsley, Director, Motor Vehicle Division

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August 1982

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In June 1977, the Texas SDHPT contracted the Center for Transportation Research to conduct a study into the truck size and weight issue. As a part of the truck study, a shifting methodology has been developed for the projection of future truck weight distribution patterns. This methodology can be applied either manually or by using a series of computer programs. It can be used to predict both gross vehicle weight and axle weight distributions.

In this report, a brief review of available methodologies and a detailed discussion of the new methodology are presented. Illustrative applications of predicting gross vehicle weight and axle weight distributions as a result of changes in weight limits are presented in the text. Comparison of prediction results generated by all the available shifting methodologies is also included.

KEY WORDS: truck, size, weight, motor carrier, shifting methodology, highway load, forecasting, load prediction, truck laws and regulations, inter- and intra-state commerce

SUMMARY

One important element in the assessment of impacts due to changes in legal truck weight limits is the prediction of the shifting of future truck weight distribution as affected by the change. A number of methodologies have been developed for this purpose. However, with the availability of more recent truck weight data, most of these methodologies have been proven inadequate. A new methodology, known as the average GVW factor methodology, was developed. Both the development and the application of this methodology are discussed explicitly in this report.

The shifting methodology can be applied either automatically by computer software or manually with the aid of pocket calculators. For the former case, a series of computer programs was developed for immediate application. The shifting methodology, in general, can be divided into two phases; one phase to predict the average weight for the truck type under the proposed weight limits and another to shift a typical truck weight distribution curve to a new position so that the mean of the shifted curve is compatible with the average truck weight obtained in the first phase.

In predicting the average truck weight, a regression model can be constructed over the historical data and estimation performed thereafter. However, for a prediction of average truck weight affected by changes in legal weight limits, the expected value issued from the regression model may be purely a guess.

Based on extensive analyses of historical data and their relationship to past changes in legal weight limits, a ratio was found to remain quite stable regardless of the weight limits. The ratio is defined as the average GVW factor. It is the ratio between the current average GVW and the maximum practical GVW. An average GVW factor for each type of truck can be found. This finding is very significant in that once the maximum practical GVW is derived from the proposed weight limits, it is possible to find the expected average vehicle weight for the truck type. By applying this expected value

to the proposed shifting methodology, it may be possible to precisely predict the weight distribution for the truck type.

Another significance of the finding is the relationship discovered between the steering axle, tandem axle, and GVW distributions. For two representative types of trucks, 3A and 3-S2, it was found that the relationship of the three weight distribution types can be represented by the axle configurations. In other words, the tandem axle weight distributions for 3A can be constructed by the algebraic subtraction of the single (steering) axle weight distribution from the GVW distribution at the specific percent intervals. It was observed that the steering axle weight distributions for most of the truck types did not undergo significant changes in the past years. Based on these findings, it becomes possible to predict tandem axle weight distribution patterns for vehicles such as 3A and 3-S2. One may obtain a precise GVW distribution curve for either 3A or 3-S2 from the average GVW factor and the proposed shifting methodology. Then, by algebraic subtraction, one may obtain a precise tandem axle distribution for the truck type.

Although the methodology was developed by analyzing Texas data only, the principles behind the methodology can be applied to other states. Compared to other methodologies, the proposed one requires analysis of more historical data and the shifting procedure is quite time-consuming. However, with available computer software, this shortcoming can easily be overcome. The design of better roadway systems is based on precise prediction, and optimum design should, by no means, be sacrificed in the interest of reducing effort.

IMPLEMENTATION STATEMENT

This report deals with one element of the ongoing study to assess the various issues and effects of increased truck size and/or weight on the rural highways in Texas. This element is the methodology of predicting truck weight distribution patterns as a result of changes in weight legislation. This report should be used in concert with previous and/or subsequent reports as a guide in the consideration of the realism of issues surrounding vehicle size and/or weight limits. The methodology provided in this report will assist with the estimation of changes in truck weight distribution patterns associated with different degrees of changes in weight limits. It also provides a guide to the assessment of truck weight distribution patterns associated with various degrees of weight violation.

DEFINITION OF TERMS AND ACRONYMS

AASHTO	The American Association of State Highway and Transportation Officials (formerly the AASHO: The American Association of State Highway Officials)
AGVWF	Average Gross Vehicle Weight Factor
CTR	Center for Transportation Research
18-KESAL	Eighteen-Kip Equivalent Single Axle Loads
FHWA	The Federal Highway Administration
GVW	Gross Vehicle Weight
NCHRP	The National Cooperative Highway Research Program
PMGVWF	Practical Maximum Gross Vehicle Weight (Future)
PMGVWP	Practical Maximum Gross Vehicle Weight (Present)
SAW	Single Axle Weight
SDHPT	The Texas State Department of Highways and Public Transportation
TAW	Tandem Axle Weight

METRIC CONVERSION TABLE

1 pound force = 4.448 newtons

1 kip = 1,000 pounds = 4.448 kilonewtons

1 ton = 2 kips = 2,000 pounds = 8.896 kilonewtons

1 inch = 25.40 millimeters

1 foot = 12 inches = 304.8 millimeters

1 mile = 5,280 feet = 63,360 inches = 1.609 kilometers

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CHAPTER 1. INTRODUCTION

Changes in legal truck weight and size limits always result in a complicated interaction among highway systems, transport economics, industry, and society. The issue is a complex problem faced by state legislatures and highway engineers. Its complexity is due to the fact that the assessment of impacts of changes involves an interaction of a multitude of disciplines.

The impacts due to changes of legal weight and size limits may be quantified in monetary terms, which can be categorized into benefit and cost components. The major elements of benefit are social (i.e., decreased consumer prices) and motor freight industry benefits (i.e., decreased operating costs). The major elements of cost are highway costs, social costs, and user costs. The highway costs may be subdivided into bridge cost, pavement cost, and maintenance cost. Social costs may be subdivided into costs of noise pollution, air pollution, vibration, and, most important of all, the indirect cost of accidents. User costs have the elements of direct cost of accidents and cost of travel delays. The impact on these economical elements due to changes of legal vehicle limits can be assessed by studying the changes in vehicle operating characteristics, which are the initial and direct result of the legal limit changes. The relationship between these elements and the changes of legal vehicle weight limits is shown in Fig 1.

To evaluate the impact of proposed changes in legal weight limits, vehicle operating characteristics must be precisely forecast. One of the major elements in the vehicle operating characteristics is the future truck weight pattern. The pattern is composed of two components——namely, the gross vehicle weight (GVW) frequency distributions and axle weight frequency distributions. The prediction of the GVW distribution directly affects the assessment of the efficiency of truck operation. For an increase in allowable GVW, a given quantity of payload can possibly be hauled by fewer vehicles. In other words, fewer trips may be required as the payload per vehicle increases; thus, total costs incurred by the truckers might decrease. The prediction of

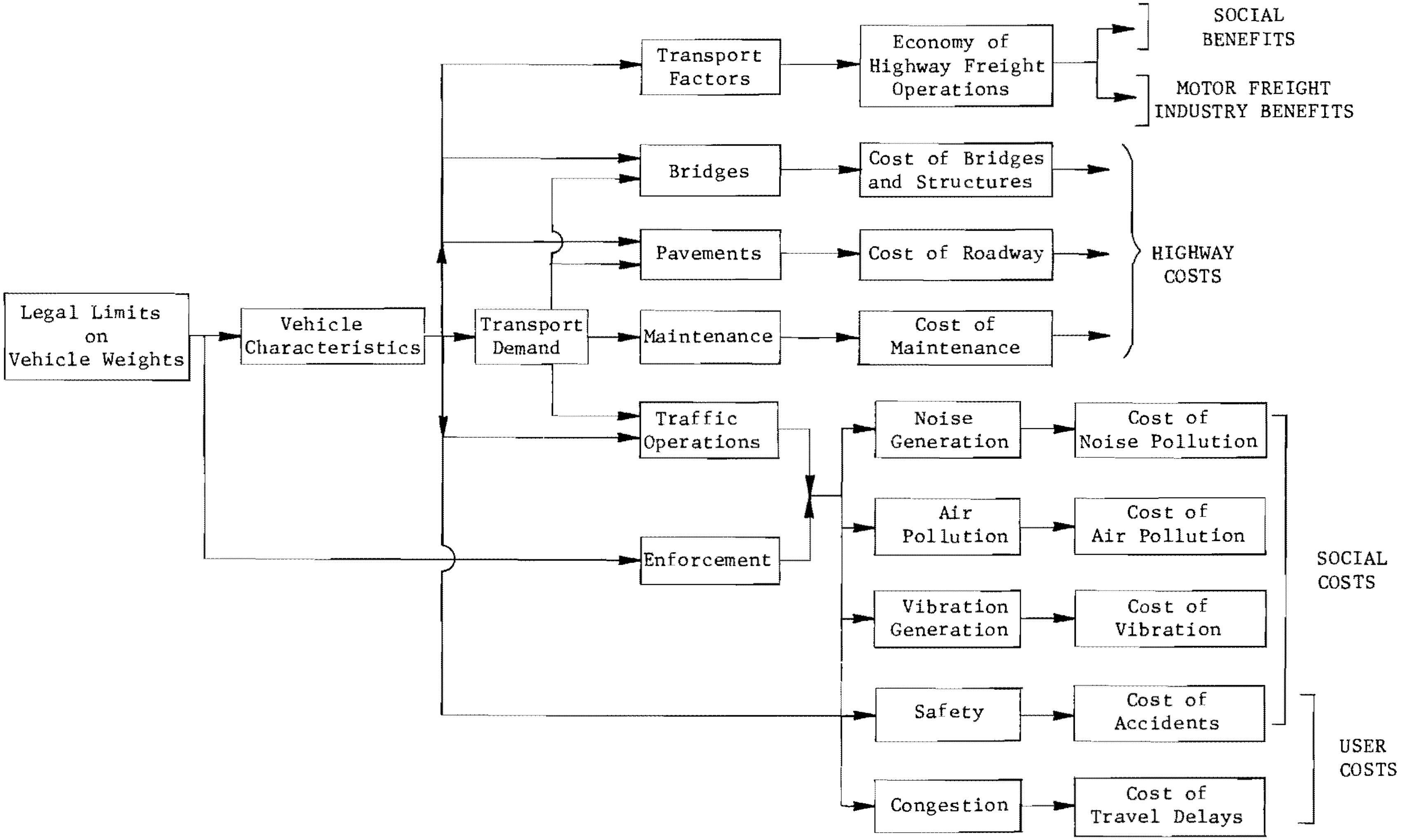


Fig 1. Influence flow between legal vehicle weight limits, basic elements, and benefits and costs to highways, users, and society (Ref 15).

axle weight distribution, which has a close relationship with GVW distribution, directly influences the calculation of highway costs. According to the methodology suggested by AASHTO in pavement design, a precise prediction of axle load distribution will yield a better and more efficient pavement system. Moreover, a precise prediction of axle load distribution will provide a better estimation of pavement cost and bridge cost as results of changes in legal weight limits.

AVAILABLE SHIFTING METHODOLOGIES

Since the prediction of future weight distributions is so vital to the evaluation of impacts due to changes in legal weight limits, a number of methodologies were developed in the past. The effort was focused on forecasting of future truck weight trends precisely so that engineers and planners "may adequately assess the impact of such legislation on the economic vitality of the states and the nation." (Ref 7). The process of predicting future truck weight trends is known as the shifting procedure. The term implies that a truck weight frequency distribution curve is shifted from one position to another as affected by the changes in weight limits. In the past, four different shifting procedures have been developed by federal or state transportation agencies:

(1) first FHWA procedure,
(2) second FHWA procedure,
(3) NCHRP procedure, and
(4) SDHPT procedure.

These procedures will be discussed in the next chapter with the evaluations of their precision and applications.

The impact of a change in legal vehicle size has an influence on the economic elements similar to that caused by the changes in weight limits. However, changes in dimensions cannot be easily forecast because of "the complexity of possible combinations of dimensions and their relationship to geometric design, highway operations, safety, etc" (Ref 15).

Thus, in this report, only the procedure for forecasting truck weight distributions will be presented. The data base for the analysis and research was provided by FHWA (Ref 11).

DATA BASE OF THE RESEARCH

The Transportation Planning Division of the Texas State Department of Highways and Public Transportation is responsible for collecting field truck weight data. These data are then turned over to FHWA, where they are processed and summarized into W-tables. These W-tables are generally published in seven different forms in the annual truck weight survey study report. The following information is obtained from each table (Ref 17).

- Table W-1. Location and time of operation of each truck weigh station and the description and the number of vehicles weighed by type compared to corresponding data from the previous year.
- Table W-1A. Gives the same type of information as W-1, except that W-1 is based on vehicles weighed, while W-1A is based on vehicles counted.
- Table W-2. Gives the number and percentage of vehicles of each type counted at truck weigh station by highway system.
- Table W-3. Gives the number of loaded and empty vehicles counted and average loads of vehicles of each type counted and weighed at the stations by highway system.
- Table W-4. Gives the axle weight distribution at various magnitudes of different truck types counted and weighed at truck weigh stations by highway system.
- Table W-5. Gives the distribution of GVW of different types of vehicles by stations and by highway system.
- Table W-6. This table shows the axle weight, axle spacing, and gross weight of trucks in violation of State limit based on AASHTO recommendations.
- Table W-7. Gives the number and accumulative percentage of vehicles at or below State limit based on AASHTO recommendations.

Based on data provided in W-tables, a study on the shifting procedure was conducted at the Center for Transportation Research. The shifting procedure was studied as a part of the research project entitled "Truck Use of Highways in Texas," which was sponsored by the Texas State Department of Highways and Public Transportation.

In this report, evaluations of several available shifting methodologies based on the truck weight W-tables published since 1959, up to 1979, are made. In the evaluations, four vehicle types were considered. The four vehicle types selected in the analysis constitute the majority of the payload carrying trucks operating on the Texas highway network. These truck types are

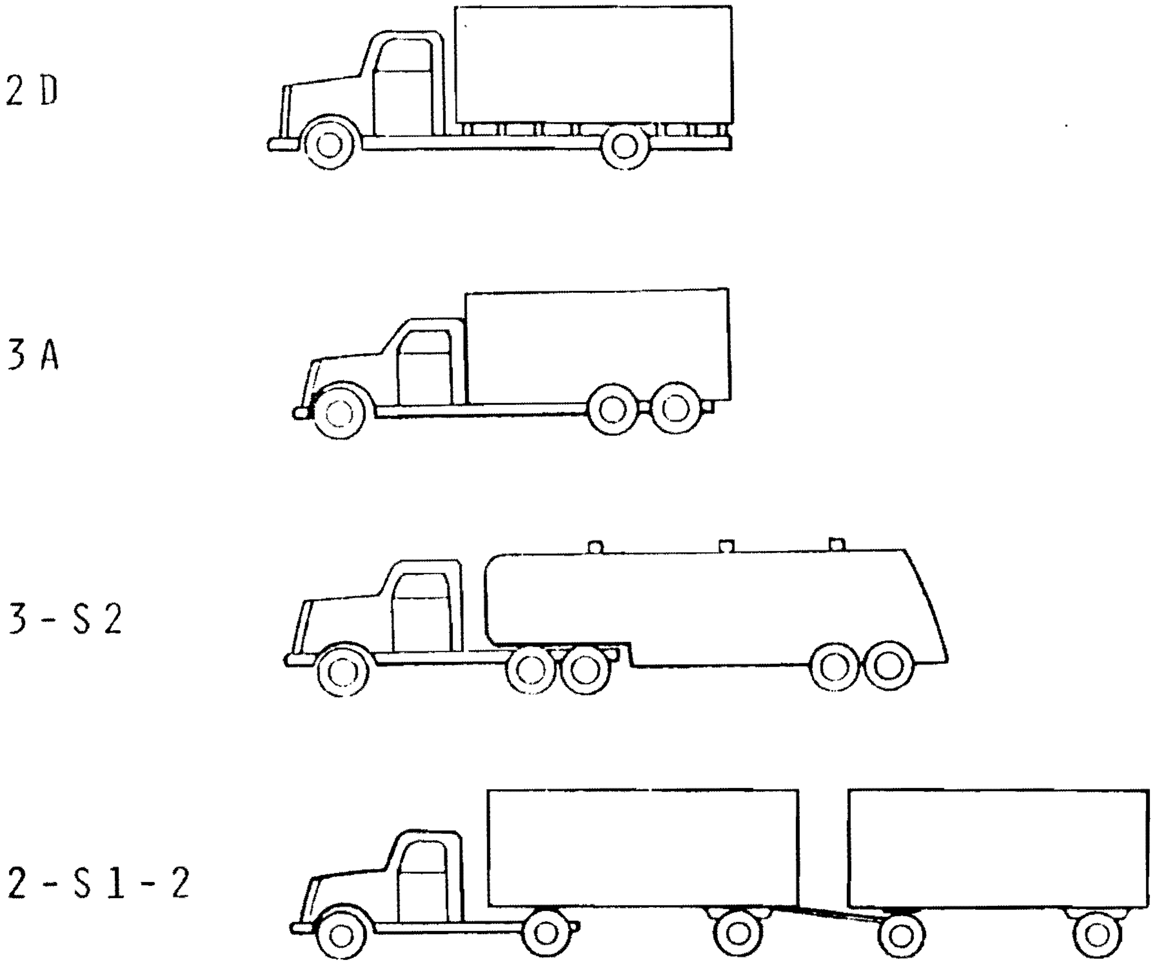


Fig 2. Vehicle configurations included in the study.

2D, 3A, 3-S2, and 2-S1-2. Diagrammatical presentations of these four truck types are provided in Fig 2. With extensive use of GVW distribution and axle weight distribution data, a new methodology known as the Average GVW Factor Procedure was developed at the Center. This procedure can be used in predicting both GVW and axle weight distributions as a result of changes in legal weight limits.

ORGANIZATION OF THE REPORT

In Chapter 2, the existing shifting methodologies will be discussed briefly. Based on the contribution of each shifting methodology, a new shifting procedure was developed. The development of this methodology is discussed explicitly.

The discussion in Chapter 3 relates to the shifting procedure with respect to forecasting truck weight distribution after changes in truck weight limits. A factor known as Average GVW Factor is used to forecast weight distribution trends under proposed limits. The derivation of this factor is also discussed.

Within Chapter 4, the application procedure for the shifting methodology is presented as an illustrative example.

In Chapter 5, the computer procedure of the shifting methodology is introduced. Modifications of the methodology to cope with computer application are discussed in the same chapter.

In Chapter 6, the application of this shifting procedure in forecasting axle weight distribution and the 18-kip equivalent single axle load applications is presented.

Summary and recommendations are provided in the last chapter.

CHAPTER 2. A NEW METHODOLOGY FOR ESTIMATING SHIFTS IN VEHICLE WEIGHT DISTRIBUTION——AVERAGE GVW FACTOR APPROACH

In light of the materials presented in the previous chapter, a brief summary of the evaluations of the available shifting methodologies is presented in the beginning of this chapter. In the second half of the chapter, a modified shifting methodology will be presented.

EVALUATION OF AVAILABLE SHIFTING METHODOLOGIES

The first procedure was published in 1970 by the FHWA in the report "Manual Procedures for Conducting Studies of the Desirable Limits of Dimensions and Weights of Motor Vechicles" (Ref 16). The procedure estimates axle weight distribution by resorting to data from states having higher vehicle size and weight limits. When other states have data for the proposed limits, this procedure may be a useful one, assuming other influences are similar or not significant. Otherwise, this procedure is not flexible enough to study size and weight limits that are not found to exist in other states' size and weight laws (Ref 7).

The second procedure was published in the same report (Ref 16). It uses existing data to predict weight redistribution under the proposed limits. This procedure assumes that "both vehicle empty weights and vehicle payloads will increase with an increase in gross vehicle weight limits and axle weight limits" (Ref 7). The procedure does not take into account commodities which reflect the volume and demand constraints on vehicle usage. Hence, it projects shifting in the lower portion of the weight distribution curve which may not occur (Ref 7).

The NCHRP procedure provides more flexibility in adjusting for volume and demand constraints (Ref 15). In this procedure, ratios of the practical maximum GVW under present and proposed limits are obtained. Through these ratios, or multiplying factors, the weight distribution under the present limit is shifted. The pattern of shift in the NCHRP Shifting Procedure is based on prior research, which indicates that the GVW distribution is shifted to the right with an increase in GVW limit or axle weight limit. This pattern is illustrated in Fig 3. Nevertheless, "this model was based on 1962 truck weight study data and did not apply to the 1975 weight law change situation" (Ref 17). The NCHRP model was reviewed during the initial phase of the Texas truck weight study and modifications were recommended. These recommendations were then incorporated into the SDHPT model (Ref 17).

The SDHPT shifting model (named after the Texas State Department of Highways and Public Transportation) is different from the NCHRP model in the following major areas (Ref 17).

1. Heavily loaded vehicle trips would shift to a higher GVW in proportion to the ratio of practical maximum weight at the future upper limit and practical maximum weight at the present upper limit.
2. Empty and lightly loaded vehicles would be unaffected by the law change.

These differences are illustrated in Fig 4. The shifting produced by SDHPT does not occur immediately, but is introduced at levels which are most likely to be affected by law changes. The multiplying factors for the SDHPT procedure increase more rapidly than the NCHRP procedure.

Further study of existing truck weight data suggests that both NCHRP and SDHPT should be challenged for the following reasons:

1. The historical shift pattern shown in Fig 3 is not clearly observed in the cumulative frequency curves for most vehicle types (Figs 5, 6, 7, 8).
2. With respect to the actual multiplying factors obtained by NCHRP and SDHPT methodologies, a comparison of the differences between the actual and predicted factors proved significant (Figs 9, 10).

DEVELOPMENT OF A NEW SHIFTING PROCEDURE

More recent research surrounding the shifting methodology has been performed at the Center for Transportation Research. The work performed by Walton, Larkin, and Yu provided some very valuable recommendations for the improvement of the shifting procedure. In Walton and Larkin's study (Ref 7), it was observed that the multiplying factors for the 2D and 3A start increasing at a point at approximately 50 percent of the cumulative percentage curve, while 3-S2 and 2-S1-2 started from approximately the 33 percent point. The reason cited for such a difference was based on the observation of the differences in operating characteristics and the types of

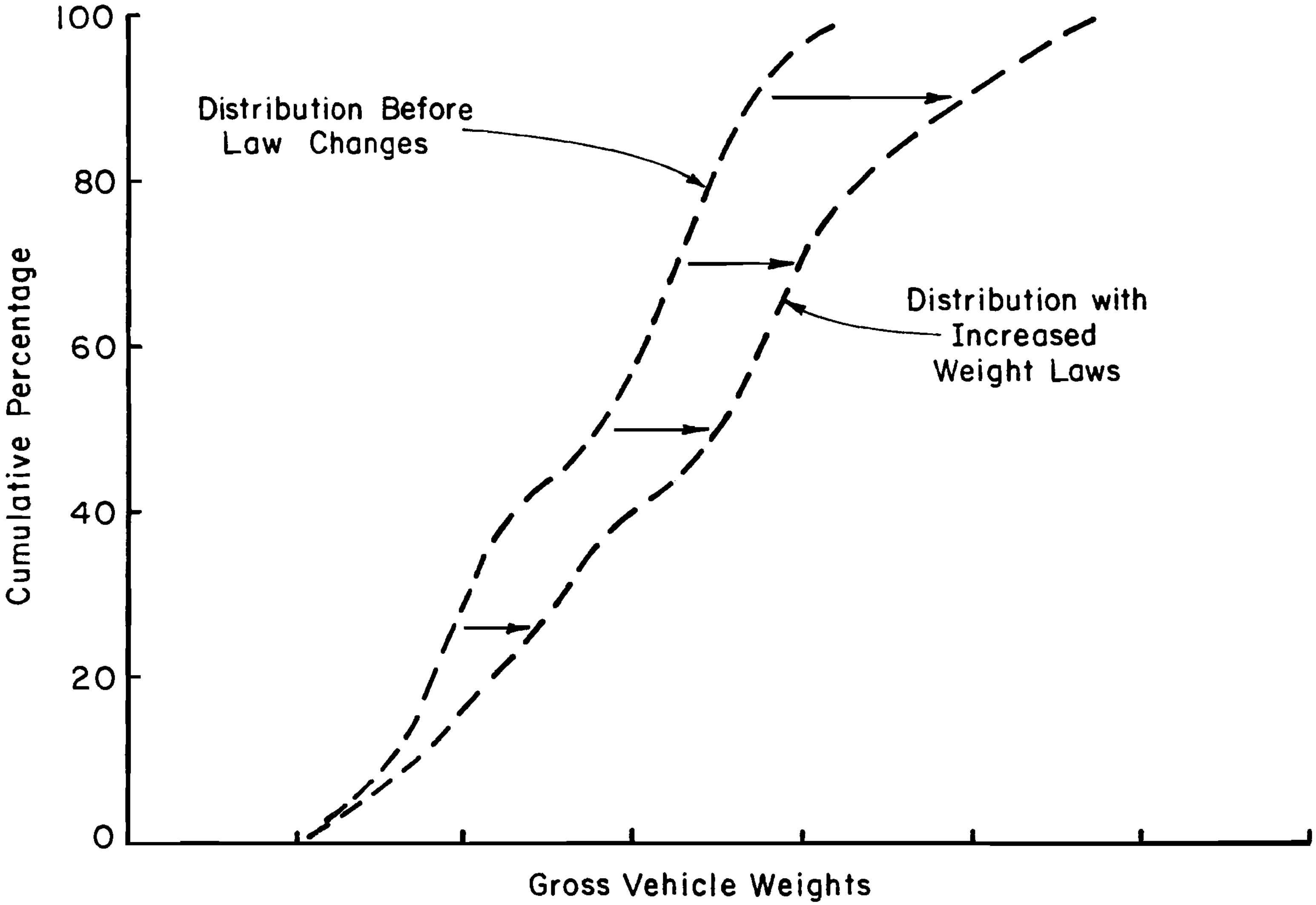


Fig 3. Typical historical shifts in gross vehicle weight distribution (Ref 7).

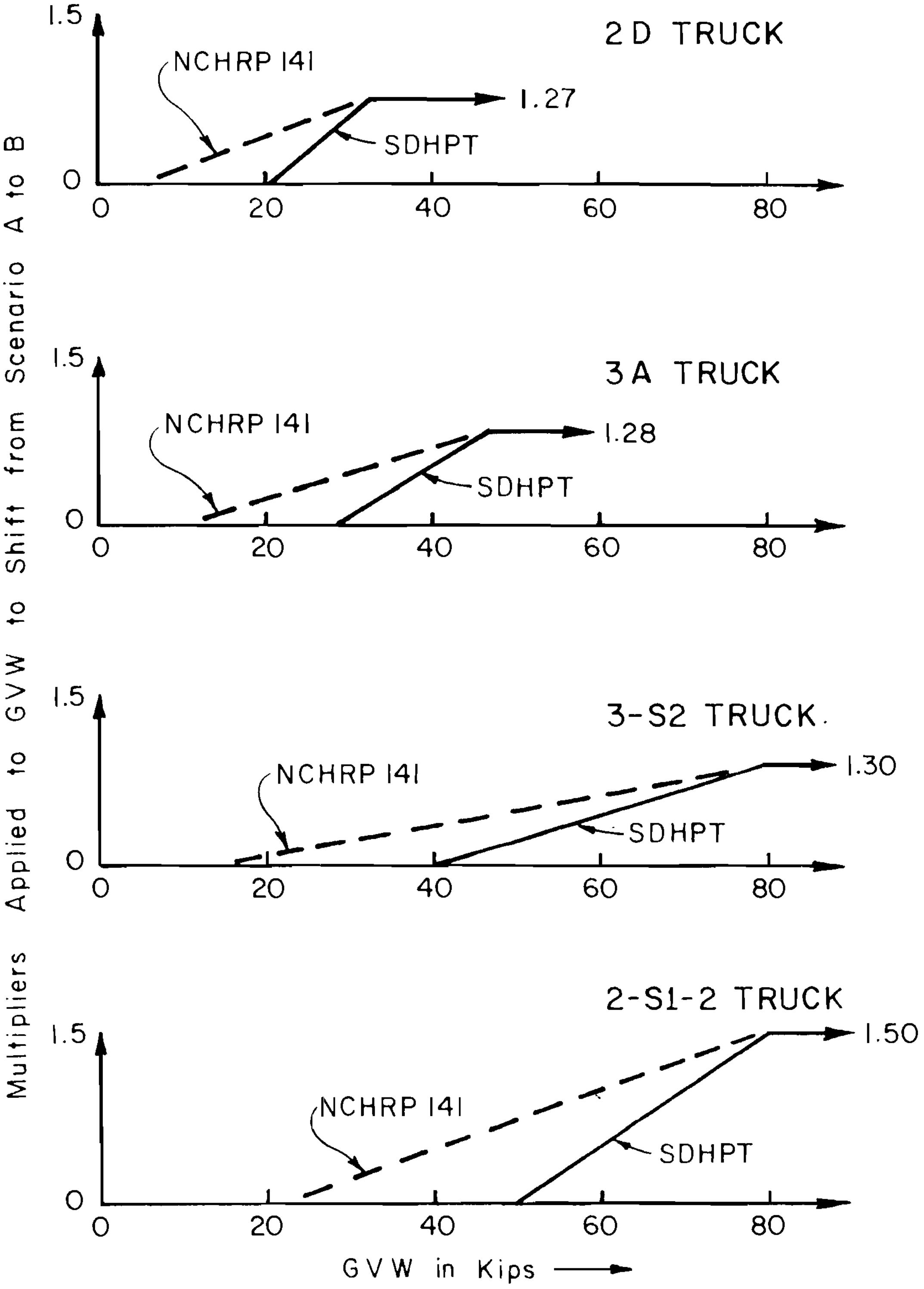


Fig 4. An example of multipliers adopted for shifting GVW distributions (Ref 17).

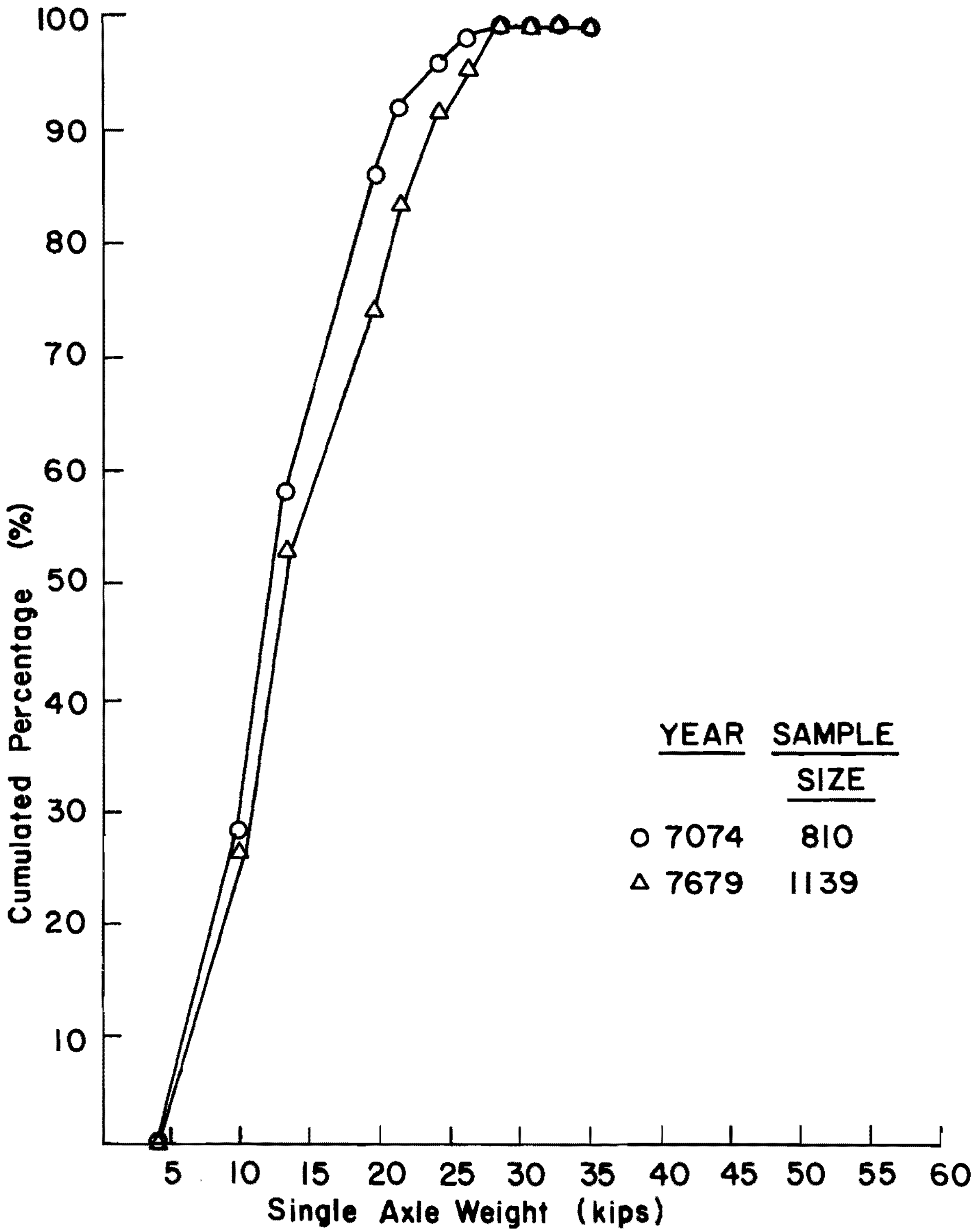


Fig 5. Shifting of GVW distribution of 2D after weight limits changed in 1975.

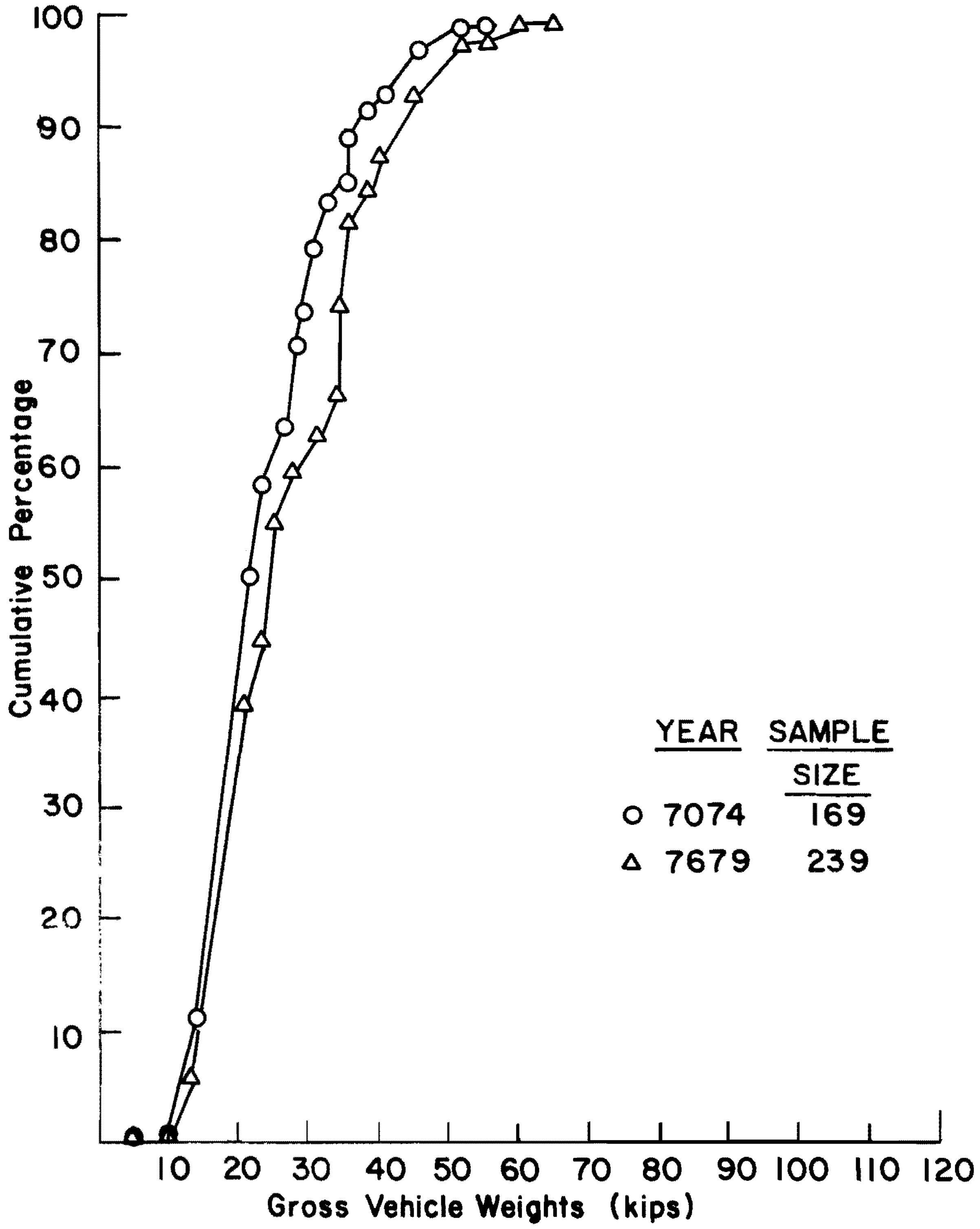


Fig 6. Shifting of GVW distribution of 3A after weight limits changed in 1975.

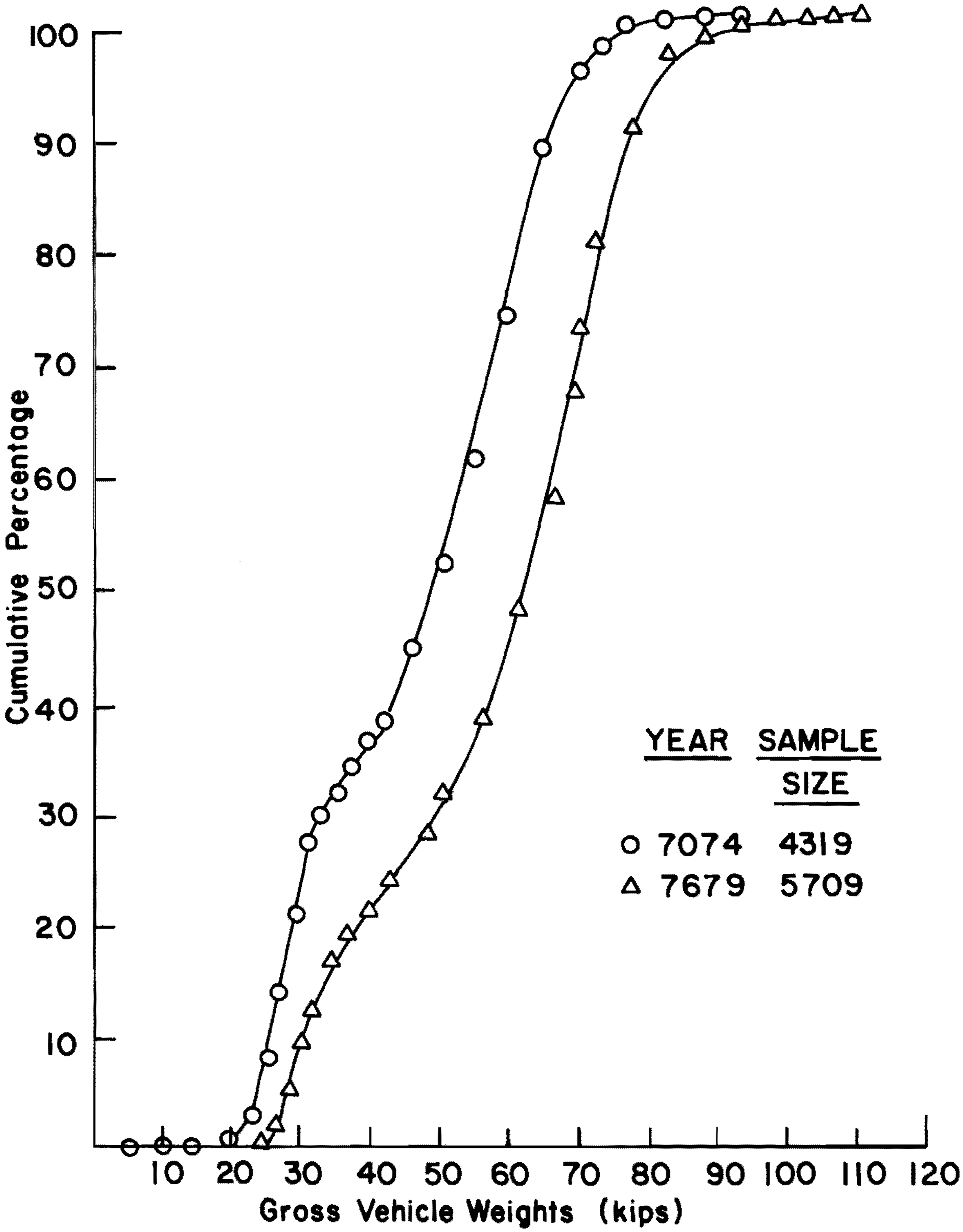


Fig 7. Shifting of GVW distribution of 3-S2 after weight limits changed in 1975.

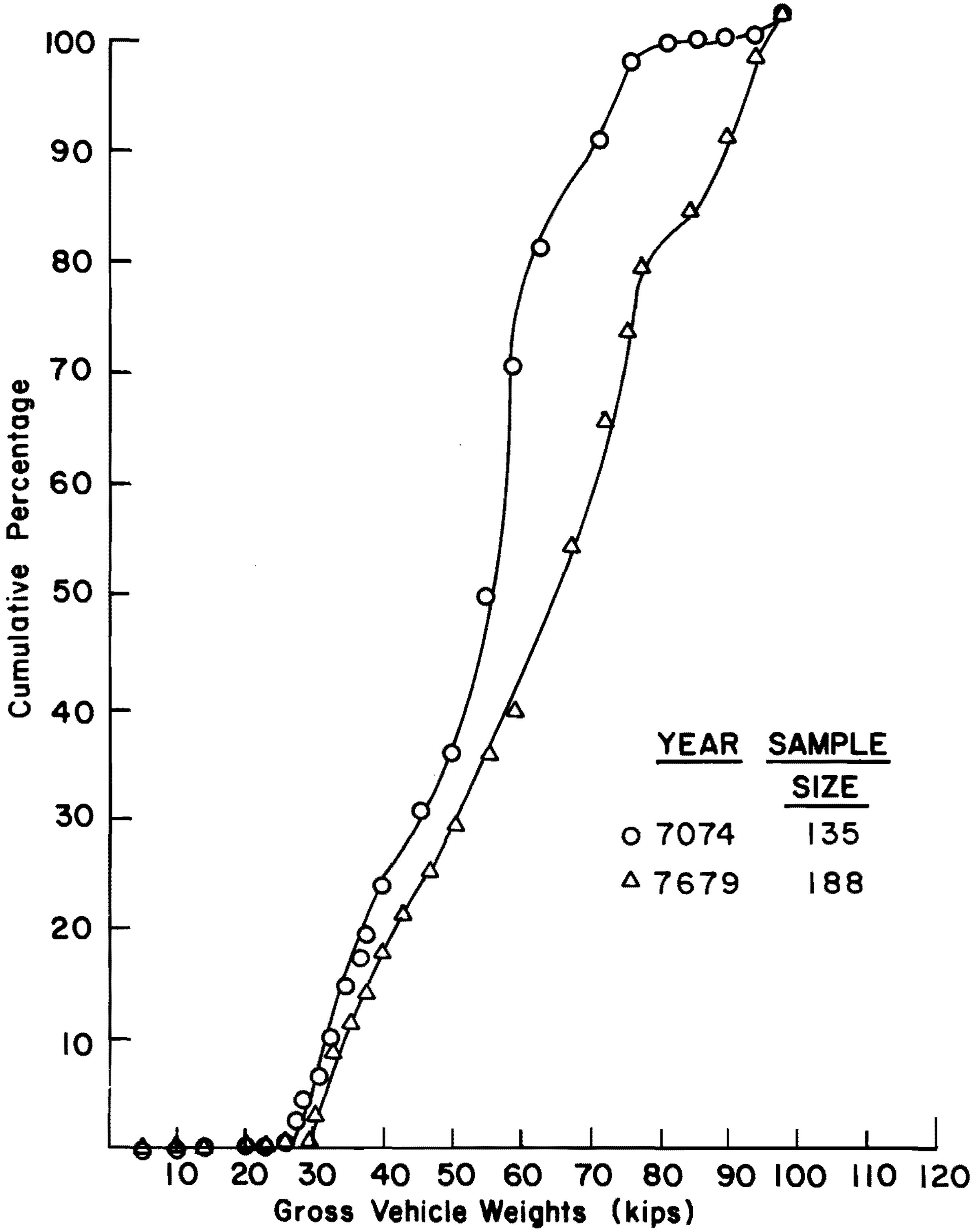


Fig 8. Shifting of GVW distribution of 2-S1-2 after weight limits changed in 1975.

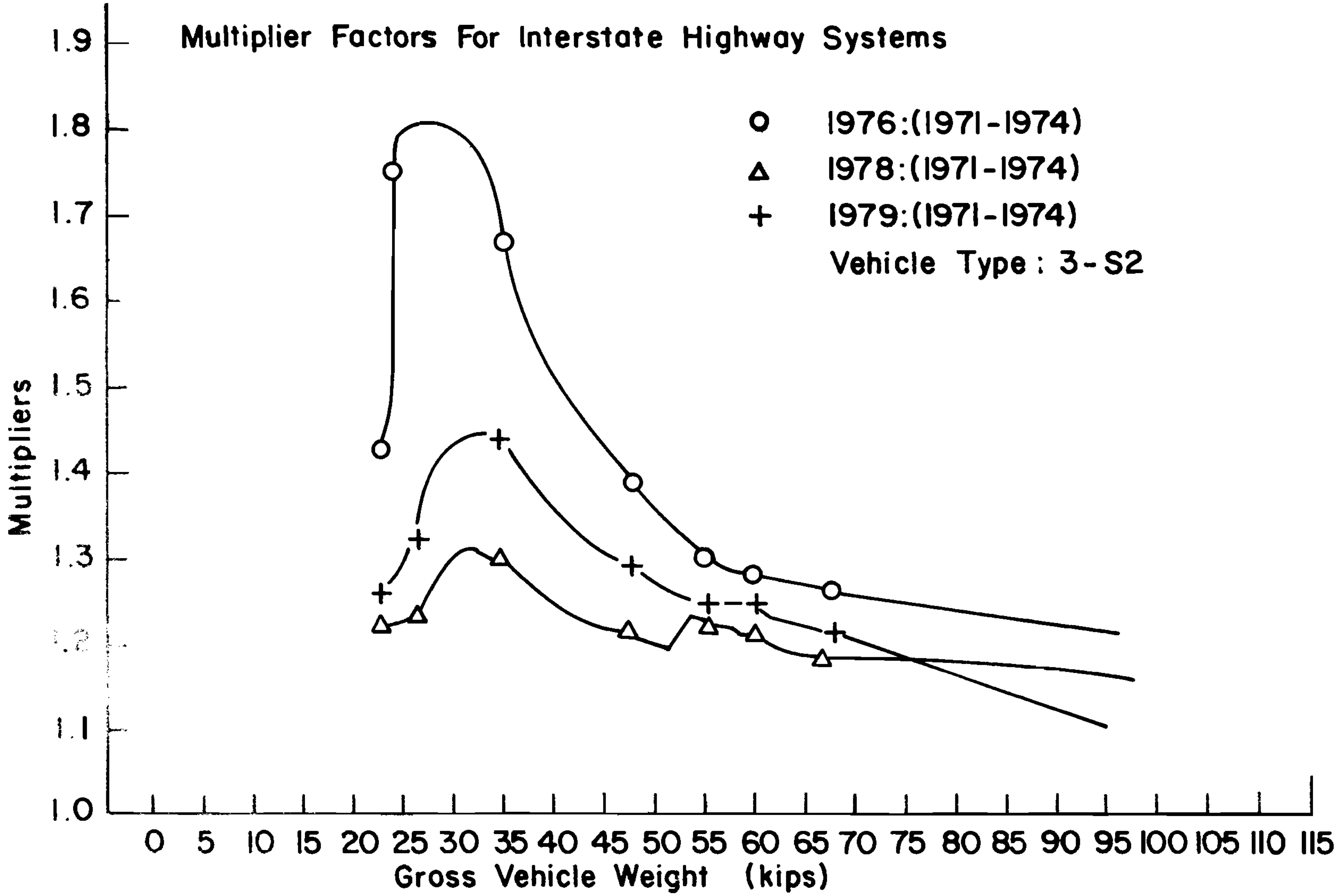


Fig 9. Comparison of NCHRP, SDHPT, and actual multiplying factors for Texas interstate rural highways.

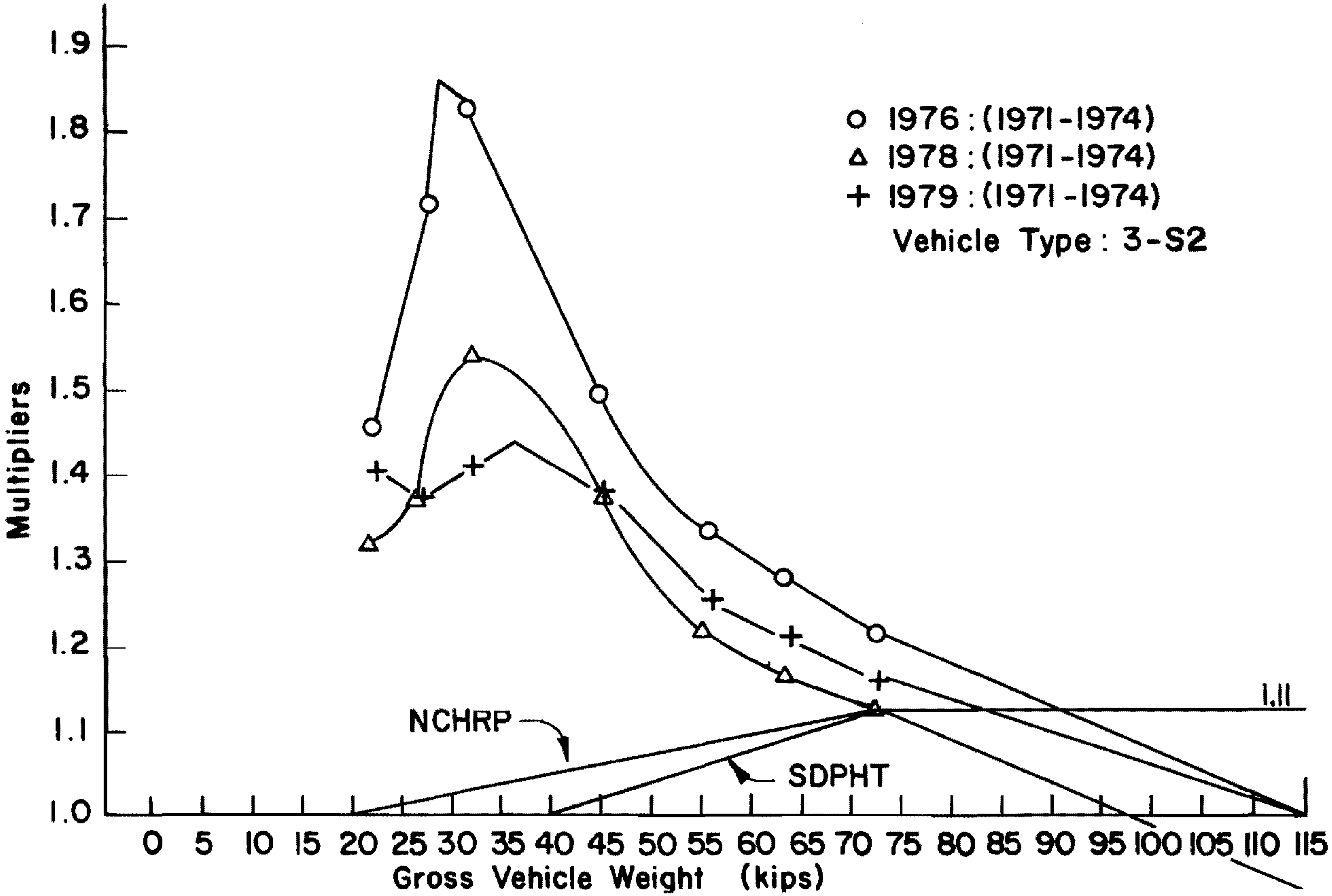


Fig 10. Comparison of NCHRP, SDHPT, and actual multiplying factors for other main rural highways.

commodities transported. It was stated that the 3-S2 and 2-S1-2 vehicles are less likely than 2D and 3A to be demand and volume constrained (Ref 7).

In Walton and Yu's study (Ref 13), they concluded that the redistribution of vehicle weight due to changes in size and weight laws varies from one vehicle class to another. They also pointed out that a specific highway class based methodology is preferred to a more general one.

Based on these findings and recommendations, further research to develop a more precise shifting methodology was pursued.

DESCRIPTION OF THE METHODOLOGY

The new shifting procedure extends the contribution of the previous shifting models. For instance,

1. Existing data within the state are analyzed and used as a base for projection as in the second FHWA method.
2. Multiplying factors are used as a means of performing the shifting as suggested in NCHRP procedure (Ref 15).
3. Initial shifting points in the accumulated percentage are used to take into account demand and volume constraint considerations (Ref 7).
4. A vehicle-class based methodology is used (Ref 13).

In addition to these contributions, some additional improvements have also been incorporated.

1. Most of the accumulated distribution curves of vehicle weight resemble a normal distribution pattern; therefore, both the mean and the variance of a curve are used to characterize the truck weight distribution pattern.
2. Past truck weight distribution data are used for trend analysis. Figure 11 illustrates that the trend of the mean truck weight did reflect the changes that occurred in truck size and weight laws in Texas.
3. More statistical analysis and testing are used in the shifting procedures.

Before discussing the procedure in more detail, it is worthwhile to review some of the estimators that are used.

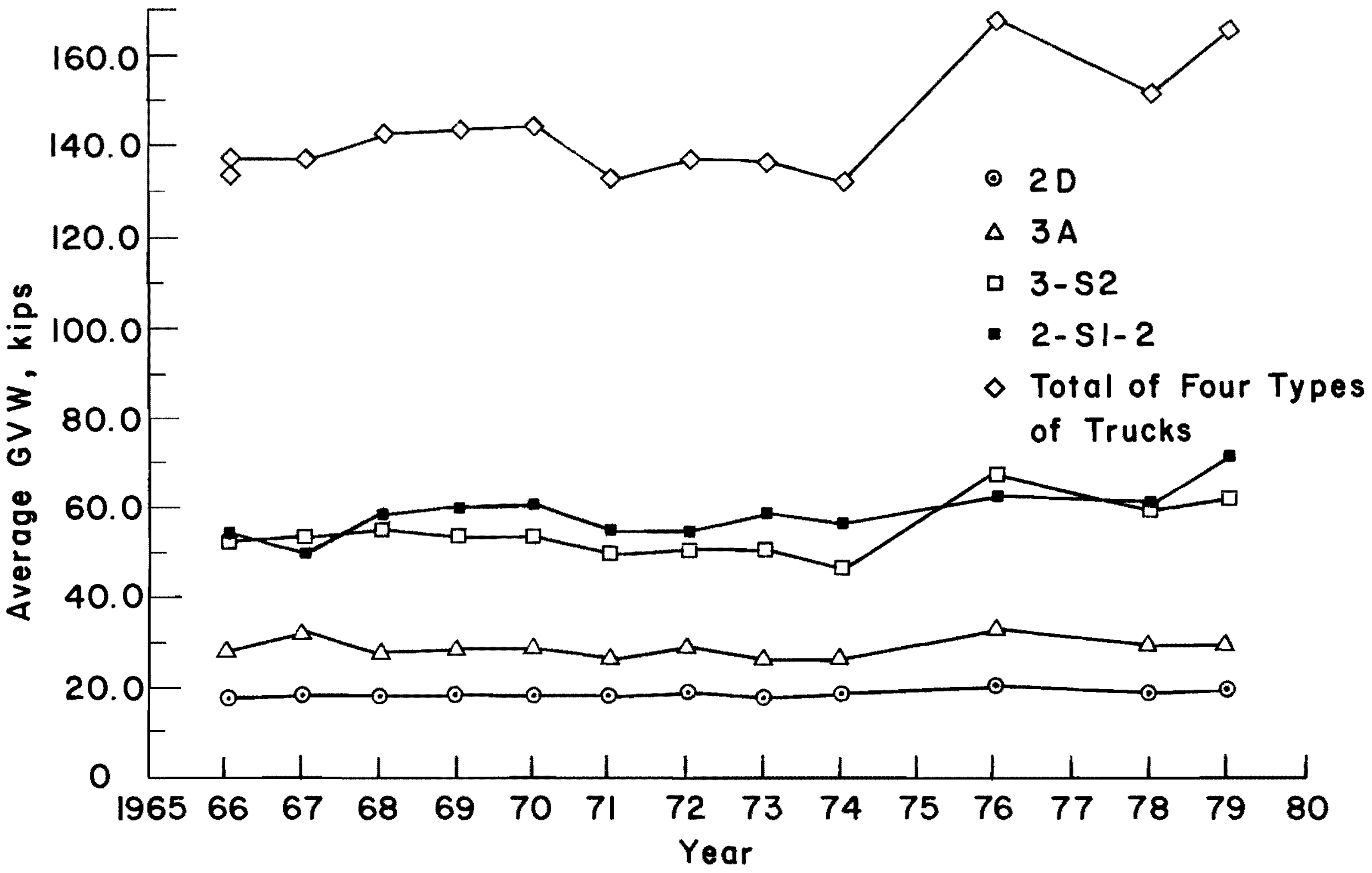


Fig 11. Average gross vehicle weight for four types of trucks on Texas interstate highways.

ESTIMATORS FOR THE SHIFTING PROCEDURE

When the sample size is sufficiently large (e.g., the number of observations is more than 100), the truck weight distribution data resemble a normal distribution pattern. Thus it is convenient and accurate to use both the mean and the variance of each distribution curve as the estimators to characterize a truck weight distribution curve. In Fig 11 the mean truck weights for four types of vehicles from 1966 to 1979 are shown. The trends suggest that the usage of mean truck weight as a detector of changes in the truck weight laws may be justified. For instance, the curves show significant jumps between 1974 and 1976. Within the same span of time, the truck size and weight laws in Texas were changed. Figure 12 shows a set of typical truck weight distribution curves for the 3-S2. It indicates that the curves shifted to the right following the changes in Texas weight laws in 1975. From Fig 11, substantial variations are observed in the truck weight distribution for 1978 and 1979. These variations can be confirmed by referring to Fig 12. The mean GVW increases as the curve shifts to the right and the mean GVW decreases as the curve moves to the left. Thus, the mean GVW can be used as an index to detect the direction of shifting of the truck weight distribution curve.

The other estimator used is the variance of the distribution curves. It is insufficient to use the mean as the only estimator. This insufficiency is shown in Figs 13 and 14. Figure 13 shows the plotting of both the mean and variance of a set of distribution curves for the 3-S2 on the Interstate Rural Highway System. Figure 14 shows a set of truck weight distribution curves from the same set of truck weight data. The mean weight curve in Fig 13 does not suggest any shifting in the truck weight distribution for the period 1966 through 1974. However, in actuality, some amount of shifting did occur, as is shown in Fig 14. By using just the mean GVW, such shifting trends may go undetected. However, with the second estimator, the variance of GVW distribution, such a shift is more readily apparent. Thus, the variance is requied as a second estimator.

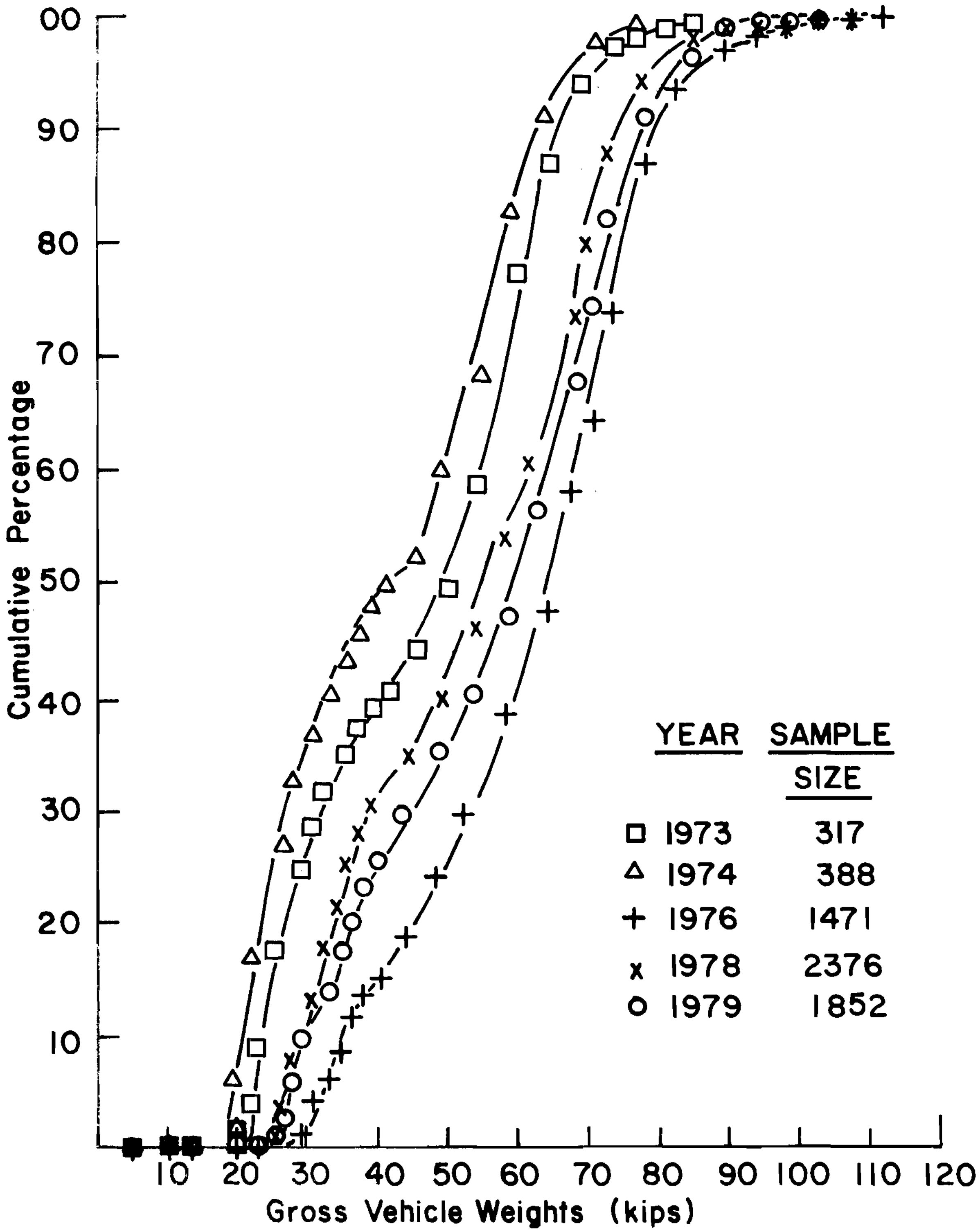


Fig 12. A set of typical weight distribution curves showing shifting occurred after weight limits changed in 1975.

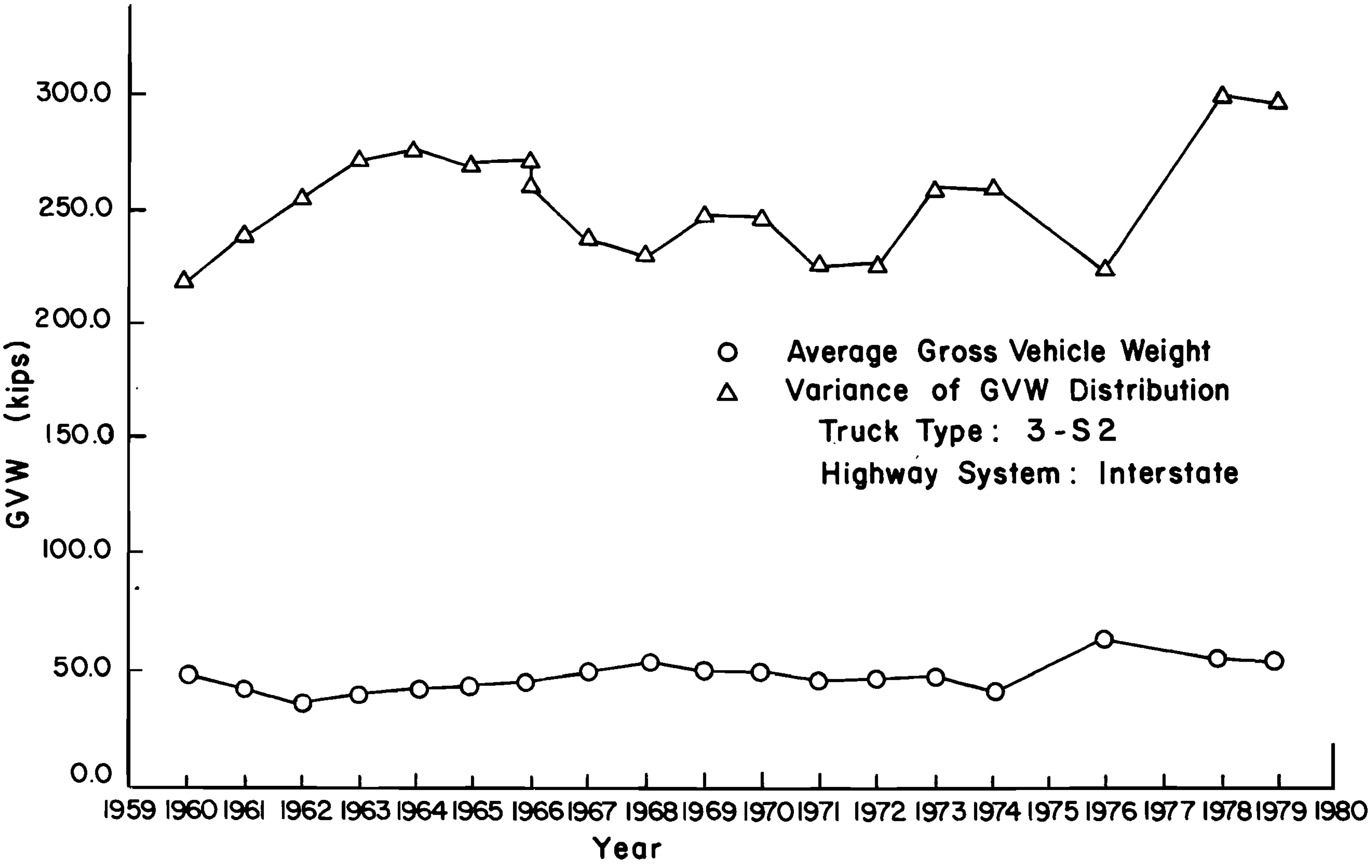


Fig 13. Trends of mean and variance of GVW distribution for 3-S2 on Texas interstate rural highways.

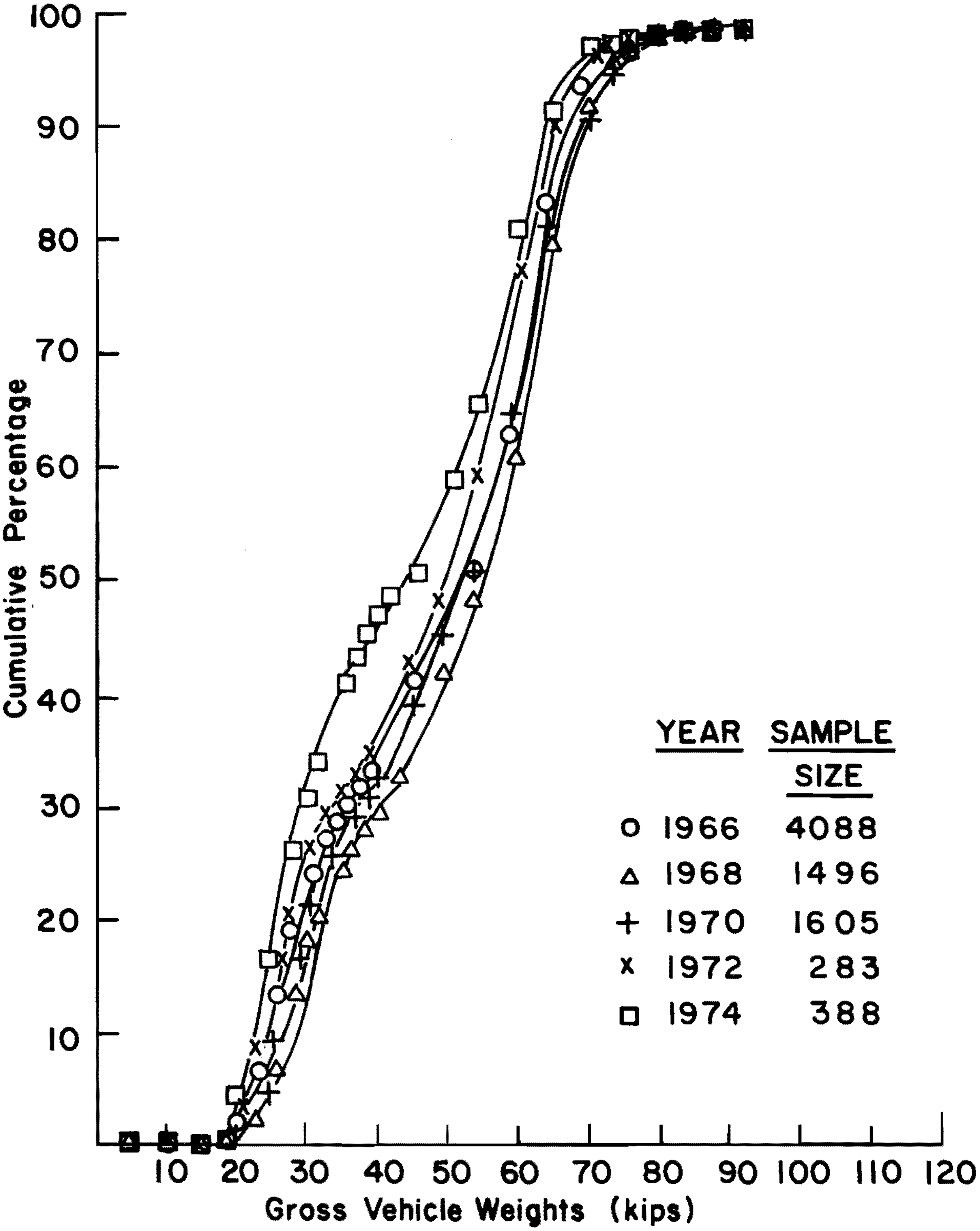


Fig 14. Truck GVW distribution curves obtained before the 1975 weight law changes.

DISCUSSION OF THE NEW SHIFTING METHODOLOGY

The shifting methodology is composed of two major parts. The first part is to analyze the past truck weight trend by studying the patterns of both the mean and variance of historical truck GVW distribution data. The second part is the prediction of the future truck GVW distribution. The prediction may be for a certain year given an existing or a proposed weight law. The first part of the procedure is discussed in the rest of this chapter. The second part of the procedure may be done either manually or with computer application. The manual application of the procedure is discussed in Chapter 4 and the computer application in Chapter 5. At any rate, the mean and variance of the predicted curve should be compatible with (i.e., within the desirable confidence levels) the respective values estimated from the first part of the procedure.

ANALYSIS OF HISTORICAL TRUCK WEIGHT DATA

At periodic intervals most states submit truck weight survey data to the FHWA. The survey data are processed and summarized by FHWA, with summaries of truck weight distribution data formated into W-tables. These W-tables are the most complete information available on the vehicle weight carried by the highway system. In order to study truck weight trends, the means and the variances for each year for which data are available must be computed. The computation procedure (given below) is illustrated by the example shown in Table 1. In the example, the data for a 3-S2 truck type operating on Texas interstate rural highways are used. The data required are the GVW's which were obtained from the W-5 tables.

Step 1. Enter the GVW distribution intervals in column A; compute the mid-GVW and enter the values in column B.

Step 2. Enter the number of vehicles weighed in each GVW interval in column C.

Step 3. Compute the products of values in columns B and C for each row; enter results in column D.

Step 4. By rows, compute the square of the values in column B, then multiply the square with values in column C. Enter results in column E.

Step 5. Find the summations of columns C, D, and E.

TABLE 1. EXAMPLE OF COMPUTATION OF MEAN AND VARIANCE FOR TRUCK WEIGHT DISTRIBUTION DATA (3-S2, TEXAS INTERSTATE RURAL HIGHWAYS, 1980)

(A) Truck Weight Distribution Intervals	(B) Mid-Point	(C) Accumulated Frequency (%)	(D) Percentage (%)	(E) B x D	(F) B^2 x D
0.0-4.0	2.0	0.0	0.0	0.0	0.00
4.0-10.0	7.0	0.0	0.0	0.0	0.00
10.0-13.5	11.75	0.0	0.0	0.0	0.00
13.5-20.0	16.75	0.0	0.0	0.0	0.00
20.0-22.0	21.0	0.5	0.5	10.5	5.25
22.0-24.0	23.0	1.0	0.5	11.5	5.75
24.0-26.0	25.0	2.0	1.0	25.0	25.00
26.0-28.0	27.0	5.5	3.5	94.5	330.75
28.0-30.0	29.0	12.5	7.0	203.0	1,421.00
30.0-32.0	31.0	16.0	3.5	108.5	379.75
32.0-34.0	33.0	20.0	4.0	132.0	528.00
34.0-36.0	35.0	23.5	3.5	122.5	428.75
36.0-37.0	37.0	26.0	2.5	92.5	231.25
38.0-40.0	39.0	29.0	3.0	117.0	351.00
40.0-45.0	42.5	34.0	4.0	212.5	1,062.50
45.0-50.0	47.5	38.0	4.0	190.0	760.00
50.0-55.0	52.5	44.0	6.0	315.0	189.00
55.0-60.0	57.5	53.0	9.0	517.5	4,657.50
60.0-65.0	62.6	61.0	8.0	500.0	4,000.00
65.0-70.0	67.5	73.0	12.0	810.0	9,720.00
70.0-72.0	71.0	83.0	10.0	710.0	7,100.00
72.0-75.0	73.5	87.5	4.5	330.75	1,488.38
75.0-80.0	77.5	95.0	7.5	581.25	4,359.38
80.0-85.0	82.5	97.0	2.0	165.0	330.00
85.0-90.0	87.5	98.0	1.0	87.5	87.50
90.0-95.0	92.5	99.0	1.0	92.5	92.50
95.0-100	97.5	99.5	0.5	48.75	24.38
100.0-105	102.5	100.0	0.5	51.25	25.63
105.0-110	107.5	100.0	0.0	0.0	0.00
110.0-115	112.5	100.0	0.0	0.0	0.00
			Σ = 100.00	Σ = 5,509.00	Σ = 338,814.25

$$\text{MEAN} = \frac{5,509}{100} = \underline{\underline{55.09}}; \quad \text{VARIANCE} = \frac{338,814.25 - (5,509)^2/100}{100} = \underline{\underline{353.23}};$$

$$\text{STANDARD DEVIATION} = \underline{\underline{18.79}}$$

Step 6. Compute the mean GVW using

$$\text{Mean GVW} = \frac{\Sigma(\text{Column D})}{\Sigma(\text{Column C})}$$

Step 7. Compute the variance:

$$\text{Variance} = \left[\frac{\Sigma(\text{Column E}) - \dfrac{\Sigma(\text{Column D}) \times \Sigma(\text{Column D})}{\Sigma(\text{Column C})}}{\Sigma(\text{Column C}) - 1} \right]$$

With all the available truck GVW weight data, compute the mean and variance for each year and plot both values versus time. Once the curves have been plotted, specific trends of GVW means and variances may be realized. An example for the 3-S2 truck type is shown in Fig 13. Although the figure suggests possible trends with respect to mean and variance, no specific regression model has been developed for the analysis.

The importance of a shifting methodology is not based on its ability to predict the new weight distribution within the span of the same weight laws. Rather, the major concern of a methodology is its capability to predict changes in distribution trends under proposed weight laws. In Fig 11, it is shown that for each type of truck there were two significant deviations in 1960 and 1975. These deviations or "jumps" could not have been predicted through extrapolation of previous trends.

CHAPTER 3. A SHIFTING PROCEDURE TO INCORPORATE INFLUENCES DUE TO CHANGES IN TRUCK WEIGHT LIMITS

From a detailed study of the average vehicle weight trends as replicated in the Texas data, some conclusions were drawn:

1. Within the span of same truck weight laws, the average GVW for each truck type did not change abruptly. Rather, the changes over a period of time were gradual.
2. Correlation among the four major trucks (i.e., 2D, 3A, 3-S2, and 2-S1-2) was studied; however, no significant correlation on the average GVW among the four truck types was observed.
3. The average GVW factor is defined as the ratio between the average GVW and the practical maximum GVW allowed by current weight laws for a specific truck type. The variation of this ratio throughout the years for a specific truck type is virtually insignificant.

DERIVATION OF AVERAGE GVW FACTORS

Among the three findings, the most significant one is the third item. Tables 2, 3, 4, and 5 show the average truck weights and ratios with respect to the practical maximum GVW for 2D, 3A, 3-S2, and 2-S1-2, respectively. The ratio can be expressed mathematically as

$$\begin{array}{c}\text{Average GVW}\\ \text{Factor}\end{array} = \frac{\text{Average GVW}}{\text{Practical maximum GVW}}$$

For each type of truck, a linear regression analysis was applied to determine the relationship between the average GVW and the practical maximum GVW. In the regression, the independent variable was the practical maximum GVW and the dependent variable was the average GVW. The regression model had no constant term; it can be expressed as

$$Y = AX,$$

where Y = Average GVW,
X = Practical maximum GVW, and
A = Coefficient.

TABLE 2. RELATIONSHIP OF AVERAGE GVW AND PRACTICAL MAXIMUM GVW FOR 2D, TEXAS INTERSTATE RURAL HIGHWAYS

Year	Average Legal GVW (kips)	Practical Maximum GVW (kips)	Average GVW Factor
1960	12.39	24.60	0.50
1961	12.55	24.60	0.51
1962	12.17	24.60	0.49
1963	12.10	24.60	0.49
1964	12.11	24.60	0.49
1965	12.49	24.60	0.51
1966	12.31	24.60	0.50
1967	13.06	24.60	0.53
1968	12.82	24.60	0.52
1969	12.75	24.60	0.52
1970	12.79	24.60	0.52
1971	12.86	24.60	0.52
1972	13.00	24.60	0.53
1973	12.84	24.60	0.52
1974	13.34	24.60	0.54
1975	(Texas weight limits changed)		
1976	15.67	27.22	0.58
1978	13.87	27.22	0.51
1979	14.41	27.22	0.53

Note: 1976 data were not included in the following statistics.

Mean of GVW Factor = 0.51
Standard Deviation = 0.0147

One-Sample t-test = 1.24 (D.F. = 16)
Two-Sample t-test = -0.58 (D.F. = 16)

TABLE 3. RELATIONSHIP OF AVERAGE GVW AND PRACTICAL MAXIMUM GVW FOR 3A, TEXAS INTERSTATE RURAL HIGHWAYS

Year	Average Legal GVW (kips)	Practical Maximum GVW (kips)	Average Legal Factor
1960	26.45	42.46	0.63
1961	19.90	42.26	0.47
1962	21.35	42.26	0.51
1963	22.62	42.26	0.54
1964	21.13	42.26	0.50
1965	21.19	42.26	0.50
1966	21.62	42.26	0.51
1967	24.50	42.26	0.58
1968	20.22	42.26	0.48
1969	21.59	42.26	0.51
1970	21.59	42.26	0.51
1971	20.15	42.26	0.48
1972	24.05	42.26	0.57
1973	21.25	42.26	0.50
1974	20.23	42.26	0.48
1975	(Texas Weight Limits Changed)		
1976	27.11	44.90	0.60
1978	22.45	44.90	0.50
1979	23.13	44.90	0.52

Note: 1960 and 1976 data were not included in the following statistics.

Mean of GVW Factor = 0.51
Standard Deviation = 0.0302

One Sample t-test = -0.108 (D.F. = 15)
Two Sample t-test = 0.34 (D.F. = 17)

TABLE 4. RELATIONSHIP OF AVERAGE GVW AND PRACTICAL MAXIMUM GVW FOR 3-S2, TEXAS INTERSTATE RURAL HIGHWAYS

Year	Average Legal GVW (kips)	Practical Maximum GVW (kips)	Average GVW Factor
1960	48.52	72.00	0.67
1961	46.68	72.00	0.65
1962	45.63	72.00	0.63
1963	46.51	72.00	0.65
1964	46.70	72.00	0.65
1965	47.22	72.00	0.66
1966	47.46	72.00	0.66
1967	47.91	72.00	0.67
1968	49.35	72.00	0.69
1969	47.51	72.00	0.66
1970	47.65	72.00	0.66
1971	44.92	72.00	0.62
1972	44.54	72.00	0.63
1973	45.21	72.00	0.63
1974	41.32	72.00	0.57
1975	(Texas Weight Limits Changed)		
1976	59.43	80.00	0.74
1978	53.20	80.00	0.67
1979	54.86	80.00	0.69

Note: 1974 and 1976 data were not included in the following statistics.

Mean of GVW Factor = 0.66
Standard Deviation = 0.0183

One-Sample t-test = -1.15 (D.F. = 15)
Two-Sample t-test = -1.78 (D.F. = 14)

TABLE 5. RELATIONSHIP OF AVERAGE GVW AND PRACTICAL MAXIMUM FVW FOR 2-S1-2, TEXAS INTERSTATE RURAL HIGHWAYS

Year	Average Legal GVW (kips)	Practical Maximum GVW (kips)	Average GVW Factor
1966	48.28	72.00	0.67
1967	45.40	72.00	0.63
1968	52.92	72.00	0.74
1969	53.16	72.00	0.74
1970	53.78	72.00	0.74
1971	50.17	72.00	0.70
1972	50.17	72.00	0.70
1973	53.88	72.00	0.75
1974	49.25	72.00	0.68
1975	(Texas Weight Limits Changed)		
1976	57.19	80.00	0.71
1978	53.65	80.00	0.67
1979	57.18	80.00	0.71

Note: 1974 and 1976 data were not included in the following statistics.

Mean of GVW Factor = 0.072
Standard Deviation = 0.0359

One-Sample t-test = 0.271 (D.F. = 10)
Two-Sample t-test = 0.41 (D.F. = 9)

The statistical package MINITAB was used in the analysis. The coefficient for each type of truck obtained from the analysis can be used as the recommended average GVW factor. These coefficients are shown in Table 6.

TABLE 6. RECOMMENDED AVERAGE GVW FACTORS FOR FOUR TYPES OF TRUCKS OPERATING ON TEXAS INTERSTATE RURAL HIGHWAYS

Truck Type	Recommended Average GVW Factor
2D	0.51
3A	0.51
3-S2	0.66
2-S1-2	0.70

<u>One-Sample t-test</u>

In order to test the validity of these average GVW factors, two statistical tests, one-sample t-test and two-sample t-test, were used. The one-sample t-test is to test

$$H_o : \mu = \mu_o \quad \text{versus} \quad H_o : \mu \neq \mu$$

where

μ = the mean of average GVW factors observed from truck weight data,

μ_o = the mean of average GVW provided by the regression model.

The null hypothesis would be rejected at an α level of significance if the t-value exceeds the limits provided by the student t-distribution statistical tables. The t-value of the sample is expressed in terms of the mean, standard deviations, and the number of observations. It can be expressed as

$$t = \frac{\bar{y} - \mu_o}{s/\sqrt{n}}$$

where

$\bar{y}$ = mean of the observed average GVW factors,

μ_o = average GVW factor suggested by the regression analysis,

s = standard deviation of the observed average GVW factors,

n = number of observations.

The concept of rejection or acceptance of the null hypothesis is illustrated in Fig 15. Table 7 is the summary of the decision process. Since the computed t-values for four types of trucks are within the limits suggested by the student t-distribution, it can be concluded that the average GVW factors obtained from regression analysis may be used to represent the relationships between average GVW and practical maximum GVW for the four types of trucks.

TABLE 7. SUMMARY OF RESULTS FROM ONE SAMPLE T-TESTS

Truck Type	Degree of Freedom	Observed t-value	Student t-Distribution
2D	16	1.2423	± 2.1199
3A	15	-0.1083	± 2.1315
3-S2	15	-1.1505	± 2.1314
2-S1-2	10	0.2706	± 2.2281

*Confidence level = 0.95

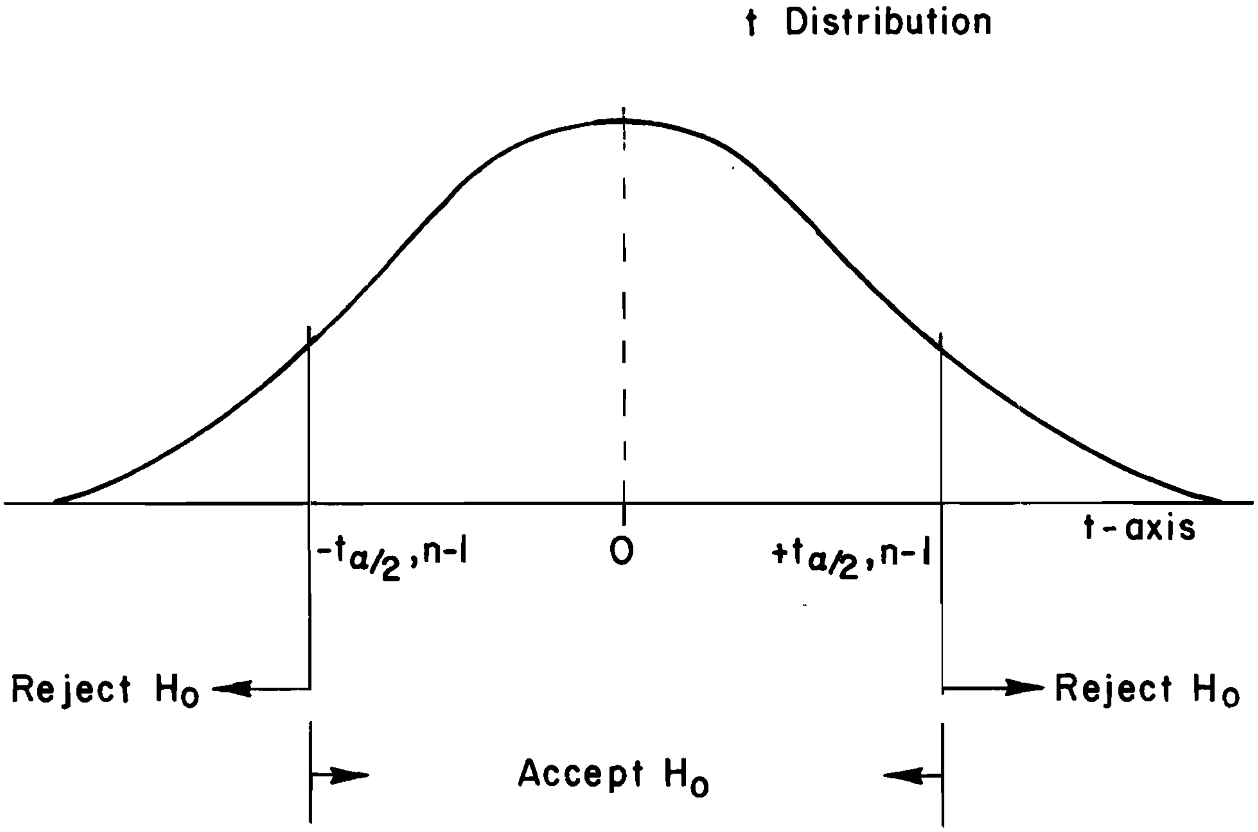


Fig 15. Distribution of t when H_o is true. (Ref 8)

Two-Sample t-test

In the regression analysis of the average GVW and the practical maximum GVW, it was assumed that the relationship of these two parameters would not be affected by changes in truck weight limits. In order to validate such an assumption, a two-sample t-test was used to check the significance of variations of the average GVW factor before and after the weight law changes that occurred in 1975. The null and alternate hypotheses are expressed as

$$H_o : \mu_o = \mu_1$$

and

$$H_1 : \mu_o \neq \mu_1$$

where

μ_o = the mean of average GVW factors obtained from 1960 through 1974 and

μ_1 = the mean of average GVW factors obtained in 1975.

The concept of rejection or acceptance of the null hypothesis is similar to that illustrated earlier, in Fig 15. Computation of the two-sample t-value is different from that in the one-sample t-test. The t-value is dependent on the means, standard deviations, and numbers of observations in both samples. It was assumed that observations made before 1975 constituted one sample and those made after 1975 the other. By definition (Ref 8),

$$t = \frac{\bar{x} - \bar{y}}{S_p\sqrt{\frac{1}{n} - \frac{1}{m}}}$$

where $\bar{x}$ = mean of average GVW factor before 1975,

n = number of observations before 1975,

$\bar{y}$ = mean of average GVW factor after 1975,

m = number of observations after 1975,

S_p = pooled variance of the two samples, and the pooled variance is defined as

$$S_p^2 = \frac{(n-1)S_x^2 + (m-1)S_y^2}{n + m - 2}$$

where

S_x^2 = variance of average GVW factor before 1975,

S_y^2 = variance of average GVW factor after 1975.

The decision process was summarized in Table 8. The computed t-values for the two sample tests are within the allowable range of the t-distribution. It shows that the variation between the means of two samples is not significant at the 95 percent level. Thus, it can be concluded that changes in weight laws in 1975 did not have a significant effect on the average GVW factors.

TABLE 8. SUMMARY OF RESULTS FROM TWO-SAMPLE T-TESTS

Truck Type	Degree of Freedom	Two-sample t-value	Student t-distribution Acceptable Range
2D	16	0.58	± 2.1199
3A	17	0.34	± 2.1098
3-S2	14	-1.78	± 2.1448
2-S1-2	9	0.41	± 2.2622

*Confidence level = 0.95

RELATIONSHIP BETWEEN PRACTICAL MAXIMUM GVW'S AND AVERAGE GVW FACTORS

Note that the practical maximum GVW is used in the equation above instead of maximum allowable GVW. By using practical maximum GVW, changes in both GVW and axle weight limits can be expressed in one single parameter. If maximum allowable GVW were used, the average GVW factor would yield incorrect predictions in cases where weight law changes occurred in either GVW or axle weight alone.

For illustrative purposes, consider the 2D. The total truck weight is bounded by axle weight limits as well as safety considerations. An increase in maximum GVW limit only will not affect the weight trend of the 2D. To attain the maximum GVW limits, 2D would have had to have a total axle weight as high as 36 kips before 1975. However, axle weight limits control the GVW of the 2D; therefore, an erroneous shift would be projected if care were not taken in developing the average GVW factors.

Due to the considerations of operational safety, the steering axle weight cannot reach the maximum allowable single axle weight limit. A review of the trends in steering axle weight distributions shows that there has not been a change in the past years. This can be seen in the steering axle weight distribution curves for 3A and 3-S2 in Figs 16, 17, and 18. For 2D and 2-S1-2, the single axle weight distribution curves represent steering axles and the loading axles as well. Thus, this analogy for 2D and 2-S1-2 may not be appropriately illustrated in the distribution curves.

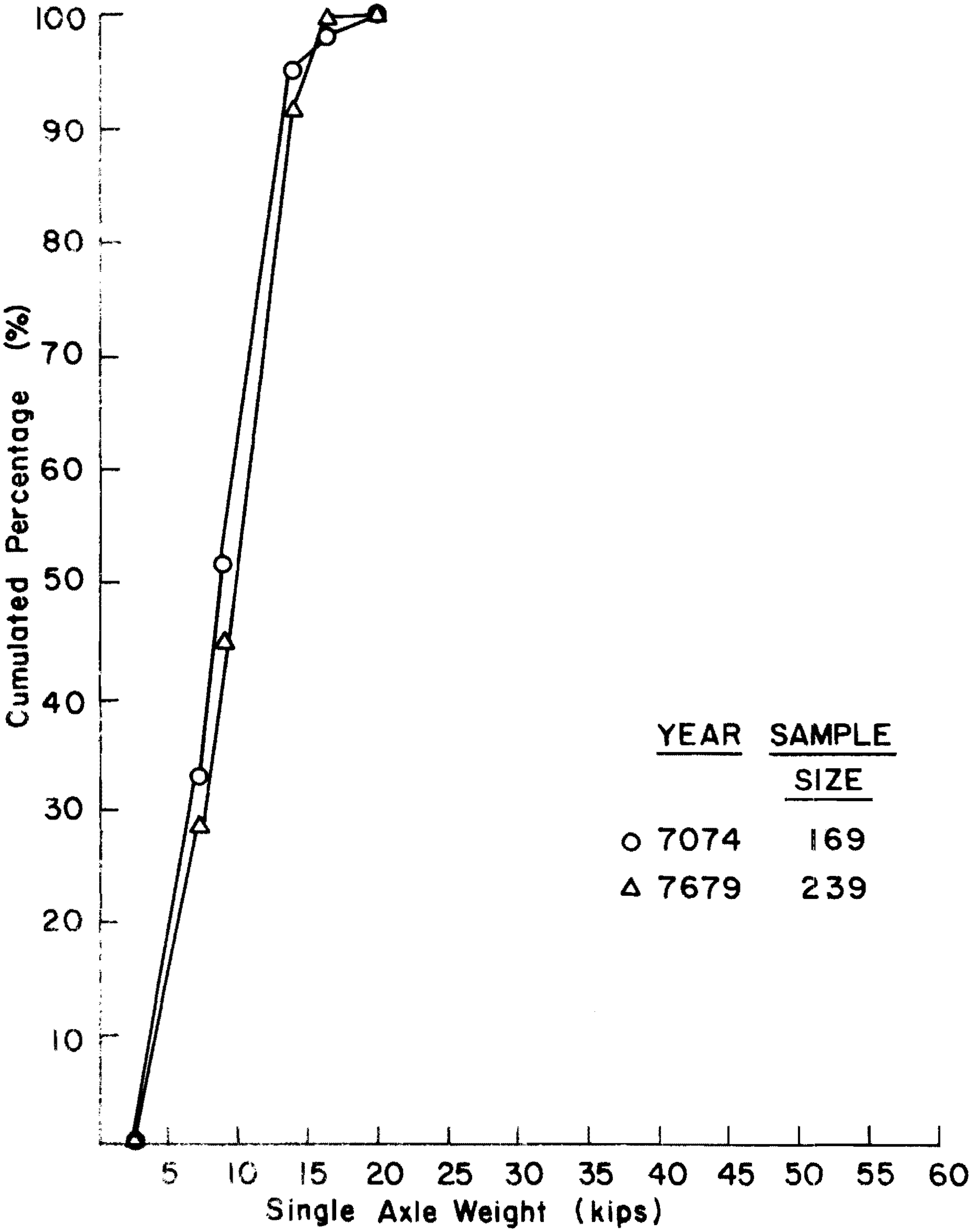
From the observation of historical data and review of the pertinent literature, practical maximum steering axle weights for four types of trucks are recommended. These limits are summarized in Table 9 (Ref 15).

The practical maximum steering axle limits for 2D and 3A provided in Table 9 were suggested by Whiteside (Ref 15). The steering axle limits for 3-S2 and 2-S1-2 were based on the values provided by the Texas Department of Public Safety.

The use of these steering axle limits is recommended to arrive at the practical maximum GVW limits. A summary of practical maximum GVW for Texas since 1951 is shown in Table 10.

With the practical maximum GVW as a function of the average GVW factor, engineers and planners may derive the practical maximum GVW for any proposed law and for selected truck types. With the available average GVW factor provided in Table 6, one can obtain the expected average truck weight under any proposed weight limits. From the expected average truck weight, a shifted curve can be obtained by using the methodology discussed in the next chapter.

The average GVW factors provided in Table 6 were derived from the Texas weight survey data. Whether such factors are transferrable to other states is unknown. It is believed that there may be some variation in the factors



Note: Data were combined to provide a smooth distribution curve.

Fig 16. Axle weight analysis (steering axle) for 3A, interstate rural, 1970-1979, State of Texas.

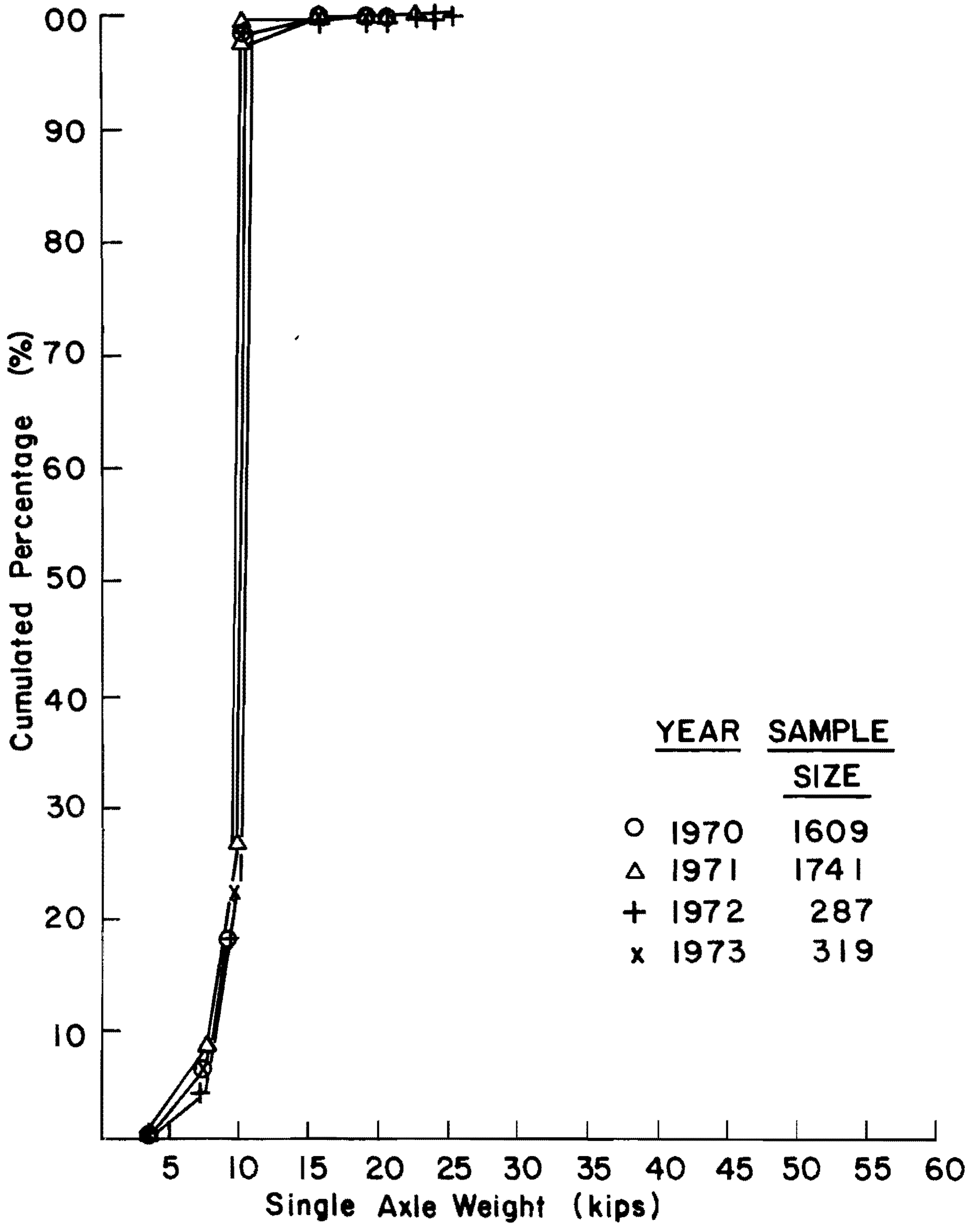


Fig 17. Axle weight analysis (steering axle) for 3-S2, interstate rural, 1970-1973, State of Texas (Ref 14).

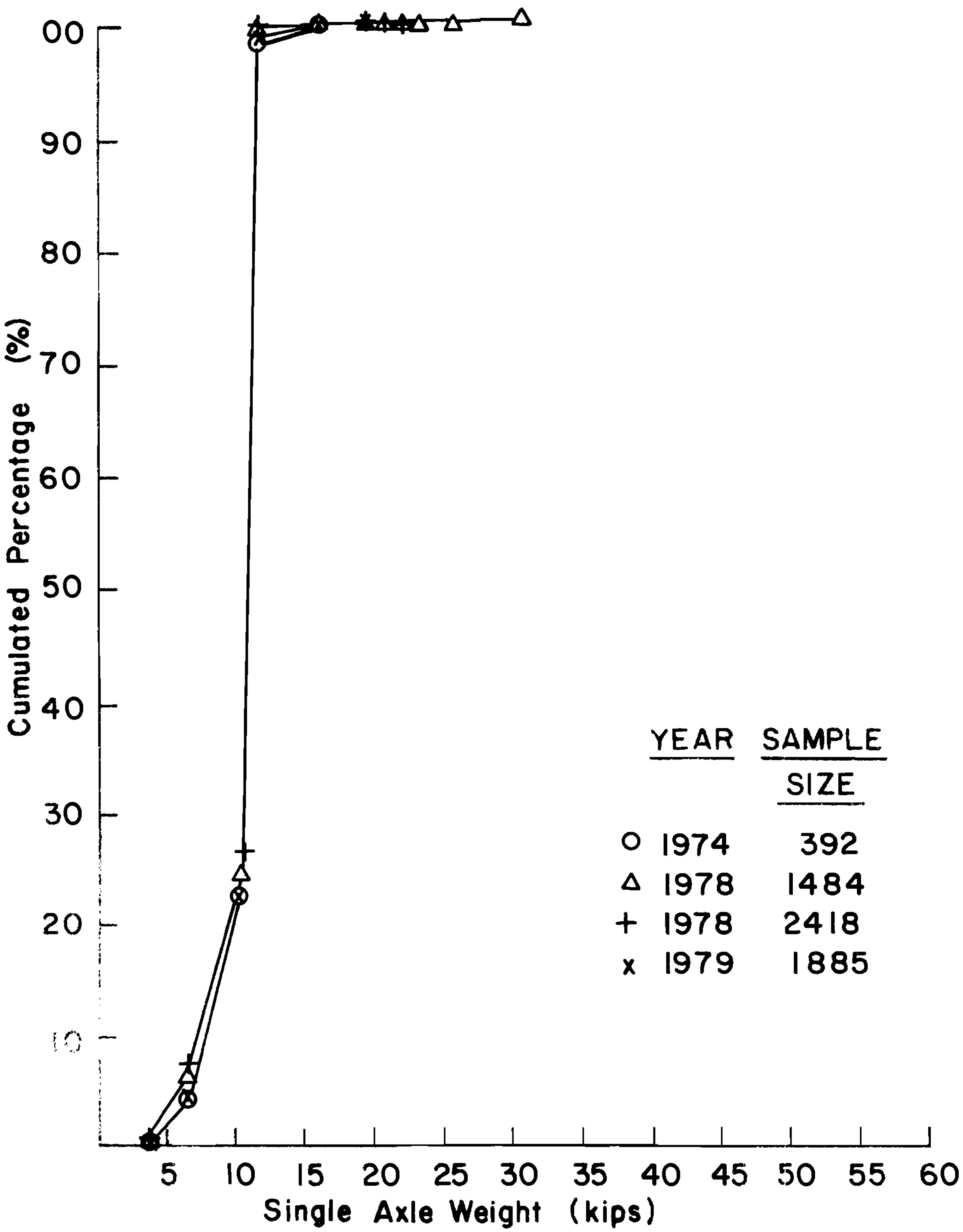


Fig 18. Axle weight analysis (steering axle) for 3-S2, interstate rural, 1974-1979, State of Texas (Ref 14).

TABLE 9. PRACTICAL MAXIMUM STEERING AXLE LIMITS FOR TRUCKS

Truck Type	Practical Maximum Steering Axle Limits
2D	7.22 Kips
3A	10.90 Kips
3-S2	12.0 Kips
2-S1-2	13.0 Kips

TABLE 10. PRACTICAL MAXIMUM GVW FOR TRUCKS IN TEXAS

Truck Type	1951-1959	1960-1974	1975-date
2D	24.6	24.6	27.22
3A	42.26	42.26	44.90
3-S2	58.4	72.0	80.0
2-S1-2	58.4	72.0	80.0

explained by different physical factors such as terrain, route systems in states and levels of enforcement in weight laws. Thus, if this methodology is used by states other than Texas, some adjustments in these factors are required. However, for practical purposes, these factors may be used to arrive at a reasonable prediction.

CHAPTER 4. MANUAL APPLICATION OF THE NEW SHIFTING PROCEDURE

In Chapter 2, the first part of the shifting procedure (i.e., analysis of historical truck weight data) is discussed thoroughly. In this chapter, the second part of the shifting procedure is discussed. This part of the procedure can be applied either manually or by resorting to computer programming. In this chapter, only the manual procedure is discussed. The computer application will be presented in the next chapter.

SHIFTING OF TRUCK WEIGHT DISTRIBUTION CURVE

Application of the manual shifting methodology is summarized in the flowchart on Fig 19. The methodology is composed of three major parts. The first part is to determine the expected mean and variance of the GVW distribution for a truck type under the proposed limits. This part involves the analysis of historical data and the application of the average GVW factors. It has been discussed explicitly in the previous chapters. The second part is to obtain a cumulative distribution curve from a set of representative truck weight data provided in the W-5 tables. The third part of the procedure is to shift the cumulative distribution curve so that the mean and variance of the shifted curve is within the acceptable tolerance of the parameters obtained in the first part of the procedure. In this part of the procedure, statistical testing is used to make the decision to accept or to reject a shifted curve.

In performing the procedure, it is necessary to shift a cumulative distribution curve and test the shifted curve with statistical tests. Once the tests are satisfied, the shifting procedure is completed and the latest shifted curve is the projected truck weight distribution curve.

In the following sections, the details of the shifting procedure and statistical testing are discussed.

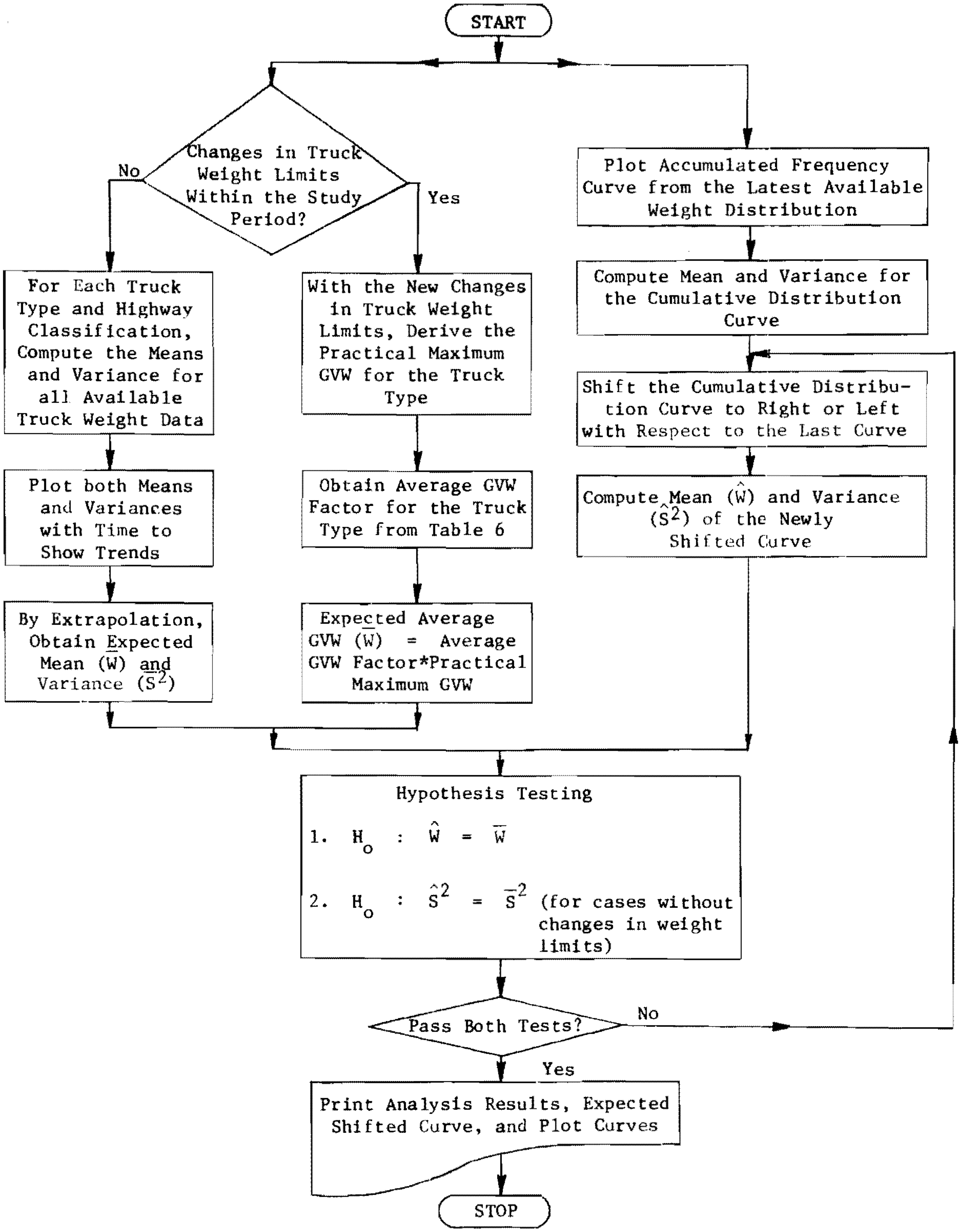


Fig 19. Flowchart showing the manual application of the shifting procedure.

Preparation of a Cumulative Frequency Curve

This part of the procedure is to provide a base curve from which the shifting may occur. It is preferable to use statistically significant data from the most recent years since the shift should incorporate the most up-to-date distribution trends.

Step 1. Read data from W-4 or W-5 weight distribution tables. Sum the number of trucks weighed.

Step 2. Calculate the percentage of trucks in each truck weight interval; obtain the cumulative percentage.

Step 3. Plot the cumulative percentage for the truck weight distribution intervals.

Shifting of Curve to Obtain Expected Mean and Variance

It has been suggested by Larkin (Ref 7) that shifting for 2D and 3A starts at 50 percent and for 3-S2 and 2-S1-2 starts at 33.3 percent. However, these figures are based on Texas data. In the shifting procedure, users may start at any percentage that intuitively or explicitly represents this experience.

The shifting procedure is basically an iterative one. With adequate practice and experience, the number of iterations may be reduced. Obviously, the application of computer programming to handle the shifting procedure will reduce the time consumed in performing the iterations. The computer application is discussed in the next chapter. In this section, a manual step-by-step method is provided.

Step 1. Choose an initial shifting point and start the procedure by shifting the accumulated distribution curve to the right or left from that of the unshifted curve according to the magnitude of the difference of the expected mean weight difference. The shifted curve should resemble the same pattern as the unshifted curve (Fig 20).

Step 2. Compute the mean of the shifted curve . This can be done by taking the cumulative percentage of each weight interval and obtaining the percentage for the corresponding interval. The average weight for the shifted curve is the summation of the product of the mid-point intervals with the corresponding percentage.

Step 3. Compute the variance of the shifted curve. Computation of variance is similar to that mentioned in the first part of the procedure. The computation of variance for the example is shown in Table 11.

Step 4. To test the acceptability of the estimated curve, two statistical tests are applied. These two tests will be discussed later in this chapter. Briefly, the student t-test is used to test if the mean is within the 95 percent confidence intervals of the expected average truck weight. The chi-square test is used to test the variance (Ref 8). If either the mean or variance of the estimated curve are outside the confidence intervals of the corresponding values, go back to Step 1 and repeat the procedure again. If both mean and variance are within acceptability, go to the next step.

Step 5. Once a distribution curve is accepted, a truck weight distribution table can be constructed.

The steps are shown in Figs 20 and 21 and the computation of mean and variance is shown in Table 11. The example demonstrates the prediction for the 3-S2 truck weight curve in 1978. The base year in 1970. This year was chosen because of its large sample population.

In 1975, the weight laws of Texas were changed as follows:

(1) Gross Vehicle Weight from 72 kips to 80 kips,

(2) Tandem Axle Weight from 32 kips to 34 kips,

(3) Single Axle Weight from 18 kips to 20 kips.

From the 1975 weight laws, it can be derived that the practical maximum GVW is equal to 80.0 kips. From Table 6, the average GVW factor for 3-S2 is 0.66. Thus, the expected average GVW after the weight law changes is 52.80 kips.

When the average GVW factors were derived, only the legal vehicles were included in the computation of average GVW. Thus, for projecting future truck weight distributions, it is necessary to consider the percentage of the truck population that violate the weight laws. In applying the average GVW methodology, this consideration can be taken care of by a violation factor. If the population of violation is about 5 percent of the total population of a particular type of truck, the violation factor is then equal to 1.05. In the example, the adjusted GVW is 52.8 x 1.05, or 55.44 kips.

As shown in Table 4, the average GVW for 1970 is 47.65 kips. From the 1970 weight distribution curve, a first shifting was attempted (Fig 20). From the shifted curve, an average GVW of 62.5 kips was obtained. By comparing it with the expected average GVW, 55.44 kips, it is obvious that the second curve should be somewhere between the unshifted and the first shifted curves. A new plotting is shown in Fig 21. From the new shifted curve, a mean of 55.09 and

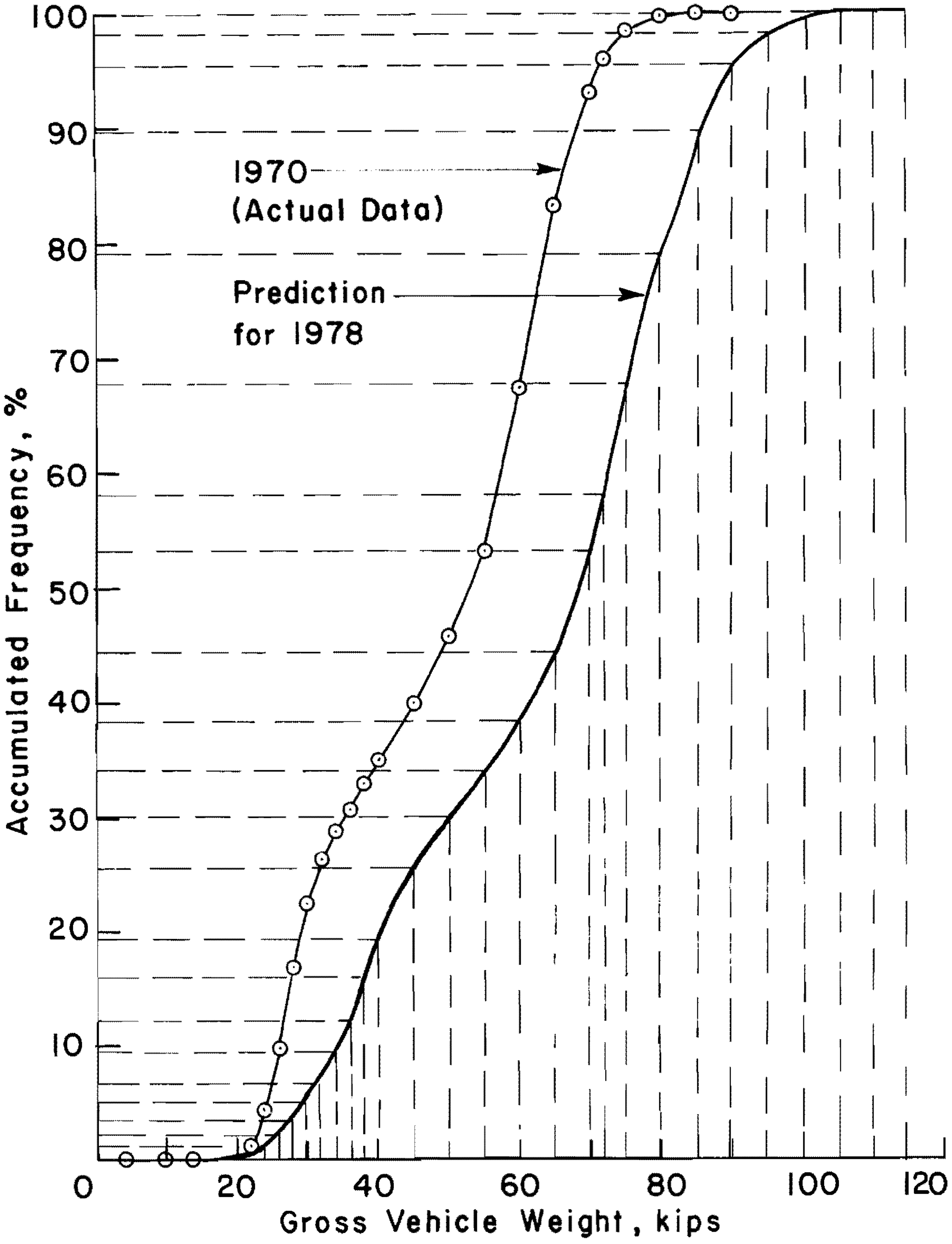


Fig 20. First trial shifting from 1970 data for the projection of 1978 GVW distribution, 3-S2, Texas interstate rural highways.

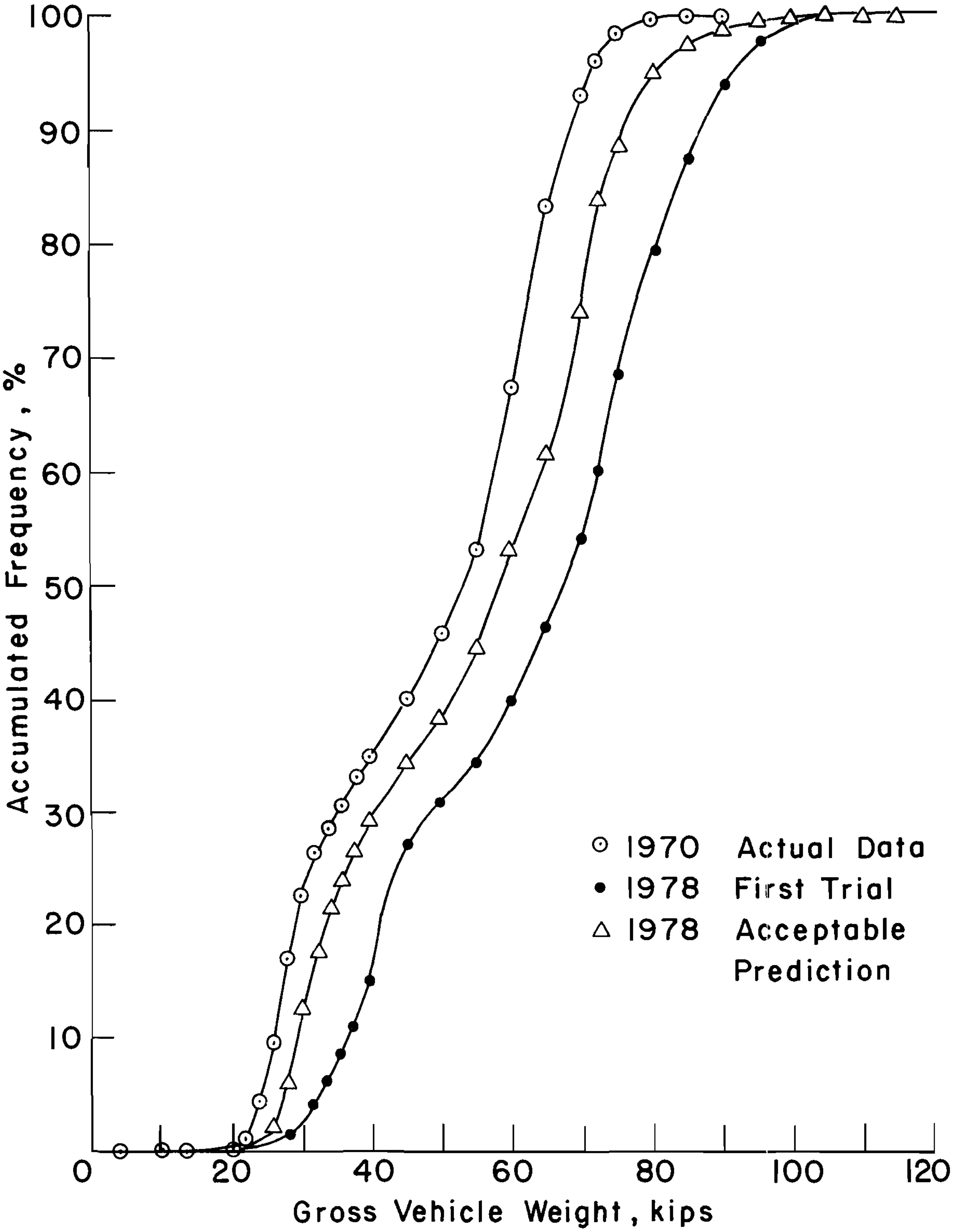


Fig 21. Acceptable shifting for the projection of 1978 GVW distribution, 3-S2, Texas interstate rural highways.

TABLE 11. COMPUTATION OF MEAN AND VARIANCE FROM AN ESTIMATED CUMULATED DISTRIBUTION CURVE

(A) GVW Distribution Intervals	(B) Mid-GVW Intervals	(C) Number of Trucks	(D) B x C	(E) B^2 x C
0.0-4.0	2.0	0	0.0	0.00
4.0-10.0	7.0	0	0.0	0.00
10.0-13.5	11.75	0	0.0	0.00
13.5-20.0	16.75	2	33.5	561.13
20.0-22.0	21.0	15	315.0	6,615.00
22.0-24.0	23.0	51	1,173.0	26,979.00
24.0-26.0	25.0	85	2,125.0	53,125.00
26.0-28.0	27.0	117	3,159.0	85,293.00
28.0-30.0	29.0	92	2,668.0	77,372.00
30.0-32.0	31.0	61	1,891.0	58,621.00
32.0-34.0	33.0	37	1,221.0	40,293.00
34.0-36.0	35.0	31	1,085.0	37,975.00
36.0-38.0	37.0	39	1,443.0	53,391.00
38.0-40.0	39.0	32	1,248.0	48,672.00
40.0-45.0	42.5	79	3,357.5	142,693.75
45.0-50.0	47.5	95	4,512.5	214,343.75
50.0-55.0	52.5	117	6,142.5	322,481.25
55.0-60.0	57.5	229	13,167.5	757,131.25
60.0-65.0	62.5	254	15,875.0	992,187.50
65.0-70.0	67.5	157	10,597.5	715,331.25
70.0-72.0	71.0	48	3,408.0	241,968.00
72.0-75.0	73.5	39	2,866.5	210,687.75
75.0-80.0	77.5	20	1,550.0	120,125.00
80.0-85.0	82.5	4	330.0	27,225.00
85.0-90.0	87.5	1	87.5	7,656.25
90.0-95.0	92.5	0	0.0	0.00
		Σ = 1,605	Σ = 78,256	Σ = 4,240,727.88

$$\text{MEAN} = \frac{78{,}256}{1{,}605} = \underline{\underline{48.76}};\quad \text{VARIANCE} = \frac{4{,}240.727.88 - \dfrac{(78{,}256)^2}{1{,}605}}{(1{,}605 - 1)} = \underline{\underline{265.06}}$$

STANDARD DEVIATION = $\underline{\underline{16.28}}$

a variance of 352.23 are obtained. The standard deviation of the curve is 18.79. The computation of mean, standard deviation, and variance is shown in Table 11.

Before considering accepting or rejecting the second shifted curve, it is appropriate to consider some statistical tests applied to the procedure.

STATISTICAL TESTS APPLIED IN THE PROCEDURE

Since the shifting procedure is based on a logical iteration method, it is difficult and time-consuming to find a curve whose mean and variance are exactly the same as those predicted by regression analysis. Thus, for a given shifted curve, statistical tests are needed to examine whether the parameters are within tolerable limits, or confidence intervals, of the expected values. In the analyses of the mean and the variance, a student t-test and chi-squared test are applied, respectively.

Student t-test of the Mean

To examine the mean of a shifted curve to determine if it is within the confidence intervals of the mean estimated by regression analysis, the student t-test is employed (Ref 4, 8). For each shifted curve, a testing of null and an alternative hypothesis are established:

$$H_o : \hat{W} = \bar{W}$$

$$H_1 : \hat{W} \neq \bar{W}$$

The null hypothesis states that the mean computed from a shifted curve is actually equal to the mean obtained from regression analysis of past trends. The alternate hypothesis states that they are not equal. H_o should be rejected at the α level of significance if

$$t = \frac{\hat{W} - \bar{W}}{S/\sqrt{n}}$$

is either $\leq - t_{\alpha/2,\ n-1}$ or $\geq + t_{\alpha/2,\ n-1}$ (Ref 8).

Notations for the symbols are as follows:

$\hat{W}$ = mean truck weight computed from a shifted curve,

$\bar{W}$ = mean truck weight obtained from regression of past truck weight data,

S = standard deviation of truck weight computed from a shifted curve,

n = number of distribution intervals, degree of freedom,

α = level of significance; use $\alpha = 0.05$ in the shifting procedure, and

$t_{\alpha/2,\, n-1}$ = student t-distribution with n degrees of freedom. Values for student t-distribution may be obtained from statistical tables.

Chi-Squared (χ^2) Test of the Variance

To determine the acceptance of a shifted curve based on its variance, a variance ratio test, or chi-squared (χ^2) test, is applied (Ref 4, 8). The chi-squared test is used to test:

$$H_o : S^2 = S_o^2$$

versus

$$H_1 : S^2 \neq S_o^2$$

The null hypothesis states that the variance of a shifted curve is equal to that estimated from regression analysis. The alternate hypothesis states that the two variances are not equal. The null hypothesis should be rejected under two situations:

$$\frac{(n - 1)S^2}{S_o^2} \leq \chi^2_{\alpha/2,\, n-1}$$

and

$$\frac{(n - 1)S^2}{S_o} \geq \chi^2_{\alpha/2,\, n-1}$$

Notations for the symbols are as follows:

n = degree of freedom, or the number of weight intervals in the W-tables,

S^2 = variance of the shifted curve,

S_o^2 = variance obtained from regression analysis,

$\chi^2_{\alpha/2,\, n-1}$ = chi-square distribution with level of significant $\alpha/2$, and (n-1) degree of freedom.

From the example, the parameters of the shifted curve are

mean = 55.09,

variance = 353.23,

standard deviation = 18.79.

From the average GVW, the expected mean is 55.44.

In order to accept the shifted curve, it is necessary to have a satisfactory t-test. The t-value for the shifted curve is

$$t = \frac{55.09 - 55.44}{18.79/\sqrt{30}} = -0.1020$$

The value 30 corresponds to the number of weight groups considered. From the t-distribution statistical table, for a level of significance of 0.05 and 29 degrees of freedom,

$$t_{0.025.29} = \pm 2.0452$$

Since the t ratio is less than that from the t-distribution curve, it can be concluded that the second shifted curve is acceptable.

It should be pointed out that in response to weight law changes, only the average truck weight is used to predict a shifted curve. The variance is not used for the following reasons:

(1) It is difficult to quantify the change in variance with respect to changes in weight laws. It is definite that the variance shows a jump at each increase of weight limits (Fig 13). However, the magnitude of a jump cannot be expressed in terms of the magnitude of changes in truck weight limits.

(2) With careful selection of the base distribution curve and inducing that the shifting has the general shape of the unshifted curve, a shifted curve under proposed weight limits should yield a reasonably accurate estimate. The best base distribution curve is one that has sufficient sample size so that the curve is generally smooth. The next definition of a good base distribution curve is one that represents the latest distribution trend, which, in turn, conveys the latest technology and practice trends in the trucking industry.

Based on the available 1978 truck weight data, the results of a chi-squared test on the predicted truck weight distribution are shown in Table 12. At a confidence level of 0.05 and 29 degrees of freedom, the chi-square value obtained from a distribution table is 42.56 (Ref 8). Since the computed chi-square value, 1.47, is much lower than 42.56, it indicates that the projection is acceptable.

From experience gained in using the iterative procedure outlined herein, a few insights have occurred which may save time. Before starting to shift a curve, the mean of the curve should be computed. After the first shift, the mean weight of the shifted curve should also be computed. The next step is to decide to which side of the first shifted curve the next curve should be shifted. If the mean weight of the first shifted curve is above the expected weight provided by regression analysis obtained from the average GVW factor, the second shifted curve should be somewhere between the original curve and the first shifted curve. The position of the second shifted curve can be carefully chosen so as to minimize the number of shiftings.

GENERAL DISCUSSION OF THE METHODOLOGY

The methodology provided in this chapter, like other available methodologies, cannot render a precise prediction of what kind of shifting may occur under proposed weight law changes. However, it is the researchers' belief that this model can provide a more statistical and reasonable solution to the shifting problem. The accuracy of the prediction provided by this methodology should also be superior to other methodologies as it makes extensive use of past data.

TABLE 12. CHI-SQUARE TEST ON OBSERVED AND PREDICTED TRUCK WEIGHT DISTRIBUTIONS

GVW	Predicted Cumulated Frequency	Observed Cumulated Frequency
0.0-4.0	0.0	0.0
4.0-10.0	0.0	0.0
10.0-13.5	0.0	0.0
13.5-20.0	0.0	0.0
20.0-22.0	0.5	0.21
22.0-24.0	1.0	0.42
24.0-26.0	2.0	1.94
26.0-28.0	5.5	5.89
28.0-30.0	12.5	12.42
30.0-32.0	16.0	17.51
32.0-34.0	20.0	21.84
34.0-36.0	23.5	24.96
36.0-38.0	26.0	27.36
38.0-40.0	29.0	29.63
40.0-45.0	34.0	35.14
45.0-50.0	38.0	40.15
50.0-55.0	44.0	46.42
55.0-60.0	53.0	53.70
60.0-65.0	61.0	60.31
65.0-70.0	73.0	73.61
70.0-72.0	83.0	80.30
72.0-75.0	97.5	88.55
75.0-80.0	95.0	95.50
80.0-85.0	97.0	97.94
85.0-90.0	98.0	99.28
90.0-95.0	99.0	99.83
95.0-100	99.5	99.92
100.0-105	100.0	99.96
105.0-110	100.0	100.0
110.0-115	100.0	100.0

$\chi^2 = 1.47$

However, if this model is used manually with a non-programmable calculator, it requires much more work and time to arrive at the desirable result than other methodologies do and that may be considered an undesirable aspect of the methodology. Nevertheless, with available computer technology and sophisticated programmable hand calculators, much work and time can be saved. In the next chapter, a computer application of this methodology is presented.

CHAPTER 5. COMPUTERIZED SHIFTING METHODOLOGY IN THE ESTIMATION OF TRUCK WEIGHT DISTRIBUTION

Due to the large amount of data and parameters required in the shifting methodology, the procedure is tedious and users may accidentally insert errors. To increase the accuracy of application and reduce computation time, computer programs in FORTRAN language have been developed for the shifting methodology and procedure discussed in the last chapter. However, due to some factors which will be discussed later, some modifications and adjustments in the procedure have been incorporated.

The computer program series consists of two major programs. One of the programs computes the means and variances of the available data. This program generally follows the guideline provided in the last chapter under the topic "Computation of mean and variance of truck weight distribution data." Equations used in the program are listed in the same section. Users need to input sample sizes for the corresponding truck weight intervals for each year. The computer will provide mean, standard deviation, and variation for each year. With a plotting option, users may obtain the graphical presentation. The program listing and user's manual are listed in Appendices 1 and 6, respectively. A flowchart of the program is shown in Fig 22.

The other program facilitates the shifting element of the methodology. This procedure required some modification, which will be discussed in the next section.

MODIFICATIONS OF SHIFTING METHODOLOGY TO BE COMPATIBLE WITH AUTOMATION

Generally, truck weight distributions resemble the normal distribution pattern. When the truck weight distribution is transformed into an accumulated distribution curve, it shows a traditional S-shaped curve. This S-shaped curve may be represented by the following expression (Ref 3):

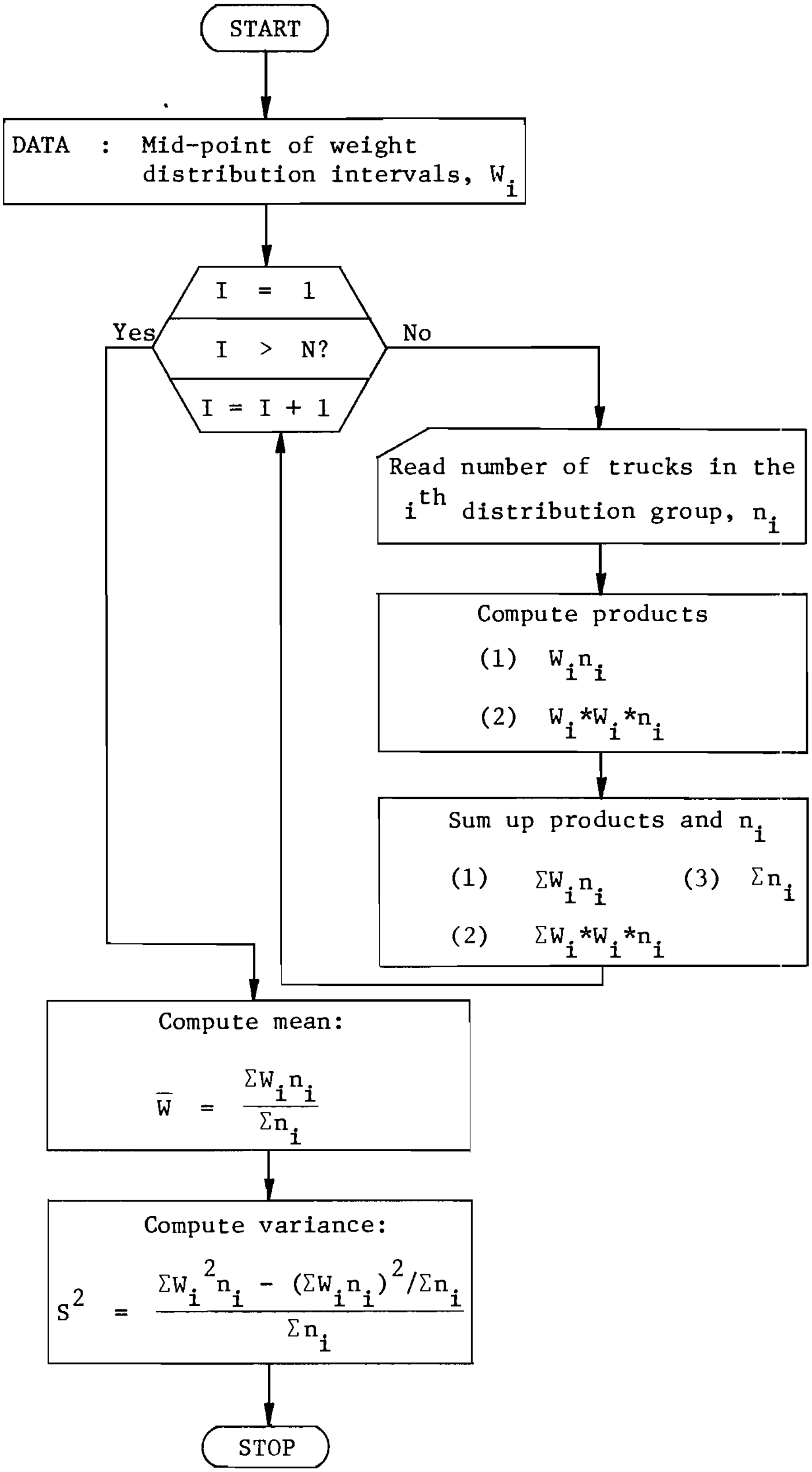


Fig 22. Flowchart showing procedure of computation of mean and variance.

$$Y = \frac{1}{A + B^{-CX}}$$

where A, B, and C = coefficients of the S-curve

Y = accumulated percentage, and

X = mid-point of weight distribution intervals.

This expression is a non-linearizable equation in that the coefficients A, B, and C cannot be obtained from a linear regression analysis. Only through the trial and error method may these coefficients be found. Yet, certain errors may be induced in this process. These errors will be intensified when the actual shifting is performed. Thus, it is unprofitable and time-consuming to fit data and predict shifts utilizing this non-linearizable equation. To expedite the shifting procedure and to ensure acceptable results, a linear equation was derived.

In the computer model, a "detour" is made in order to make use of a compatible linear equation. The detour is based on the method of using multiplying factors, as suggested in the NCHRP report. Let GVW (1,i%) be the denotation of GVW for year one at the i% on the accumulated frequency curve and GVW (2,i%) be that of year two at the same percentage. Then,

$$\text{Multiplying factor (i\%)} = \frac{\text{GVW}(2,i\%)}{\text{GVW}(1,i\%)} \qquad \text{(Eq 5-1)}$$

For each of the two years, a cumulative frequency is computed from which the GVW's at one percent increment intervals may be obtained. The GVW (2,i%) should be based on the most recent data as it will affect the shape of the shifted curve through the multiplying factors. From 1 percent to 100 percent, the multiplying factors can be curves fitted into a modified linear equation. The normal form of the equation is given as (Ref 3)

$$Y_i = AX_i^B e^{CXi}, \qquad \text{(Eq 5-2)}$$

and the linear form is

$$\log_e(Yi) = \log_e A + B \log_e X_i + CX_i \qquad \text{(Eq 5-3)}$$

In this shifting procedure, the following deviations are used for Y_i and X_i:

Y_i = multiplying factors at one percent increment intervals,

X_i = GVW (1,i%).

Generally speaking, all the cumulative distribution curves for truck weight data can be fitted into this equation. However, to guard against any discrepancy, a chi-squared test is introduced in the computer shifting methodology to reject any bad fitting. The chi-squared test checks the goodness-of-fit between the observed Y's and the expected Y's computed by the fitted equation.

The fitting of data into Eq 5-3 is done by the least squares method. Regression coefficients A, B, and C are computed by solving the following system of equations:

$$\begin{bmatrix} n & \Sigma(\log_e X_i) & \Sigma X_i \\ \Sigma(\log_e X_i) & \Sigma(\log_e X_i)^2 & \Sigma(X_i * \log_e X_i) \\ \Sigma X_i & \Sigma(X_i \log_e X_i) & \Sigma(X_i)^2 \end{bmatrix} \begin{bmatrix} A \\ B \\ C \end{bmatrix} = \begin{bmatrix} \Sigma(\log_e Y_i) \\ \Sigma(\log_e X_i)(\log_e Y_i) \\ \Sigma(X_i \cdot \log_e Y_i) \end{bmatrix}$$

In the 3 x 3 matrix, n is equal to 100, which represents the number of multiplying ratios obtained from the cumulative frequency curve.

Once the regression coefficients A, B, and C are found, the values are used as inputs into Eq 5-2. With GVW (1,i%) as the X-values, the multipliers and their respective GVW (2,i%) may be found. In the computer model, the regression coefficients are used as initial values from which the shifting will be started. After checking against criteria which will be discussed later, a new set of regression coefficients may be obtained. With Eq 5-1, GVW (2,i%), which represents the GVW (i%) for a future year, can be computed by multiplying the new multiplying factor and GVW (1,i%). This operation can be expressed by the following equation:

$$\text{GVW (2,i\%)} = \text{GVW (1,i\%)} \times \text{multiplying factor (i\%)} \qquad \text{(Eq 5-4)}$$

The whole procedure is summarized in the flowchart shown in Fig 23.

As suggested in the previous chapter, the shifting of the distribution curve is performed by an iterative procedure. For each iteration, the shifted curve is to be accepted or rejected based on the compatibility of its mean and variance with those projected by regression analysis or average GVW factors. The iterative method that is programmed into FORTRAN language will be presented next.

ITERATION METHOD IN THE SHIFTING PROCEDURE

In the shifting procedure, Powell's method is used to perform the iterations (Refs 6 and 9). In Powell's method the three coefficients given in Eq 5-2 for the proposed year are located through a series of iterations so as to minimize the objective function. Each iteration involves a search for a minimum along a set of three linearly independent directions. These directions are the coordinate directions initially, but at each iteration a new direction is defined to replace one of the initial directions. The new directions formed after a series of iterations will be mutually conjugate (Ref 6). The objective function used in the Powell method is the difference between the mean computed from a curve characterized by the coefficients A, B, and C and the mean obtained from regression analysis or average GVW factors. It can be expressed as follows:

$$f(u) = \overline{W} - \Big[GVW(1,i\%) * u(1) * GVW(1,i\%)^{u(2)} * \mathrm{Exp}(u(3) * GVW(1,i\%)) \Big]$$

where $f(u)$ = objective function to be minimized by Powell's method

$\overline{W}$ = mean weight obtained from regression analysis or average GVW factors,

$GVW(1,i\%)$ = GVW for base year at 1% increment intervals,

u(1), u(2), and u(3) are the regression coefficients; they correspond to the coefficients A, B, and C, respectively, as given in Eq 5-2.

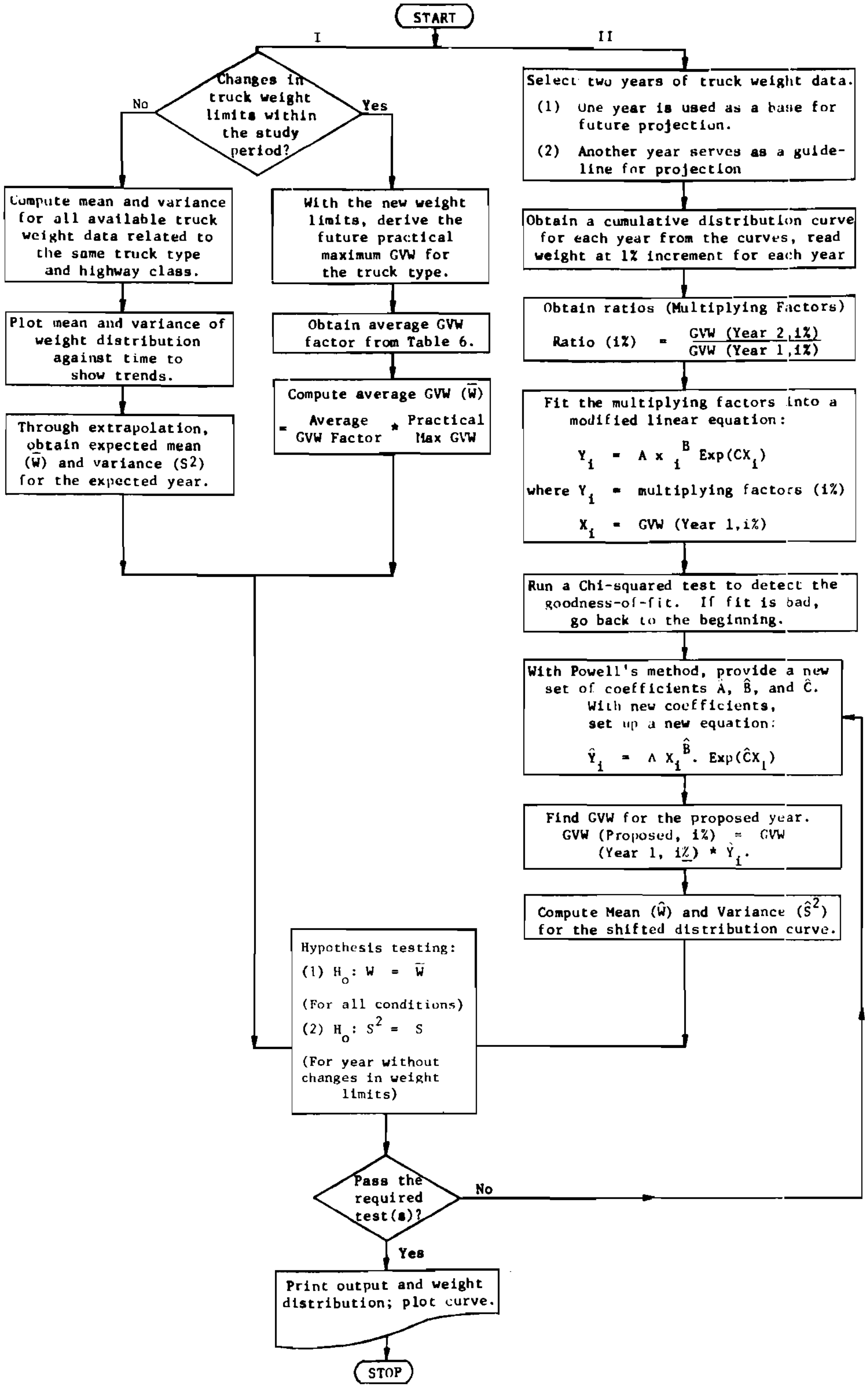


Fig 23. Flowchart showing the computerized shifting methodology.

For the Powell method, better initial values for u(1), u(2), and u(3) ensure a faster convergence. Thus, in choosing truck weight distribution data, this principle should serve as a guide. One should choose data with sufficient sample size so that smooth cumulative curves and, thus, better initial values for the coefficients may be provided.

LIMITATIONS OF THE COMPUTER PROGRAM

In general, the Powell method works well with most of the initial coefficients that were derived from available truck weight data. However, the possibility that the iteration does not converge cannot be eliminated. In any case, if it fails to converge and provide new coefficients, one should consider using another set of truck weight data so as to provide a new set of initial coeffients.

Since the objective function to be minimized by Powell's method is expressed in terms of the means of truck weight only, the new truck weight distribution will be shaped according to the mean rather than the variance. Hence, distribution with unacceptable variance may be derived from the computer shifting methodology. Recommendations for a remedy are given as follows:

(1) Change either set of the truck weight distribution data; i.e., change either GVW (1,i%) or GVW (2,i%) or even obtain and use new sets of data.

(2) Due to certain problems in data collection procedures, some data may not reflect expected trends. Obviously, erroneous data should not be used unless altered by combining data that was collected in different years. The process of combination dilutes any extremities in a set of data and, thus, smooths the distribution curve.

(3) To predict the shifting that occurred after changes in weight laws, one should not be overly concerned about the variance of a new shifted curve provided the most recent truck weight data were used. Generally, the Powell method generates new coefficients that provide a distribution curve with a pattern compatible with that characterized by the initial coefficients.

APPLICATIONS OF THE COMPUTERIZED SHIFTING METHODOLOGY

To illustrate the usage of the computerized shifting methodology, results of two runs are presented in this section. Input data are given in Appendix 6. In order to check the precision and accuracy of the prediction, shifting was performed for past years. This would provide the comparison of the results derived from the computer model and actual field data. The first run is to demonstrate a shifting within the span of the same weight limits. The second run is to demonstrate a shifting to cope with the weight law change.

Based on the study of weight trends as discussed in the last chapter, it is shown that, within the span of the same weight laws, the mean and variance change gradually. The changes of the mean and variance over a period of time, provided that there were no weight law changes, can be fitted into a certain regression model. In this example, a prediction for 2D on Interstate highways in 1974 was estimated by the computer model. In Fig 24, both trends, for the mean and variance, of 2D from 1959 to 1973 are shown. It was assumed that the data for 1974 and afterwards were not available. The trend observed from 1960-1973 shows that the mean can be fitted into a linear regression model. For 1974, the expected mean weight is thus 13.38 kips. The variance basically does not show any major variation. Thus, the average of the variance, 32.0 (or Standard Deviation of 5.6), is used. The data collected in 1973 were used as the base to project for 1974 distribution. Figure 25 shows the predicted and actual distribution curves for 1974. Table 13 shows the comparison of the accumulative frequencies of the two curves. The chi-squared value of 2.02 shows that the goodness of fit is exceptional. Both the student t-test and the chi-squared test on mean and variance are acceptable.

The second example illustrates prediction of a truck distribution curve for 1978. In the prediction, the data after 1975 were assumed to be unavailable. In this example, the basic difference from the previous example is that there was a change in weight law in 1975. Thus, this example deals with the shifting including the effects of weight law changes. For later comparison of various methodologies, the example will be the same as in the example discussed in the last chapter. In this example, the 3-S2 on Interstate highways was used. The prediction was for 1978. From Table 6, in the previous chapter,

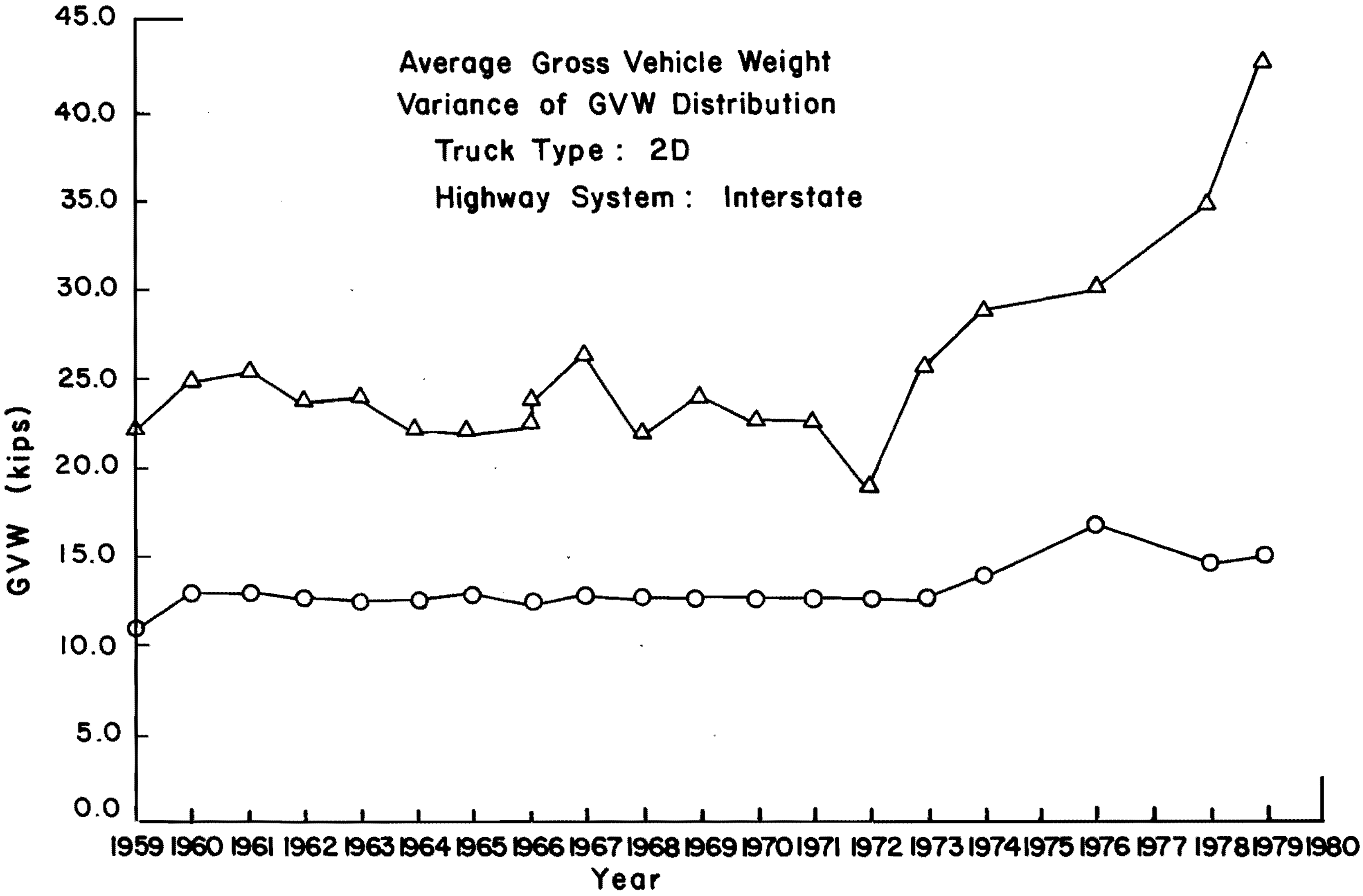


Fig 24. Trends of mean and variance for truck GVW distribution (2D, Texas interstate rural highways).

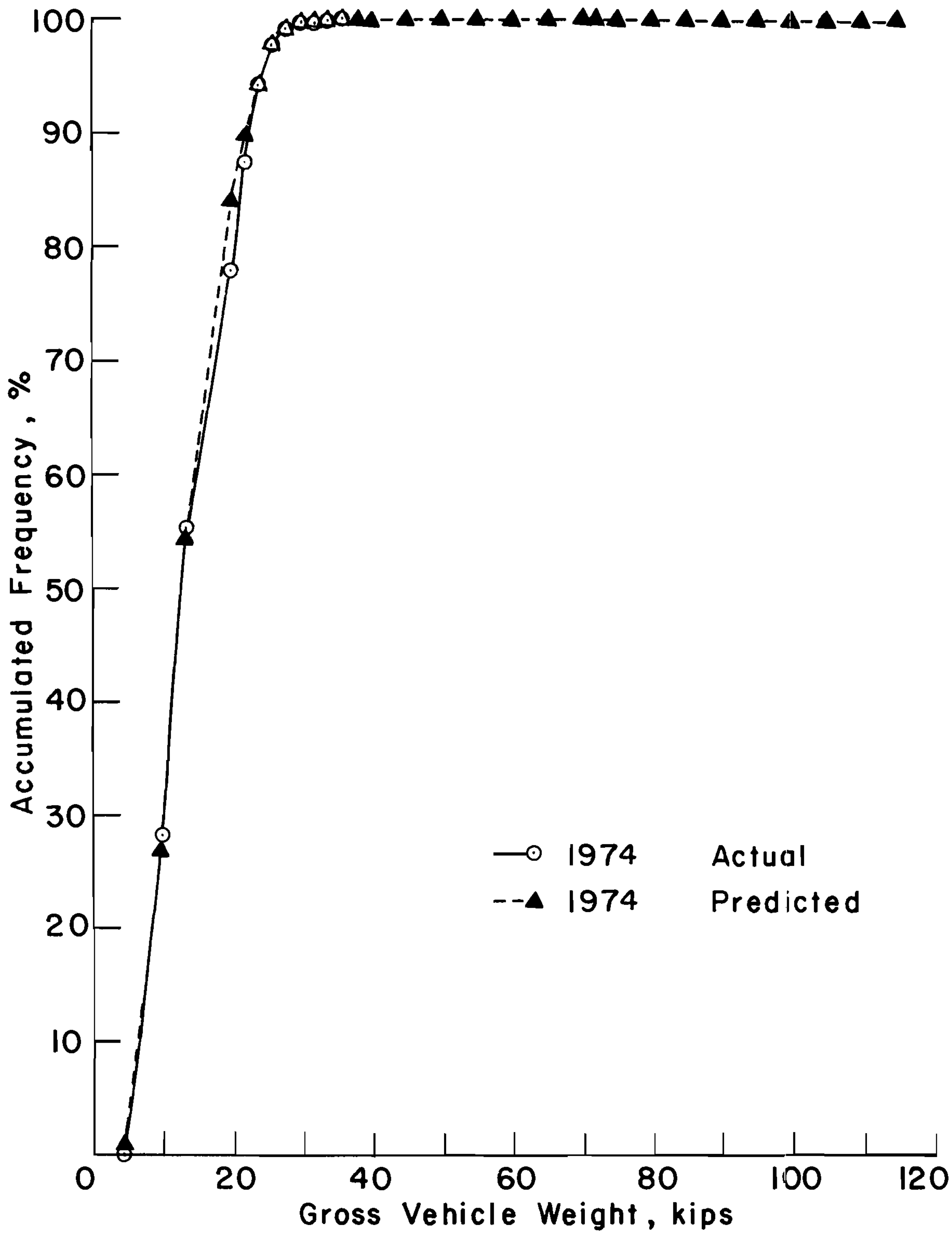


Fig 25. Comparison of accumulated frequency distribution curves derived from actual field data and computerized shifting methodology (2D, 1974, Texas Interstate rural).

TABLE 13. COMPARISON OF OBSERVED ACCUMULATED FREQUENCIES OF ACTUAL FIELD DATA AND EXPECTED ACCUMULATED FREQUENCIES FROM SHIFTING MODEL FOR 2D ON TEXAS INTERSTATE RURAL HIGHWAYS (PREDICTION IS FOR 1974)

GVW Distribution Intervals	Observed Accumulated Frequency	Expected Accumulated Frequency
0.0-4.0	0.0	.9986
4.0-10.0	30.61	26.7740
10.0-13.5	51.02	54.4751
13.5-20.0	81.63	83.9244
20.0-22.0	89.80	89.7085
22.0-24.0	95.92	94.1995
24.0-26.0	95.92	97.9639
26.0-28.0	97.96	99.1991
28.0-30.0	97.96	99.5054
30.0-32.0	97.96	99.8118
32.0-34.0	97.96	100.0000
34.0-36.0	100.00	100.0000

$\chi^2 = 2.02$

the average GVW factor for 3-S2 was 0.66. The practical maximum GVW after the 1975 weight law changes was 80 kips. Thus, the expected mean weight was 80.0 x 0.66, or 52.8 kips. Assuming five percent of trucks were overloaded the expected mean weight thus becomes 52.8 x 1.05, or 55.44 kips. For the reasons discussed earlier in the last chapter, the variance is not important in this shifting application. The inputs for this example are shown in Appendix 6. Data sets collected in 1974 and 1970 are used as the prediction basis. Figure 26 shows the predicted and actual distribution curves for 1978. Table 14 presents the comparison of the accumulated frequencies of the two curves. The chi-squared value shows that the prediction fits well with actual field data.

COMPARISON OF VARIOUS SHIFTING METHODOLOGIES

The NCHRP and SDHPT shifting methodologies are similar in their procedures. Both methodologies apply the concept of multiplying factors. Before the initial weight is reached, the multiplying factor remains as unity. Then, the multiplying factor increases gradually from the initial weight to the present practical maximum GVW, where it levels off. The difference between the two methodologies centers on the initial weights for each type of truck. For prediction of truck weight distribution after the 1975 changes, the initial weights given in Table 15 were used in each methodology.

TABLE 15. INITIAL WEIGHTS OF FOUR TRUCK TYPES USED IN NCHRP AND SDHPT METHODOLOGIES (BASED ON 1974 TRUCK WEIGHT DATA)

	NCHRP (kips)	SDHPT (kips)
2-D	4.0	20.0
3-A	13.5	30.0
3-S2	13.5	40.0
2-S1-2	24.0	50.0

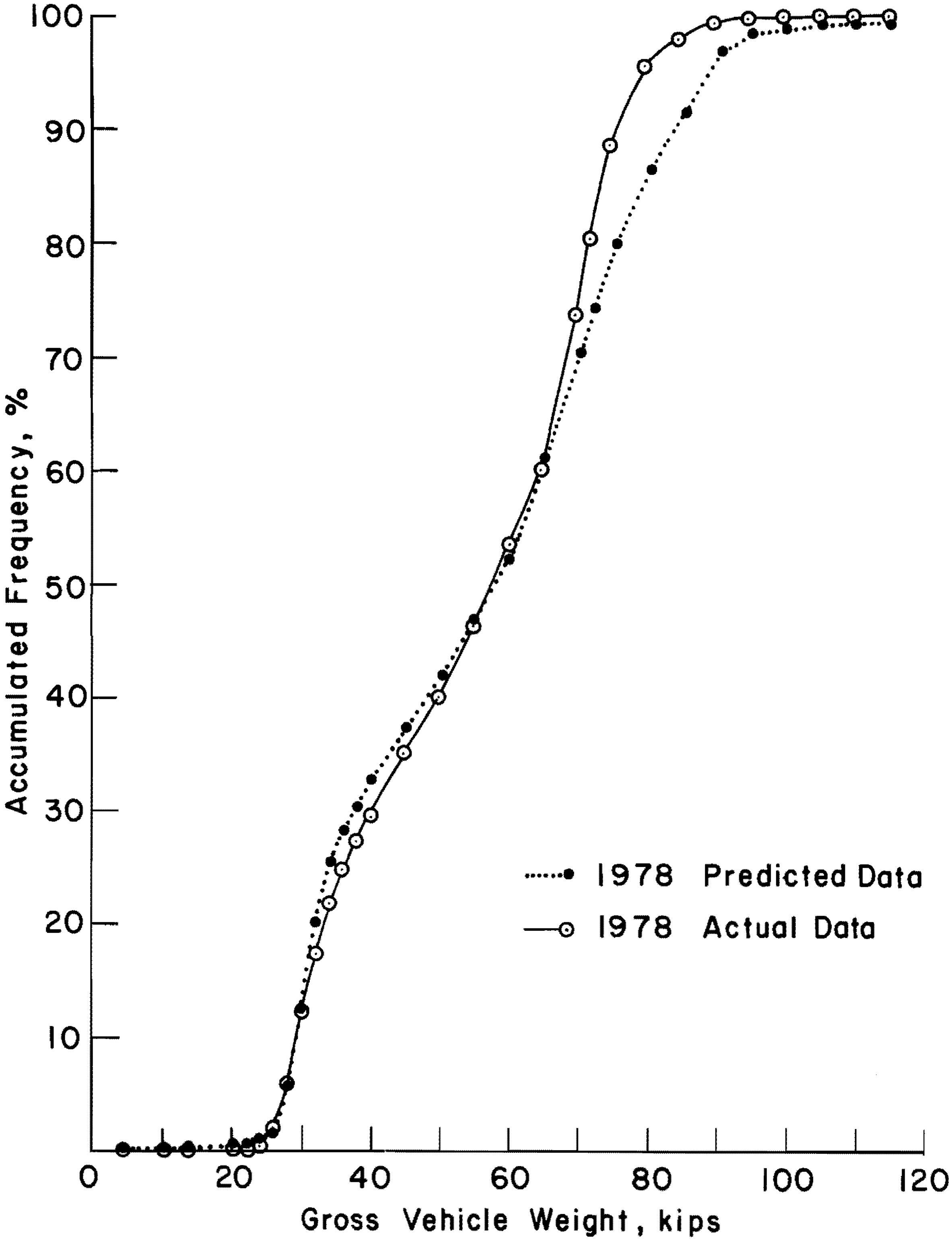


Fig 26. Comparison of actual and predicted GVW distribution curves for 3-S2 on Texas Interstate rural highways.

TABLE 14. COMPARISON OF CUMULATIVE FREQUENCIES OF WEIGHT DISTRIBUTION FOR THE 3-S2 TRUCKS BASED ON ACTUAL FIELD DATA AND PREDICTION BY COMPUTERIZED SHIFTING MODAL (PREDICTION IS FOR 1978)

Distribution Intervals (Kips)	Observed Cumulated Frequency (%)	Expected Cumulated Frequency (%)
0.0- 4.0	0.0	0.1534
4.0-10.0	0.0	0.3835
10.0-13.5	0.0	0.5177
13.5-20.0	0.08	0.7669
20.0-22.0	0.21	0.8436
22.0-24.0	0.42	0.9203
24.0-26.0	1.94	0.9970
26.0-28.0	5.89	5.1920
28.0-30.0	12.42	12.6243
30.0-32.0	17.51	20.3565
32.0-34.0	21.84	25.4414
34.0-36.0	24.96	28.3071
36.0-38.0	27.36	30.4514
38.0-40.0	29.63	32.8258
40.0-45.0	35.14	37.5394
45.0-50.0	40.15	42.1638
50.0-55.0	46.42	47.0900
55.0-60.0	53.70	52.4316
60.0-65.0	60.31	61.4669
65.0-70.0	73.61	70.8808
70.0-72.0	80.30	74.7253
72.0-75.0	88.55	80.3150
74.0-80.0	95.50	86.9204
80.0-85.0	97.94	92.1033
85.0-90.0	99.28	97.4287
90.0-95.0	99.83	99.0476
95.0-100	99.92	99.3687
100.0-105	99.96	99.6897
105.0-110	100.00	100.00
110.0-115	100.00	100.00

$\chi^2 = 8.26$

The computerized shifting methodology also applies the concept of multiplying factors. However, the multiplying factors do not show a linear trend along the truck GVW.

For the comparison of the shifted curves provided by the three methodologies, two illustrations were used. These illustrations are based on the following assumptions:

(1) The truck weight data for the 1975 periods were not available for reference.

(2) The only available information is the magnitude of changes in weight limits.

Due to an insufficient sample size for 3A and 2-S1-2, illustrations of shifting for these two types of trucks are not provided. The two illustrations used in this section are based on the 1974 truck weight data for 2D and 3-S2, assuming five percent of trucks were running overweight in both cases.

The following is the input information for each methodology.

1. 2D, Interstate highway system
   a. NCHRP——initial weight = 4.0 kips
      PMGVWP = 24.50 kips
      PMGVWF = 27.22 kips
   b. SDHPT——initial weight = 20.0 kips
      PMGVWP = 24.50 kips
      PMGVWF = 27.22 kips
   c. Computerized Average GVW Factor Methodology
      - expected mean weight = 0.41 x 27.22 x 1.05 = 14.58 kips
      - expected variance = 100.0 kips
      - 1974 truck weight data as latest year
      - 1970 truck weight data as base year
      - initial shifting point = 0 kips

The shifted curves are plotted in Fig 27. For comparison with the actual weight distribution, a curve for the actual data is provided in the same figure.

Table 16 shows the distributions provided from each methodology and the chi-squared test results for the goodness of fit.

2. 3-S2, Interstate Highway System
    a. NCHRP——Initial weight = 13.5 kips
        PMGVWP = 72.0 kips
        PMGVWF = 80.0 kips
    b. SDHPT——Initial weight = 40.0 kips
        PMGVWP = 72.0 kips
        PMGVWF = 80.0 kips
    c. Computerized Average GVW Factor methodology
        - expected mean weight = 0.66 x 80.0 x 1.05 = 55.44 kips
        - expected variance = 400.0 kips
        - 1974 truck weight data as latest year
        - 1970 truck weight data as base data
        - initial shifting point = 0 kips

The comparison between the shifted curves and the actual data is shown in Fig 28. Table 17 shows the distributions and chi-squared test goodness of fit results. The lower the chi-squared value, the better the fit of the predicted curve with the actual curve.

GENERAL DISCUSSION OF THE METHODOLOGY

Based on previous analyses, it can be concluded that the computerized shifting methodology performs satisfactorily in predicting future truck weight distribution trends. With a practical maximum GVW and the average GVW factor for a certain type of truck, engineers and planners may assume a reasonable violation rate and project the corresponding truck weight distribution. Presently, there is no specific regression model to predict the future violation rate. It is an element dependent on the interaction of several factors. The factors include, but are not limited to, the following:

(1) degree of weight law enforcement,
(2) availability of other truck types which can be used to reach the maximum GVW,
(3) price of gasoline, and
(4) other highway legislation, such as speed limits.

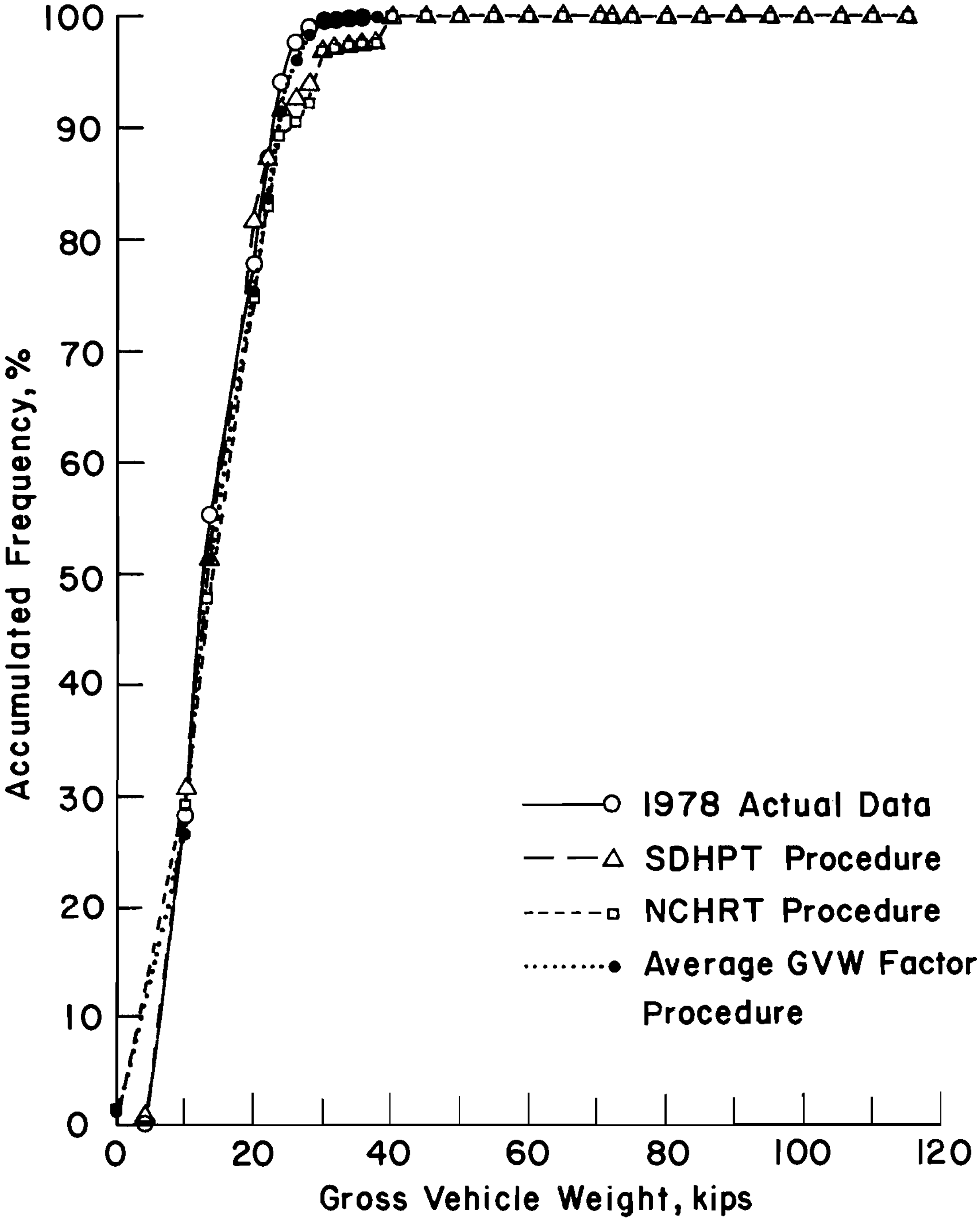


Fig 27. Comparison of GVW distribution curves derived from actual field data, NCHRP, SDHPT, and the computerized AGVWF shifting procedure (2D, Texas Interstate rural, 1978).

TABLE 16. COMPARISON OF PROJECTED CUMULATED FREQUENCY CURVES GENERATED FROM AVAILABLE SHIFTING METHODOLOGIES AND THE ACTUAL FIELD DATA FOR 2D ON TEXAS INTERSTATE RURAL HIGHWAYS (PROJECTION IS FOR 1978)

GVW Distribution Intervals	Actual Field Data	NCHRP Shifting Methodology	SDHPT Shifting Methodology	Computerized Average GVW Factor Methodology
0-4.0	0-0	0.95	0.95	0.93
4.0-10	28.33	29.08	30.64	26.64
10-13.5	55.35	47.41	51.02	51.29
13.5-20	77.86	74.76	81.50	75.21
20-22	87.43	82.54	86.98	83.54
22-24	94.18	89.29	91.54	91.32
24-26	97.75	90.57	92.54	96.12
26-28	99.06	92.45	93.78	98.41
28-30	99.62	96.94	96.94	99.13
30-32	99.62	97.19	97.19	99.37
32-34	99.81	97.40	97.40	99.60
34-36	100.00	97.60	97.60	99.84
36-38	100.00	97.80	97.80	100.00
38-40	100.00	100.00	100.00	100.00
40-45	100.00	100.00	100.00	100.00
Chi-squared Value:		4.33	2.63	1.76

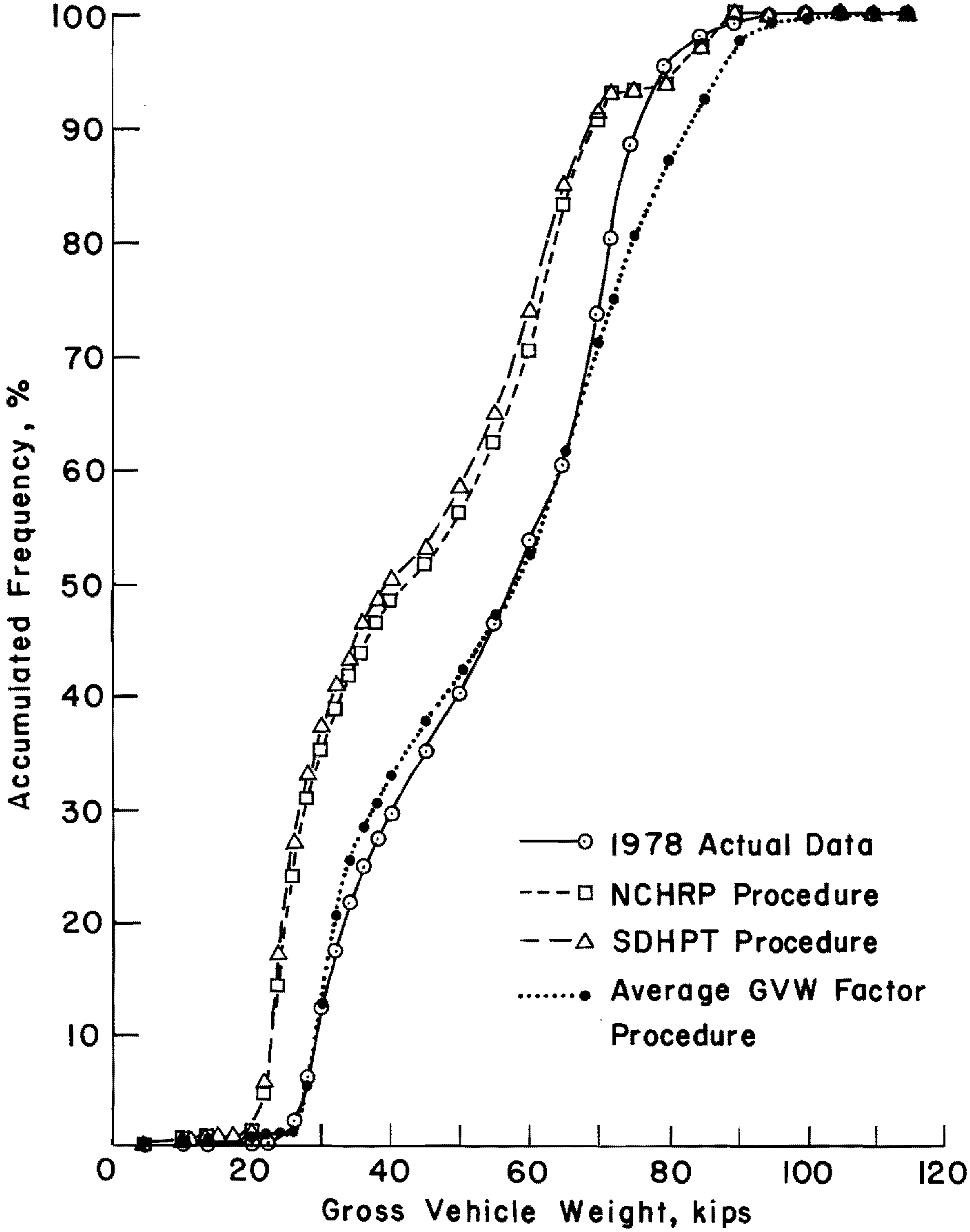


Fig 28. Comparison of GVW distribution curves derived from actual field data, NCHRP, SDHPT, and the computerized AGVWF shifting procedure (3-S2, Texas Interstate rural, 1978).

TABLE 17. COMPARISON OF PROJECTED CUMULATIVE FREQUENCY CURVES GENERATED FROM AVAILABLE SHIFTING METHODOLOGIES AND THE ACTUAL DATA FOR 3-S2 ON TEXAS INTERSTATE RURAL HIGHWAYS (PROJECTION FOR 1978)

GVW Distribution Intervals	Actual Field Data	NCHRP Shifting Methodology	SDHPT Shifting Methodology	Computerized Average GVW Factor Methodology
0.0-4.0	0.00	.1996	.2020	0.1534
4.0-10.0	0.00	.4989	.5049	0.3835
10.0-13.5	0.00	.6736	.6816	0.5177
13.5-20.0	0.00	.9979	1.2932	0.7669
20.0-22.0	0.21	4.4618	5.3447	0.8436
22.0-24.0	0.42	14.3453	17.0088	0.9203
24.0-26.0	1.94	24.1679	27.0374	0.9970
26.0-28.0	5.89	30.8721	32.9852	5.1920
28.0-30.0	12.42	35.3293	37.1071	12.6243
30.0-32.0	17.51	38.9926	40.9620	20.3565
32.0-34.0	21.84	41.8016	43.0606	25.4414
34.0-36.0	24.96	43.9880	46.1142	28.3071
36.0-38.0	27.36	46.6611	48.5965	30.4514
38.0-40.0	29.63	48.8201	50.1955	30.8258
40.0-45.0	35.14	51.8905	52.9377	37.5394
45.0-50.0	40.15	56.1453	58.3009	42.1638
50.0-55.0	46.42	62.5450	64.8687	47.0900
55.0-60.0	53.70	70.4924	73.9259	52.4316
60.0-65.0	60.31	83.0160	84.9037	61.4669
65.0-70.0	73.61	90.5734	91.6666	70.8808
70.0-72.0	80.30	93.0143	93.0878	74.7253
72.0-75.0	88.55	93.3409	93.4138	80.3150
75.0-80.0	95.50	93.8852	93.9572	86.9204
80.0-85.0	97.94	97.2693	97.5279	92.1033
85.0-90.0	99.28	100.0000	100.0000	97.4287
90.0-95.0	99.83	100.0000	100.0000	99.0476
95.0-100.0	99.92	100.0000	100.0000	99.3687
100.0-105.0	99.96	100.0000	100.0000	99.6897
105.0-110.0	100.00	100.0000	100.0000	100.0000
110.0-115.0	100.00	100.0000	100.0000	100.0000
		χ^2=149.96	χ^2=172.06	χ^2= 8.26

In predicting future truck weight distribution, engineers and planners may exercise their judgment in defining the percentage violations. One suggestion, however, is to run the program with different violation factors. This method is to test the sensitivity of prediction to violation.

Besides predicting future GVW distribution, the computerized shifting procedure may be used to predict future axle weight distribution. This topic will be presented in the next chapter. The procedure can also be used to predict additional damages due to different degrees of violation.

CHAPTER 6. PREDICTIONS OF AXLE WEIGHT DISTRIBUTION AND EQUIVALENT 18-KIP SINGLE AXLE LOAD

In the procedure for estimation of maintenance cost and highway rehabilitation cost for changing motor vehicle size and weight limits, one important element is the prediction of total equivalent 18-kip single axle load (18-KESAL). The relationship of the element with other components in the procedure is shown in Fig 29. The GVW distribution is directly affected by the axle weight distribution, which, in turn, directly affects the computation of total 18-KESAL. In previous chapters, much attention was given to the prediction of GVW distribution under proposed weight limits. In this chapter, the prediction of axle weight distribution is presented.

ESTIMATION OF TANDEM AXLE WEIGHT DISTRIBUTION FROM AVAILABLE DATA

In this section, the discussion is focused on two types of trucks, the 3A and 3-S2. Predictions for 2D and 2-S1-2 are not included in the discussion because it is not possible to separate the loading axle weight distribution from the single axle weight distribution given in W-4 tables. For 3A and 3-S2, the axle weight distributions given in the W-4 tables provide information for the steering axle and loading axle weight distributions. Due to the availability of axle weight data, it is thus possible to use past trends in predicting the future axle weight distribution.

For the single unit truck symbolized by 3A, the single axle is the steering axle while the tandem axle is the loading axle. Thus, for one particular truck it is obvious that the gross vehicle weight is the summation of the single axle weight and the tandem axle weight. This relationship is expressed in an equation as follows:

$$GVW = SAW + TAW \qquad \text{(Eq 6-1)}$$

For the 3-S2, which has one single axle (steering axle) and two tandem axles, the gross vehicle weight is obviously equal to the summation of the steering

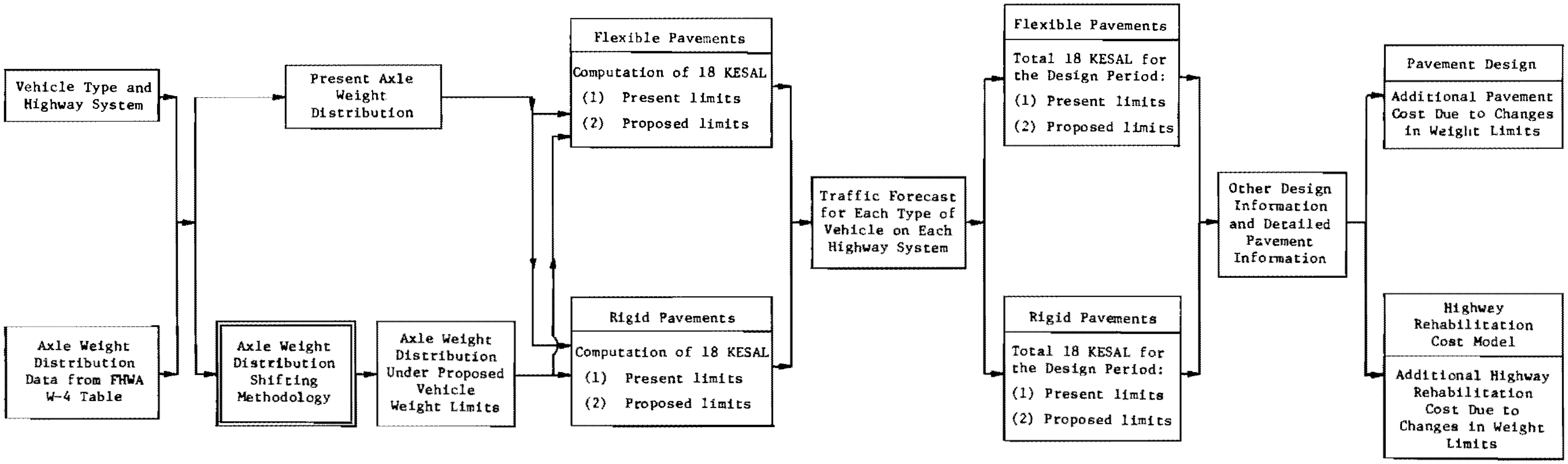


Fig 29. Schematic representation illustrating the procedure to estimate the additional pavement cost and highway rehabilitation cost for changing motor vehicle weight limits.

axle weight and the weight of tandem axles. It can be expressed as follows:

$$\mathrm{GVW} = \mathrm{SAW} + 2\ \mathrm{TAW} \qquad \text{(Eq 6-2)}$$

In consideration of these two equations, attempts were made to relate the three kinds of weight distribution data. The concept was to explore the relationship of GVW, SAW, and TAW for 3A and 3-S2 so that a prediction for TAW distribution could be made possible from the prediction of GVW distribution.

Let GVW(i%), SAW(i%) and TAW(i%) be the GVW, SAW, and TAW at i% along the truck weight cumulated percentage curves for either 3A or 3-S2. For the single unit trucks, 3A, prediction of TAW(i%) was based on the following equation:

$$\mathrm{TAW}_{3A}(i\%) = \left[\mathrm{GVW}(i\%) - \mathrm{SAW}(i\%)\right] \qquad \text{(Eq 6-3)}$$

and for 3-S2, the following equation was used:

$$\mathrm{TAW}_{3\text{-}S2}(i\%) = 0.5\left[\mathrm{GVW}(i\%) - \mathrm{SAW}(i\%)\right] \qquad \text{(Eq 6-4)}$$

In the analysis, predicted TAW values were based solely on the GVW and SAW distribution data while the field data for TAW's were used as actual data for comparison. Once the TAW(i%) values were obtained, a predicted cumulative percentage curve was constructed. The distributions of the predicted TAW's and the actual TAW's were plotted in a graph for comparison. In the study, data collected in different years were used to prove the relationships stated in Eqs 6-3 and 6-4. These years represent a spectrum of different conditions. For instance, 1970 was chosen to show the trend of the 70's. Year 1974 was used to reflect the weight distribution before the changes in Texas weight limits. Year 1976 was known as an unusual year in that the weight data reflected that weights for different trucks increased significantly after the 1975 change. Year 1979 was used to reflect the latest trends. The distribution curves for 3A are shown in Fig 30 (a-d) and 3-S2 in Fig 31 (a-d). Along with the distribution curves, the predicted actual TAW distribution data were analyzed for the goodness-of-fit with chi-squared values shown in Table 18. Both the graphical presentation and the

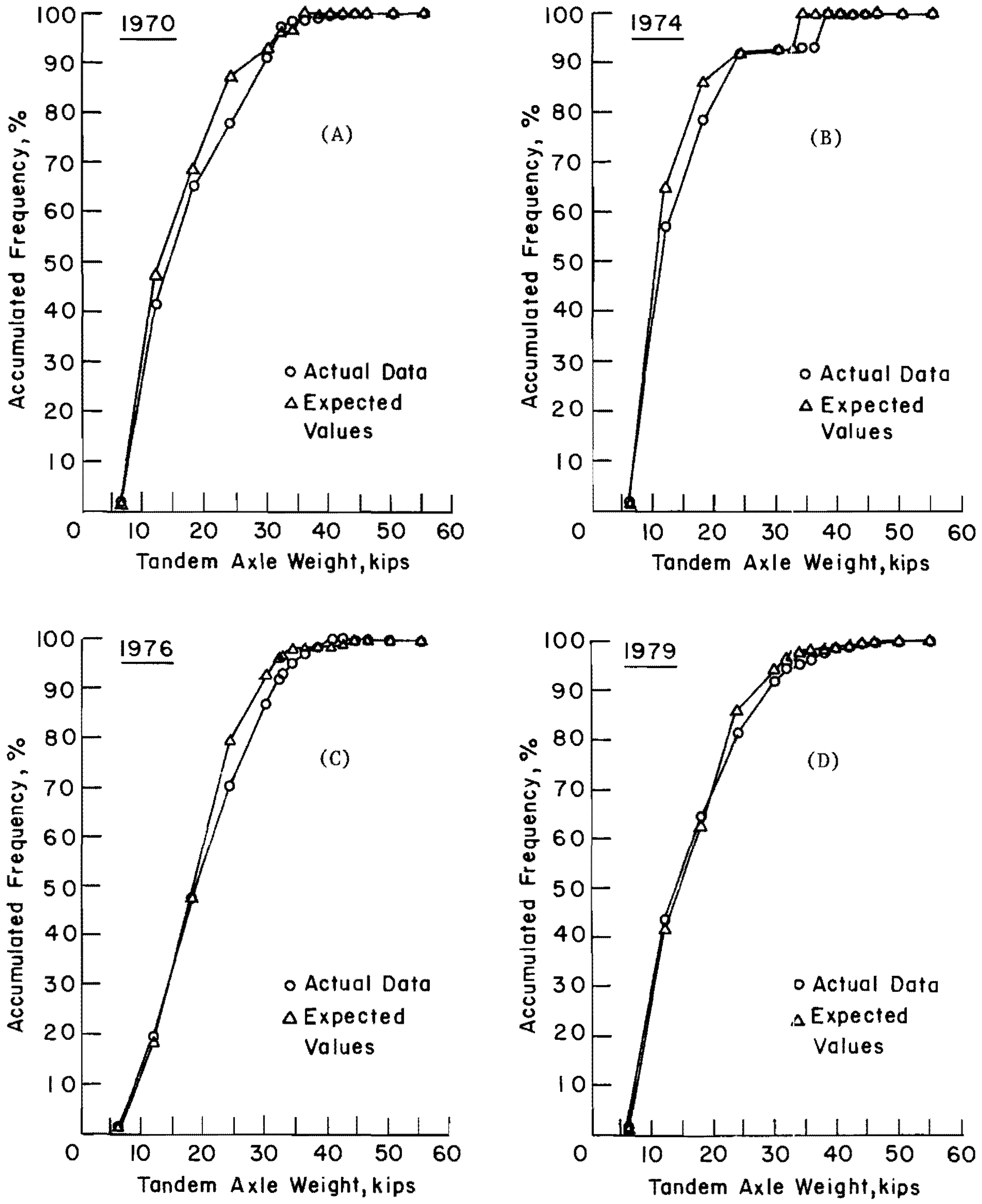


Fig 30. Comparison of actual and expected tandem axle distribution for 3A on Texas Interstate rural highways.

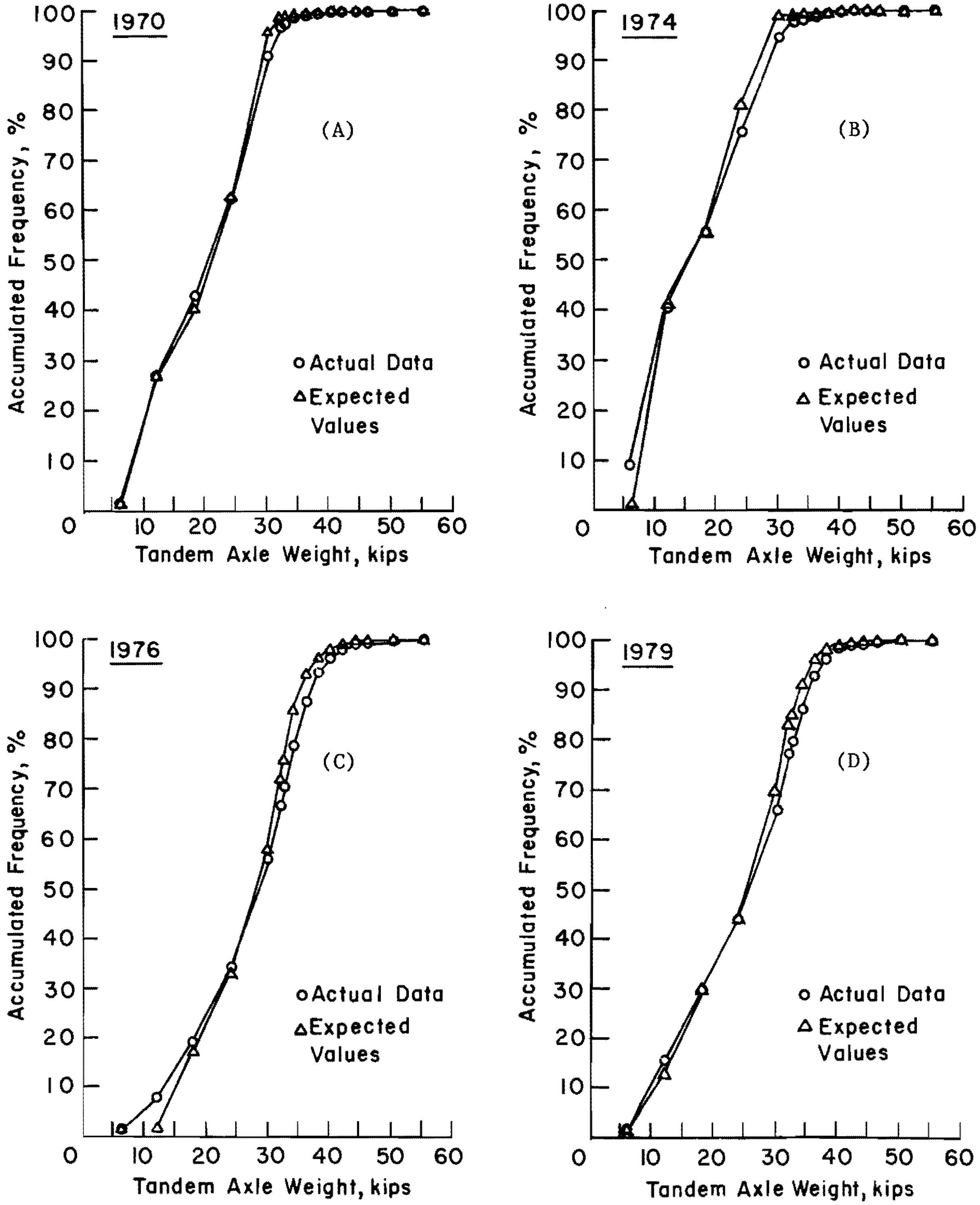


Fig 31. Comparison of actual and expected tandem axle distribution for 3-S2 on Texas Interstate rural highways.

TABLE 18. CHI-SQUARED VALUES TO SHOW THE GOODNESS-OF-FIT BETWEEN ACTUAL AND PREDICTED TANDEM AXLE WEIGHT DISTRIBUTION CURVES

3A	Chi-squared value
1970	20.68
1974	75.06
1976	19.58
1979	18.24

3-S2	Chi-squared value
1970	9.08
1974	33.85
1976	12.87
1979	10.35

chi-square values indicate that the predicted TAW distribution agrees with the actual TAW field data.

From the study of the relationship between gross vehicle weight and axle weight distributions, it can be concluded that the simple relationship of GVW, SAW, and TAW of a single truck can be applied to the weight distribution data. The relationships stated in Eqs 6-1 and 6-2 are valid for 3A and 3-S2 weight distributions, respectively. Thus, for a given year, if GVW and SAW distributions are available, it is possible to obtain the TAW distribution. This finding is essential to predictions of TAW distributions and 18-KESAL under the proposed truck weight limits.

PREDICTION FOR TANDEM AXLE WEIGHT DISTRIBUTION UNDER PROPOSED TRUCK WEIGHT LIMITS

From the extensive study of truck weight distribution patterns, it was observed that the change in axle weight as well as gross vehicle weight limits in 1975 did not change the distribution of steering axle weight. This statement is based on the analysis of steering axle weight distribution curves in Figs 16, 17, and 18. Because of practical and operational safety considerations, the steering axle weight distribution did not change even though the weight laws changed. Thus, for prediction purposes, it is acceptable to use the present steering axle weight distribution as the future steering axle weight distribution under the proposed weight laws. Along with this concept, it is possible to predict a tandem axle weight distribution for both 3A and 3-S2 with the application of the average GVW factor concept mentioned in the previous chapters. The procedures are shown in the flowchart in Fig 32 and discussed as follows:

(1) With the previous stated methodology, use the average GVW factor methodology to obtain a GVW distribution curve for a proposed truck weight limit.

(2) Obtain the SAW distribution for the truck type from the latest truck weight data in W-4 tables.

(3) Read the GVW (i%) and SAW (i%) from the GVW and SAW distribution curves.

(4) Use the appropriate equation for the truck type. For 3-S2,

$$\mathrm{TAW}(i\%) = 0.5 \left[\mathrm{GVW}(i\%) - \mathrm{SAW}(i\%) \right]$$

and for 3A,

$$TAW(i\%) = GVW(i\%) - SAW(i\%)$$

5. From the TAW(i%) values, plot the distribution curve.

To illustrate the application of the procedure, an example using the 3-S2 Texas Interstate Highway is provided in the next section.

EXAMPLE OF PREDICTION OF TANDEM AXLE WEIGHT DISTRIBUTION

In order to determine the accuracy of the prediction, an illustration using prior data is developed. In this example, the prediction is made for the tandem axle weight distribution for the 3-S2 on Texas Interstate Highway in 1978. The purpose of this example is to illustrate the prediction of tandem axle weight under the proposed truck weight laws. The data available for prediction were composed of GVW and SAW distribution from 1959 through 1975. The 1978 GVW prediction, provided in the prior chapters, serves as the basis for predicting the TAW distribution. Tables 19 and 20 show the predicted GVW distribution for 1978 and the single axle weight distribution for 1974 respectively. These weight distribution data serve as inputs for the TAW prediction. The procedure is coded into a computer program. The listing of the program TAWEXP is included in Appendix 3. Figure 33 shows the cumulative percentage curves of the actual and predicted TAW distribution. A chi-squared test on the actual and predicted curves is shown in Table 21. Both the plotting and the chi-squared value indicate that the prediction is within acceptable tolerance.

CALCULATION OF EQUIVALENT 18-KIP SINGLE AXLE LOAD

To assess the impacts on pavement structures due to changes in legal weight limits, one has to compute the equivalent 18-kip single axle load applications for the present and proposed weight limits. The difference between the two load applications is the additional impact affected by changes in weight limits. The direct source of truck weight data used in the computation of the total number of 18-kip ESAL is the W-4 tables. Equivalent factors for both flexible and rigid pavements are provided in the W-4 tables. These factors, when multiplied by the number of axle loads within a given

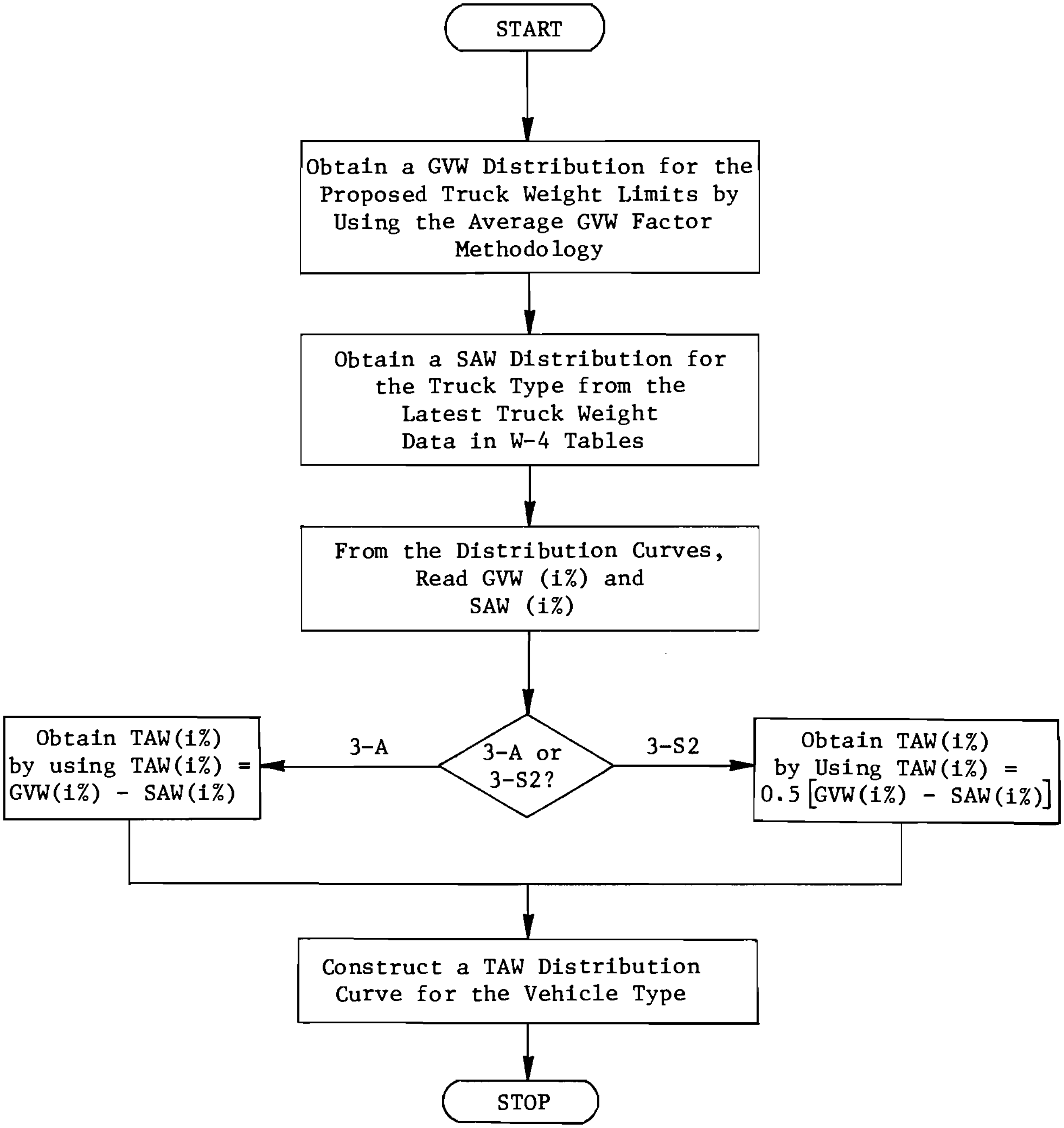


Fig 32. Flowchart for predicting tandem axle weight distribution for 3A and 3-S2.

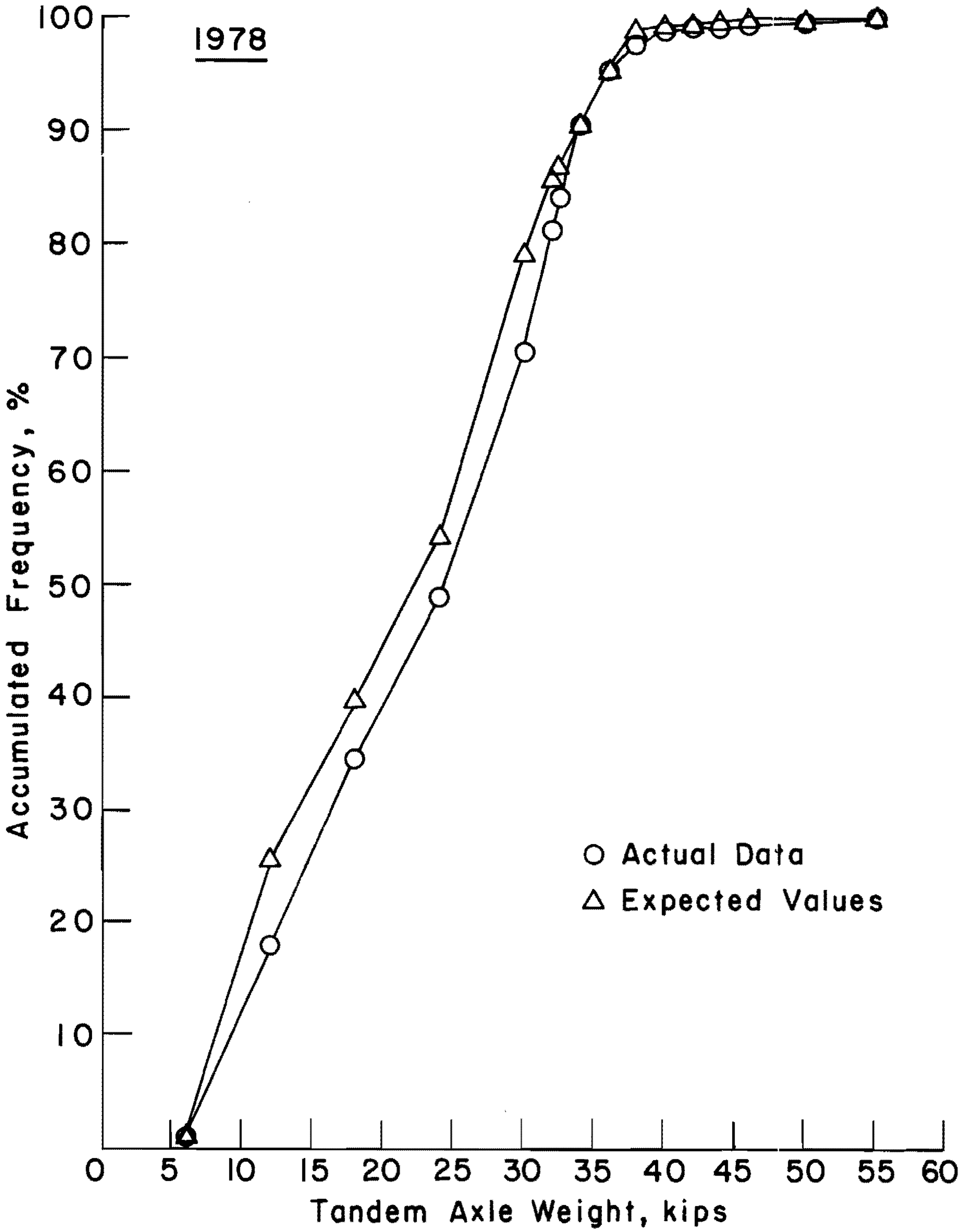


Fig 33. Comparison of actual and predicted tandem axle weight distributions for 3-S2 on Texas Interstate rural highways.

TABLE 19. PROJECTED GVW DISTRIBUTION FOR 1978, 3-S2, TEXAS INTERSTATE RURAL HIGHWAYS (INPUT DATA FOR PROJECTION OF TAW, 1978)

Weight Distribution (kips)	Percentage	Accumulated Percentage
4.0000	.1534	.1534
10.0000	.2301	.3835
13.5000	.1342	.5177
20.0000	.2492	.7669
22.0000	.0767	.8436
24.0000	.0767	.9203
26.0000	.0767	.9970
28.0000	4.1951	5.1920
30.0000	7.4323	12.6243
32.0000	7.7321	20.3565
34.0000	5.0849	25.4414
36.0000	2.8658	28.3071
38.0000	2.1443	30.4514
40.0000	2.3744	32.8258
45.0000	4.7136	37.5394
50.0000	4.6244	42.1638
55.0000	4.9262	47.0900
60.0000	5.3416	52.4316
65.0000	9.0353	61.4669
70.0000	9.4139	70.8808
72.0000	3.8445	74.7253
75.0000	5.5897	80.3150
80.0000	6.6054	86.9204
85.0000	5.1828	92.1033
90.0000	5.3254	97.4287
95.0000	1.6190	99.0476
100.0000	.3210	99.3687
105.0000	.3210	99.6897
110.0000	.3103	100.0000
115.0000	0	100.0000

TABLE 20. SINGLE AXLE WEIGHT DISTRIBUTION OF 3-S2 ON TEXAS INTERSTATE RURAL HIGHWAYS (INPUT DATA FOR PROJECTION OF TAW, 1978)

Data Obtained in 1974

A	B	C	D
End of SAW Interval (kips)	Sample Size	Percentage	Accumulated Percentage
3.	1.	.26	.26
7.	13.	3.32	3.57
8.	69.	17.60	21.17
12.	301.	76.79	97.96
16.	8.	2.04	100.00

Total Number of Trucks Weighed = 392

TABLE 21. PREDICTION OF 1978 TANDEM AXLE WEIGHT DISTRIBUTION BASED ON PROJECTED 1978 GVW AND ACTUAL 1974 SAW DISTRIBUTION DATA

Tandem Axle Weight (kips)	Actual Cumulated Percentage	Expected Cumulated Percentage
6.00	.95	.54
12.00	17.89	20.09
18.00	34.51	37.39
24.00	48.86	49.75
30.00	70.37	72.14
32.00	81.23	80.37
32.50	84.05	81.85
34.00	90.49	86.10
36.00	95.20	90.67
38.00	97.60	95.14
40.00	98.82	99.08
42.00	99.11	99.34
44.00	99.25	99.60
46.00	99.39	99.87
50.00	99.66	100.00
55.00	100.00	100.00

Chi-squared value = 14.5815

weight interval, give the number of 18-KESAL applications. The summation of the load applications throughout the whole span of weight intervals gives the total loading effect on the pavement by the sample trucks. Equivalent factors for other pavement conditions may be obtained by the equations or nomographs provided in the "AASHTO Interim Guide for Design of Pavement Structures," published by the American Association of State Highway and Transportation Officials (AASHTO) (Ref 1). An example illustrating the procedure for computing 18-KESAL is given in Table 22.

The equivalent 18-KESAL applications for the proposed weight limits can be computed by resorting to the shifted axle weight distribution curve. In the previous chapters, both the procedures and the example of shifting GVW and axle weight distribution curves have been presented. In this section, an example is used to illustrate the application of the shifting methodology in arriving at the 18-KESAL applications. The flowchart in Fig 34 summarizes the procedure.

For illustrative purposes, the predicted tandem axle weight distribution obtained earlier is used to compute the equivalent 18-kip single axle load. Both flexible and rigid pavement 18-KESAL for actual and predicted axle weight distributions are provided in Tables 23 and 24, respectively. In both rigid and flexible pavement, the differences between the actual and predicted 18-KESAL are within 6 percent.

COMMENT ON THE AXLE WEIGHT SHIFTING METHODOLOGY

The shifting procedure for GVW distribution depends on the GVW distribution data. Its accuracy is directly affected by the size and quality of the samples. The shifting for TAW distribution depends on both GVW and SAW distributions. Therefore, the accuracy of the prediction of future axle weight distributions is dependent upon the quality of the present axle weight distribution data and the sample size. An illustration of the importance of data to the procedure is reflected in Fig 30(b), where the number of both single axles and tandem axles available in the W-4 table was 14.

To remedy the deficiency in sample size, users may be able to combine data representing the same category. This may be significant for the steering

TABLE 22. EXAMPLE OF DETERMINATION OF EQUIVALENT 18-KIP (80-kN) SINGLE AXLE LOADS FROM LOADOMETER STATION DATA (Ref 16)

Axle Load Groups, lb	Representative Axle Load, lb	Equiv Factor[1]	No. of Axles[2]	Equiv 18-kip Single Axles
Single Axles				
Under 3,000	2,000	0.0003	512	0.2
3,000- 6,999	5,000	0.012	536	6.4
7,000- 7,999	7,500	0.0425	239	10.2
8,000-11,999	10,000	0.12	1,453	174.4
12,000-15,999	14,000	0.40	279	111.6
16,000-18,000	17,000	0.825	106	87.5
18,001-20,000	19,000	1.245	43	53.5
20,001-21,999	21,000	1.83	4	7.3
22,000-23,999	23,000	2.63	3	7.9
24,000 and over	-	-	0	-
			Subtotal	459.0
Tandem Axles				
Under 6,000	4,000	0.01	9	-
6,000-11,999	9,000	0.008	337	2.7
12,000-17,999	15,000	0.055	396	21.8
18,000-23,999	21,000	0.195	457	89.1
24,000-29,999	27,000	0.485	815	395.3
30,000-32,000	31,000	0.795	342	271.9
32,001-33,999	33,000	1.00	243	243.0
34,000-35,999	35,000	1.245	173	215.4
36,000-37,999	37,000	1.535	71	109.0
38,000-39,999	39,000	1.875	9	16.9
40,000-41,999	41,000	2.275	0	-
42,000-43,999	43,000	2.74	1	2.7
44,000 and over	-	-	0	-
			Subtotal	1,367.8
			Total	1,826.8
Total, all trucks = 3,146				

[1] For p_t = 2.5 and NS = 3.0

[2] Loadometer station data for 3,146 trucks

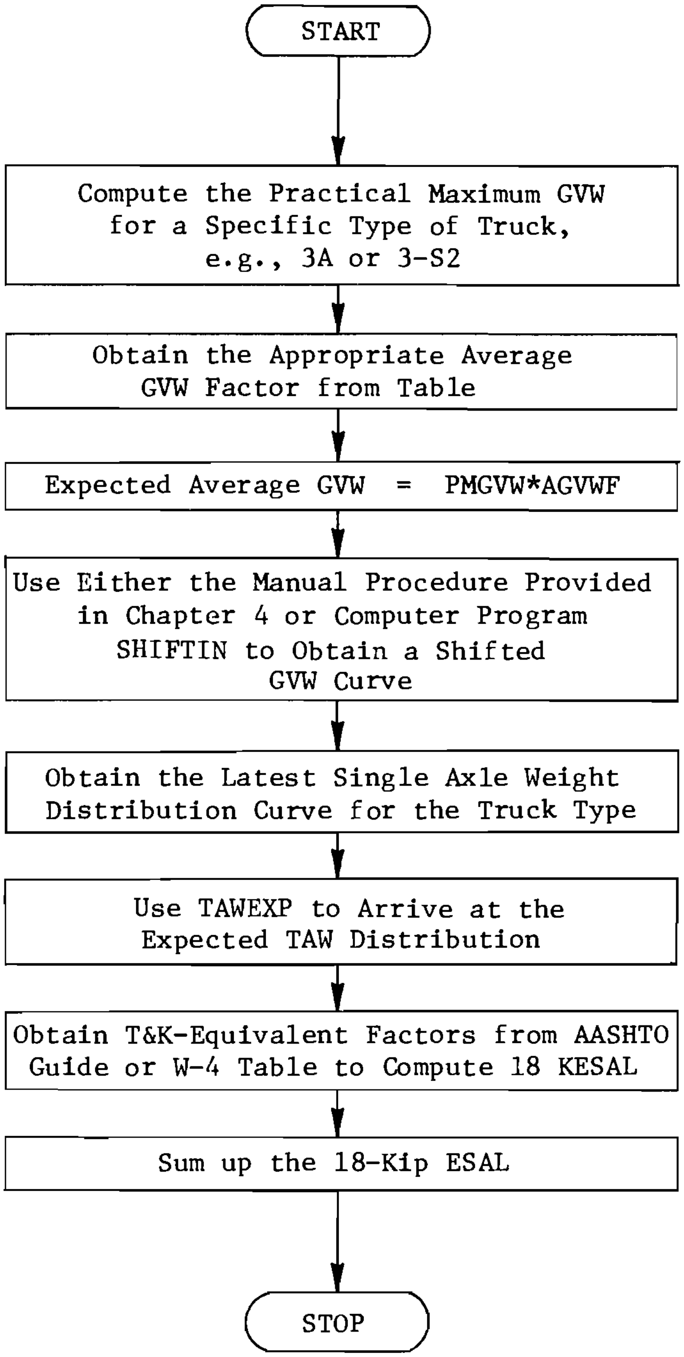


Fig 34. Shifting procedure and computation of 18-kip equivalent single axle load.

TABLE 23. COMPUTATION OF ACTUAL AND PREDICTED 18 KESAL FOR FLEXIBLE PAVEMENT (3-S2, TEXAS INTERSTATE HIGHWAYS)

Tandem Axle Weight Groups	Observed Sample	Predicted Sample	Flexible Pavement 18-K Equivalence Factor	Observed 18-KESAL Applications	Predicted 18-KESAL Applications
0- 5,999	1	25.6	0.010	0.01	0.3
6,000-11,999	848	927.5	0.010	8.48	9.3
12,000-17,999	790	820.7	0.044	34.76	36.1
18,000-23,999	676	586.4	0.1480	100.05	86.8
24,000-29,999	1019	1062.2	0.4260	434.09	452.5
30,000-32,000	519	390.4	0.7530	390.81	294.0
32,001-32,500	135	70.2	0.8850	119.48	62.1
32,501-33,999	312	201.6	1.0020	312.62	202.0
34,000-35,999	222	216.8	1.2300	273.06	266.7
36,000-37,999	116	212.1	1.5330	117.83	325.1
38,000-39,999	53	186.9	1.8850	99.91	352.3
40,000-41,999	32	12.3	2.2890	73.25	28.2
42,000-43,999	13	12.3	2.7490	35.74	33.8
44,000-45,999	4	12.8	3.2690	13.08	41.8
46,000-49,999	2	6.2	4.1700	8.34	25.9
50,000-55,000	2	0.0	5.100	10.20	0.0
	$\Sigma = 4744$	$\Sigma = 4744.0$		$\Sigma = 2092.00$	$\Sigma = 2217.0$

$$\Delta = \frac{2217 - 2092}{2092} = 5.98\%$$

TABLE 24. COMPUTATION OF ACTUAL AND PREDICTED 18 KESAL FOR RIGID PAVEMENT (3-S2, TEXAS INTERSTATE HIGHWAYS)

Tandem Axle Weight Groups	Observed Sample	Predicted Sample	Rigid Pavement 18-K Equivalence Factor	Observed 18-KESAL Applications	Predicted 18-KESAL Applications
0- 5,999	1	25.6	0.01	0.01	0.3
6,000-11,999	848	927.5	0.01	8.48	9.3
12,000-17,999	790	820.7	0.062	48.98	50.9
18,000-23,999	676	586.4	0.253	171.0	148.4
24,000-29,999	1019	1062.2	0.729	742.9	774.3
30,000-32,000	519	390.4	1.305	677.3	509.5
32,001-32,500	135	70.2	1.542	208.2	108.2
32,501-33,999	312	201.6	1.752	548.2	353.2
34,000-35,999	222	216.8	2.165	480.6	447.7
36,000-37,999	116	212.1	2.721	315.6	577.1
38,000-39,999	53	186.9	3.373	178.8	630.4
40,000-41-999	32	12.33	4.129	132.1	50.9
42,000-43,999	13	12.33	4.997	65.0	61.6
44,000-45,999	4	12.8	5.987	23.9	76.6
46,000-49,999	2	6.2	7.725	15.5	47.9
50,000-55,000	2	0.0	10.16	20.3	0.0
	Σ = 4744	Σ = 4744.0		Σ = 3637.0	Σ = 3846.3

$$\Delta = \frac{3846.3 - 3637.0}{3637} \times 100\% = 5.75\%$$

axle distribution of 3A and 3-S2. Since the SAW distribution curves did not shift throughout the years, the combination of data will surely improve the accuracy of prediction.

CHAPTER 7. SUMMARY AND RECOMMENDATIONS

The objective of this research project was to develop a shifting methodology which could be used to predict precisely future GVW distributions and axle weight distributions and 18-kip equivalent single axle load application in response to legal weight limit changes. The methodology presented in previous chapters has proved that the objective of the study has been attained. No single methodology is perfect in all aspects, and the methodology discussed in this report is no exception. However, as far as precision is concerned, the shifting methodology is highly desirable. It was developed by building upon the contributions of earlier shifting methodologies, especially that provided by Walton and Yu's research conducted at the Center for Transportation Research

SUMMARY OF NEW CONCEPTS USED IN THE SHIFTING METHODOLOGY

While developing the shifting methodology, several new concepts were introduced to facilitate more precise predictions.

(1) Extensive use of historical truck weight data in projecting future weight distribution——All available truck weight data were used in the analysis. Several computer programs were written to facilitate the analysis and statistical modeling. In the prediction of future truck weight distribution, two sets of the latest available weight distribution data were used. This practice can accurately capture the latest weight distribution trends in forecast future trends.

(2) Extensive use of statistical methods in analyzing historical data——Statistical methods such as using mean and variance to predict a normal distribution curve are the theme of the shifting methodology. Statistical test methods such as the chi-squared method and student t-tests are used extensively in the procedure. Computer statistical packages such as SPSS and MINITAB were used in sorting and analysis of data.

(3) Computer application in conducting the shifting procedure——Due to the large amount of historical data and a large number of required input parameters, computer application became a necessity in performing the shifting procedure. Computer programming has facilitated the

procedure by integrating analysis, statistical testing, regression modeling, and forecasting into one single package. It thus reduces the time required in step-by-step manual shifting procedures. Thus, unnecessary human error introduced in the procedure can be reduced to a minimum.

(4) Concept of using a mean and a variance to predict future distribution ——Both the means and variances for the weight distribution curves usually suggest specific trends over a period of time. These trends can be represented by regression models. By using these models, one may predict the two parameters for future truck weight distributions. With the suggested shifting procedure, one may obtain a future weight distribution curve with desirable precision.

(5) Concept of using an average GVW factor for projection of average GVW under proposed limit——The average GVW factor is used to relate a known parameter to an unknown parameter such as the future maximum GVW to the future average GVW. From the proposed truck weight limits, one may derive the future maximum practical GVW for a certain type of truck. By multiplying the future maximum practical GVW with a given average GVW factor, one may obtain an average GVW for the truck type under the proposed weight limits. Once the future average GVW is obtained, one may project a future truck weight distribution by using the suggested shifting methodology.

ASSUMPTIONS MADE IN THE DEVELOPMENT OF THE SHIFTING METHODOLOGY

In deriving the shifting procedure, two assumptions were made:

(1) The prediction of weight distribution does not take weight violation into account. In arriving at the average GVW for each type of vehicle, a maximum allowable GVW was input into the program so that any sample with weight greater than this value would not be included in the computation of average weight. Thus, the average GVW factors provided in previous chapters can be used only to predict future legal average GVW. However, if the percentage of truck weight violations is to be taken into consideration, one may adjust the average GVW factors accordingly.

(2) Size effects were neglected in the analysis process. Vehicle operational characteristics are affected by both volume and demand constraints. Thus, changes in size limits will have definite effects on truck weight distributions. However, due to the complexity of the issue, size effects were neglected in the development of the procedure. Hence, it is difficult to quantify the impacts due to changes in size limits. It is the authors' belief that trucks subjected to volume constraint are a relatively low percentage of the total truck population. It is even less plausible that these types of trucks would affect truck weight distribution data significantly. Thus, to cope with changes in both size and weight limits, one may concentrate one's effort on analyzing the effects of weight limit changes.

RECOMMENDATIONS

Although the main data structure concentrated on the Texas interstate highway system, the shifting procedure can be used for other types of highway systems, and is applicable to other states. If facilities such as computer hardware and FORTRAN language compilers are available, the AGVWF shifting methodology is strongly recommended.

As mentioned earlier, in previous chapters, the size of a data base is vital to the prediction of future weight distribution trends. An insufficient data base will generally handicap the precision of any estimation.

A large data base is a prerequisite to a precise prediction. In recent years, many truck weighing stations in Texas had been closed due to insufficient operation funds. Obviously, a shut-down of a weighing station sacrifices a certain degree of precision in prediction. Consequently, this adverse effect will be reflected in the inefficient design of highway systems. Thus, for a long-term investment on the existing federal and state highway systems, it is strongly recommended that truck weighing activities should be intensified and improvements made in operating efficiency.

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APPENDIX 1

SOURCE PROGRAM OF "MEANWGT"——TO COMPUTE MEAN AND VARIANCE OF TRUCK WEIGHT DISTRIBUTION DATA

```
      PROGRAM MEANWGT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C  PROGRAM SAVGWT CALCULATES THE AVGWT OF SUMB AND SUMAB WHERE
C  SUMB IS THE SUMMATION OF B AND SUMAB IS THE SUMMATION OF A
C  TIMES B
C
C
C  VARIABLE DESCRIPTION:=
C  AVGWT -- AVGWT OF SUMB AND SUMAB
C  SUMA  -- SUMMATION OF A
C  SUMAB -- SUMMATION OF A TIMES B
C  AB    -- A TIMES B
C  A, B, GVW, AXLE ARE CONSISTENT WITH PREVIOUS PROGRAMS.
C
C
      DIMENSION A(30), B(30), GVW(2,30), AXLE(2,30), IYEAR,A2(30)
      DIMENSION IROAD(2),IVEH(3),ISTATE(2)
      REAL AVGWT, AB(30), SUMB, SUMAB, A1(30)
      INTEGER IN
      DATA (GVW(1,I), I=1,30)/4.0, 10.0, 13.5, 20.0, 22.0, 24.0,
     +26.0, 28.0, 30.0, 32.0, 34.0,36.0, 38.0, 40.0, 45.0,50.0,55.0,
     +60.0, 65.0, 70.0, 72.0, 75.0, 80.0, 85.0, 90.0, 95.0, 100.0,
     +105.0, 110.0, 115.0 /

      DATA (GVW(2,I), I=1,26) /10.0, 12.0, 14.0, 16.0, 18.0, 20.0,
     +22.0, 24.0, 26.0, 28.0, 30.0, 35.0, 40.0, 45.0, 50.0, 55.0,
     +60.0, 65.0, 70.0, 75.0, 80.0, 85.0, 90.0, 95.0, 100.0, 105.0/

      DATA (AXLE(1,I), I=1,13) / 3.0, 7.0, 8.0, 12.0, 16.0, 18.0,
     +18.5, 20.0, 22.0, 24.0, 26.0, 30.0, 35.0 /

      DATA (AXLE(2,I), I=1,16) / 6.0, 12.0, 18.0, 24.0, 30.0, 32.0,
     +32.5, 34.0, 36.0, 38.0, 40.0, 42.0, 44.0, 46.0, 50.0, 55.0 /
C
C  INPUT VALUES FROM DATA SET PTAVGWT UNTIL END OF FILE
C
C
C     PRINT HEADING FOR OUTPUT
C
      CALL TITLE
C
C     READ IN WEIGHT LIMITS BEFORE AND AFTER WEIGHT CHANGES
C
      READ (5,100) WGT1,WGT2
C
  1   CALL INIT( A,B,AB,SUMB,SUMAB,AVGWT,STDEV,SUMA2B,IN)

      READ(5,10,END=999) IYEAR,IROAD,IVEH,ISTATE,IN
 10   FORMAT(I4,X,2A10,3A10,2A10,I5)
      READ(5,11) IFLAG
 11   FORMAT(I4)
      READ(5,100) ( B(I) , I = 1, IN)
 100   FORMAT(12F6.1)
C
```

```
C   DETERMINE IFLAG. IF IFLAG IS 6000, USED DATA IN AXLE(1,I)
C   IF IFLAG IS 9000 AND IYEAR IS LESS THAN 1959 USE DATA IN GVW(2,I)
C   IF IFLAG IS 9000 AND IYEAR IS GREATER THAN 1959 USE GVW(1,I)
C   IF IFLAG IS 3000 USE DATA IN AXLE(2,I)
C
      NHALF = IN / 2
      IF ( IFLAG .EQ. 3000 ) GO TO 3000
      IF ( IFLAG .EQ. 6000 ) GO TO 6000
      IF ((IFLAG.EQ.9000) .AND. (IYEAR.LE.1958)) GO TO 9002
      IF ((IFLAG.EQ.9000) .AND. (IYEAR.GT.1958)) GO TO 9001
C
C   TRANSFER VALUES FROM DATA DECLARED IN DATA ISTATEMENTS AND SUMS
C   ALL VALUES.
C
 3000 DO 12 I = 1,IN
          A(I) = AXLE(1,I)
      IF(IYEAR.LE.1975) WGTLIM = WGT1
      IF(IYEAR.GT.1975) WGTLIM = WGT2
  12  CONTINUE
C
C   CONTINUE PROCESSING UNTIL END OF FILE
C
      GO TO 1000
C
 6000 DO 13 I = 1, IN
          A(I) = AXLE(2,I)
      IF(IYEAR.LE.1975) WGTLIM = WGT1
      IF(IYEAR.GT.1975) WGTLIM = WGT2
 13   CONTINUE
C
C   CONTINUE PROCESSING UNTIL END OF INPUT DATA
C
      GO TO 1000
C
 9001 DO 14 I = 1, IN
          A(I) = GVW(1,I)
      IF(IYEAR.LE.1975) WGTLIM = WGT1
      IF(IYEAR.GT.1975) WGTLIM = WGT2
  14  CONTINUE
C
C   CONTINUE PROCESSING
C
      GO TO 1000
C
 9002 DO 15 I = 1, IN
          A(I) = GVW(2,I)
      IF(IYEAR.LE.1975) WGTLIM = WGT1
      IF(IYEAR.GT.1975) WGTLIM = WGT2
  15  CONTINUE
C
C
C   CONTINUE PROCESSING
C
      GO TO 1000
C
```

```
C      THIS PART OF THE PROGRAM CALCULATES MEANS AND STD. DEV.
C
C
 1000 AMIDPT = A (NHALF)
      SUMAB1 = 0.0
      DO 16 I=1, IN
      IF(I.EQ.1) A1(1) = A(1) / 2.0
      IF(I.NE.1) A1(I) = (A(I-1) + A(I)) / 2.0
      A2(I) = A1(I) - AMIDPT
      IF(A1(I).GT.WGTLIM) GO TO 16
      SUMB = SUMB + B(I)
      SUMAB1= SUMAB1 + A1(I) * B(I)
      SUMAB = SUMAB + A2(I) * B(I)
      SUMA2B = SUMA2B + A2(I) * A2(I) * B(I)
 16   CONTINUE
      AVGWT = SUMAB1 / SUMB
       STDEV = SQRT (( SUMA2B - SUMAB * SUMAB / SUMB)/(SUMB-1.))
C      PRINT THE OUTPUTS AND THEN PROCEED TILL END-OF-FILE
C
         CALL OUT ( A, B, AB, AVGWT, STDEV,IN, IYEAR, IROAD,
     +              IVEH, ISTATE, SUMB, SUMAB)
      GO TO 1
 999  STOP
      END

      SUBROUTINE INIT( A, B, AB, SUMB, SUMAB, AVGWT,STDEV,SUMA2B,IN)
      REAL A(1), B(1), AB(1), SUMB, SUMAB, AVGWT
      DIMENSION IROAD(2), IVEH(3), ISTATE(2)
C
C  THIS SUBROUTINE INITILIZE ALL VARIABLES USED IN PROGRAM.
C  ALL VARIABLES ARE SET TO 0.
C
      DO  1 I = 1, 30
         A(I)  = 0.0
         B(I)  = 0.0
         AB(I)  = 0.0
  1   CONTINUE
C
      IN = 0
      SUMB = 0
      SUMAB = 0
      SUMA2B = 0.0
      STDEV = 0.0
      AVGWT = 0
      RETURN
      END
C
C
C
C
C     THIS SUBROUTINE PRINTS THE HEADING FOR OUTPUT
C
      SUBROUTINE TITLE
      WRITE (6,10)
 10   FORMAT(*1*,//5X,*VEHICLE TYPE*,25X,*HWY SYSTEM*,12X,*STATE*,
```

```
     +21X,*YEAR*,8X,*AVERAGE*,6X,*STD DEV.*//)
      RETURN
      END


      SUBROUTINE OUT ( A, B, AB, AVGWT,STDEV, IN, IYEAR, IROAD,
     +                 IVEH, ISTATE, SUMB, SUMAB)
      REAL A(1),B(1),AB(1),SUMB,SUMAB,AVGWT
      INTEGER IN, IYEAR, IVEH(3), ISTATE(2), IROAD(2)
C
C     OUT PRINTS ALL PARAMETERS IN THE SUBROUTINE.
C

      WRITE(6,11) IVEH,IROAD,ISTATE,IYEAR,AVGWT,STDEV
 11   FORMAT(5X,3A10,5X,2A10,5X,2A10,5X,I4,5X,F10.4,F10.4)
      RETURN
      END
```

APPENDIX 2

SOURCE PROGRAM OF "SHIFTIN"—— A COMPUTERIZED SHIFTING PROCEDURE

```
      PROGRAM SHIFTIN (INPUT,OUTPUT,TTY,PLOT,TAPE5=INPUT,
     + TAPE6=OUTPUT,TAPE7=TTY)
C
C
C     THIS PROGRAM DOES THE TRUCK WEIGHT DISTRIBUTION SHIFTING
C     PROCEDURE.  THE SHIFTING METHODOLOGY WAS DEVELOPED BY
C     PAUL NG OF CENTER FOR TRANSPORTATION RESEARCH, UNDER THE
C     SUPERVISION OF DR.C.MICHAEL WALTON OF CIVIL ENGINEERING
C     DEPARTMENT, UNIVERSITY OF TEXAS AT AUSTIN.
C
C
C     FUNCTION OF THE PROGRAM:
C
C     THE PROGRAM READS IN TRUCK WEIGHT DISTRIBUTIONS FROM THE
C     W-4 AND W-5 TABLE
C     TABLES ARE THE SUMMARIES OF TRUCK WEIGHT DATA, WHICH WAS
C     COLLECTED BY WEIGHING STATIONS OR PORTABLE WEIGHT-IN-MOTION
C     WEIGHING MACHINES.  BY REGRESSION ANALYSIS, FUTURE AVERAGE
C     TRUCK WEIGHT WILL BE COMPUTED AND USED AS A PART OF THE
C     INPUT DATA.  BY VARIOUS REGRESSION METHODS, OPTIMIZATION,
C     COMPUTATION, AND DATA PROCESSING, PROGRAM /SHIFTIN/ WILL
C     PROJECT THE TRUCK WEIGHT DISTRIBUTION DATA FOR THE PRE-
C     DICTED YEAR(S).  THE OUTPUT WILL BE PRESENTED BOTH IN
C     TABLES AND CHARTS, AND GRAPHS.
C
C     THE FOLLOWING OUTPUTS WILL BE FURNISHED BY /SHIFTIN/
C
C        *1. RATIO CURVE OF THE INPUT TRUCK WEIGHT DATA
C        *2. REGRESSION OF LINEARIZED EQUATION FOR FITTING RATIO CURVE
C        *3. CHI-SQUARE TEST OF ITEM 2
C         4. OPTIMIZATION OF DIFFERENCE IN MEANS IN THE GUESSING PROCEDUR
C         5. NEW DISTRIBUTION CURVE (IN TERMS OF PERCENTAGE)
C         6. NEW DISTRIBUTION CURVE (IN TERMS OF WEIGHT DISTRIBUTION GROU
C
C     IN ADDITION TO THE HARDCOPY PRINT-OUT, /SHIFTIN/ ALSO PROVIDES
C     GRAPHICAL OUTPUTS:
C          *1. ACCUMULATED DISTRIBUTION CURVE
C          *2. HISTOGRAM SHOWING THE WEIGHT DISTRIBUTION
C
C
C     ITEMS MARKED WITH AN ARTERISK ARE THE OPTIONAL OUTPUTS.
C
C     PROGRAM /SHIFTIN/ HAS BEEN TESTED WITH TEXAS TRUCK WEIGHT
C     DATA.  THE RESULTS WERE THEN COMPARED WITH 1980 TRUCK
C     WEIGHT DATA, WHICH WAS NOT AVAILABLE AT THE TIME WHEN THE
C     PROGRAM WAS DEVELOPED.  THE GOODNESS OF FIT OF THE PROJECT-
C     ION WAS HIGHLY DESIRABLE.
C
C
C
C
C     ***************************************************************
C
C     DESCRIPTION OF THE SHIFTING METHODOLOGY
C
```

```
C       /SHIFTIN/ ALLOWS TWO CATEGORIES OF INPUT DATA, NAMELY,         SHI00560
C                                                                      SHI00570
C           1. RAW DATA --- (RAWDATA) , AND                            SHI00580
C           2. COEFFICIENTS --- (COEFFIC)                              SHI00590
C                                                                      SHI00600
C      THE FIRST OPTION, RAWDATA, PERFORMS ACCORDING TO THESE STEPS:   SHI00610
C                                                                      SHI00620
C      STEP I .                                                        SHI00630
C         SUBROUTINE /INDATA/ READS IN TWO YEARS OF TYPICAL TRUCK      SHI00640
C         WEIGHT DISTRIBUTION DATA.  THE DATA MAY HAVE ONE OF THE      SHI00650
C         FOLLOWING NATURES:                                           SHI00660
C                                                                      SHI00670
C            1.GROSS VEHICLE WEIGHT,                                   SHI00680
C            2.SINGLE AXLE WEIGHT, AND                                 SHI00690
C            3.TANDEM AXLE WEIGHT.                                     SHI00700
C         OTHER INFORMATION REQUIRED FOR THE EXECUTION OF /SHIFTIN/    SHI00710
C         IS AS FOLLOWING:                                             SHI00720
C            1. OPTIONS RELATED TO THE PRINTING                        SHI00730
C            2. AVERAGE TRUCK WEIGHT FOR THE PROJECTED YEAR            SHI00740
C            3. OPTIONS RELATED TO PLOTTING                            SHI00750
C                                                                      SHI00760
C         STEP II.                                                     SHI00770
C                                                                      SHI00780
C            SUBROUTINE /RATIO/ ANALYZES DATA. TRUCK WEIGHTS AT 5%     SHI00790
C            FREQUENCY INTERVALS WILL BE OBTAINED.  RATIOS OF THE      SHI00800
C            WEIGHTS OF TWO GIVEN YEARS WILL THEN BE COMPUTED.         SHI00810
C            THE OUTPUT ITEMS ARE :                                    SHI00820
C               1. ACCUMULATED FREQUENCIES AT 5 % INTERVALS            SHI00830
C               2. LATEST AVAILABLE TRUCK WEIGHT DATA                  SHI00840
C               3. BASE YEAR TRUCK WEIGHT DATA                         SHI00850
C               4. RATIO BETWEEN THE LAST TWO ITEMS                    SHI00860
C                                                                      SHI00870
C         STEP III                                                     SHI00880
C                                                                      SHI00890
C            SUBROUTINE /REGRESS/ USES THE LAST TWO OUTPUT ITEMS       SHI00900
C            ISSUED FROM STEP II AS THE PARAMETERS FOR REGRESSION      SHI00910
C            ANALYSIS.  THE LINEAR EQUATION USED IS:                   SHI00920
C                                                                      SHI00930
C               LN(RATIO) = LN (A) + B * LN (WGT2) + C * WGT2          SHI00940
C                                                                      SHI00950
C            NORMAL FORM OF THE ABOVE EQUATION IS GIVEN AS:            SHI00960
C                                                                      SHI00970
C                                                                      SHI00980
C               RATIO = A * (WGT2 ** B) * EXP( C * WGT2)               SHI00990
C                                                                      SHI01000
C            THE METHOD OF LEAST SQUARES IS USED IN THE LINEAR         SHI01010
C            REGRESSION ANALYSIS.                                      SHI01020
C            THE OUTPUT OF THIS STEP IS THE COEFFICIENTS A, B, AND C   SHI01030
C            FOR THE TWO GIVEN YEARS, I.E. THE LASTEST AVAILABE YEAR   SHI01040
C            AND THE BASE YEAR.  THESE COEFFICIENTS WILL BE TRANFERED  SHI01050
C            TO /OPTESL/, THE OPTIMIZATION PROGRAM, TO PROVIDE SOME    SHI01060
C            GENERAL GUIDELINES FOR SEARCHING NEW COEFFICIENTS.        SHI01070
C                                                                      SHI01080
C                                                                      SHI01090
C         THE FOLLOWING STEPS ARE COMMON TO *RAWDATA* AND *COEFFIC*     SHI01100
```

```
C                                                                       SHI01110
C        STEP IV                                                        SHI01120
C                                                                       SHI01130
C          TRANSFER BASE YEAR TRUCK WEIGHT DATA, WGT2'S, TO THE         SHI01140
C          OPTIMIZATION ROUTINE /OPTMSE/ FOR SEARCHING THE NEW          SHI01150
C          COEFFICIENTS A, B, AND C.                                    SHI01160
C                                                                       SHI01170
C        STEP V                                                         SHI01180
C                                                                       SHI01190
C          SET UPPER AND LOWER LIMITS FOR THE NEW A, B, AND C; THEN     SHI01200
C          TRANSFER THE LIMITS TO /OPTMSE/.                             SHI01210
C        STEP VI                                                        SHI01220
C                                                                       SHI01230
C          /OPTMSE/, WITH THE LIMITS AND GENERAL GUIDELINES, STARTS TO  SHI01240
C          SEARCH FOR THE NEW COEFFICIENTS.                             SHI01250
C     **************************************************                SHI01260
C                                                                       SHI01270
      COMMON /FLAGS/ IFLAG(10),NFLAGS                                   SHI01280
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW                              SHI01290
      COMMON /LIMITS/ AHIGH,ALOW,BHIGH,BLOW,CHIGH,CLOW                  SHI01300
      COMMON /VARIES/ WGTBASE(20),RAT(101)                              SHI01310
      COMMON /INDEX/ IVEH(3),IROAD(2),ISTATE(2),IFLG                    SHI01320
      COMMON /WGTLIM/ SUMWGT,EXPWGT,SUMVAR,EXPVAR,CPT                   SHI01330
      INTEGER COMMAND(2)                                                SHI01340
C     PROGRAM STARTS AT THIS POINT                                      SHI01350
C     READ INPUT DATA                                                   SHI01360
C                                                                       SHI01370
      CALL INPROG (COMMAND)                                             SHI01380
 3    NSTOP = 0                                                         SHI01390
C                                                                       SHI01400
C                                                                       SHI01410
C     DETERMINE WHICH STEP TO TAKE.....                                 SHI01420
C                                                                       SHI01430
      IF(COMMAND.EQ.'RAWDATA')                                          SHI01440
     +CALL RAWDATA                                                      SHI01450
 1    IF(COMMAND.EQ.'COEFFIC')                                          SHI01460
     +CALL COEFFS                                                       SHI01470
C                                                                       SHI01480
C     CHECK THE GOODNESS-OF-FIT OF EQUATION BY USING /CHISQ/ ROUTINE    SHI01490
C                                                                       SHI01500
C                                                                       SHI01510
      CALL XSQUARE(NSTOP)                                               SHI01520
C                                                                       SHI01530
C     THE NULL HYPOTHESIS:                                              SHI01540
C       HO: A,B, AND C ARE THE TRUE COEFFICIENTS FOR EQUATION           SHI01550
C           Y = A * (X ** B) * EXP (C * X)                              SHI01560
C                                                                       SHI01570
C     IF CALCULATED CHI-SQ VALUE IS TOO HIGH, REJECT THE NULL           SHI01580
C     HYPOTHESIS AND STOP PROCESSING                                    SHI01590
C                                                                       SHI01600
      IF(NSTOP.NE.0) WRITE (7,601)                                      SHI01610
      IF(NSTOP.NE.0) WRITE(6,601)                                       SHI01620
 601  FORMAT(*1*,//10X,*A,B,AND C ARE NOT THE TRUE COEFFICIENTS*/       SHI01630
     +10X,*OF THE EQUATION:*                                            SHI01640
     +10X,35HY = A * ( X ** B ) * EXP ( C * X )                         SHI01650
```

```
     +,)
      IF (NSTOP.NE.0) STOP
C     IF NULL HYPOTHESIS CANNOT BE REJECTED, PROCEED ON AND
C     OBTAIN THE COEFFICIENTS FOR THE FUTURE YEAR
C
C
      CALL OPTMSE
C
C     USE SUBROUTINE /CALWGT/ TO FIND THE EXPECTED VALUES
C
      CALL CALWGT
C
C     FIND THE EXPECTED S-CURVE AND THE PLOT THE CURVE
C
      CALL SCURVE
C
      IPLOT = 10
      DO 10 I=1,NFLAGS
      IF(IFLAG(I).EQ. 'NOPLO' ) IPLOT = 0
 10   CONTINUE
      IF( IPLOT.NE. 0) CALL SPLOT
C
C
      CALL CONCLUD
C
C
      IHIS = 10
      DO 11 I=1,NFLAGS
      IF(IFLAG(I).EQ.'NOHIS') IHIS=0
 11   CONTINUE
      IF(IHIS.NE.0) CALL HISTOGM
      WRITE(7,602)
 602  FORMAT(///10X,*TRUCK WEIGHT SHIFTING METHODOLOGY*
     +/10X,*PROGRAM /SHIFTIN/ VERSION 1*
     +/10X,*AUGUST 1, 1981*
     +/10X,*CIVIL ENGINEERING DEPARTMENT*
     +/10X,*THE UNIVERSITY OF TEXAS AT AUSTIN*//)
 999  STOP
      END
C
C
C*******************************************************
C
C        A SUBROUTINE STARTS AT THIS POINT
C
C*******************************************************
C
C
      SUBROUTINE RAWDATA
C
C
C
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW
      COMMON /LIMITS/ AHIGH,ALOW,BHIGH,BLOW,CHIGH,CLOW
      COMMON /TKWGT/ TKWGT(2,101),WGTPROJ(101)
```

```
      COMMON /VARIES/ WGTBASE(20),RAT(101)                              SHI02210
C                                                                       SHI02220
                                                                        SHI02230
C                                                                       SHI02240
C     THIS SUBROUTINE HANDLES RAW DATA ACCORDING TO STEP I - STEP IV    SHI02250
C                                                                       SHI02260
C     READ IN THE LATEST AVAILABLE TRUCK DATA AND THE DESIRABLE BASE    SHI02270
C     YEAR DATA                                                         SHI02280
C                                                                       SHI02290
C     STEP I - STEP II ARE OPERATED BY /RATIO/                          SHI02300
C     CALL SUBROUTINE /RATIO/                                           SHI02310
C                                                                       SHI02320
      CALL RATIO                                                        SHI02330
C                                                                       SHI02340
      DO 10 I=1,20                                                      SHI02350
      I5 = I * 5 + 1                                                    SHI02360
      WGTBASE(I) = TKWGT(2,I5)                                          SHI02370
 10   CONTINUE                                                          SHI02380
C                                                                       SHI02390
C     USE SUBROUTINE /REGRESS/ TO FIND THE RATIC CURVE                  SHI02400
C     FORM OF EQUATION:                                                 SHI02410
                                                                        SHI02420
C         RAT = A * (TKWGT2 ** B) * EXP (TKWGT *C)                      SHI02430
C                                                                       SHI02440
C         WHERE  A = X(1)                                               SHI02450
C                B = X(2)                                               SHI02460
C                C = X(3)                                               SHI02470
C                                                                       SHI02480
C     CALL /REGRESS/                                                    SHI02490
      CALL REGRESS                                                      SHI02500
C                                                                       SHI02510
C     SET UP LIMITS FOR A,B,AND C; THEN RETURN TO /SHIFTIN/             SHI02520
C                                                                       SHI02530
      AHIGH = 2.0 * A                                                   SHI02540
      ALOW  = 0.5 * A                                                   SHI02550
      BHIGH = 2.0 * B                                                   SHI02560
      BLOW = 0.5 * B                                                    SHI02570
      CHIGH = 2.0 * C                                                   SHI02580
      CLOW = 0.5 * C                                                    SHI02590
C                                                                       SHI02600
C                                                                       SHI02610
      RETURN                                                            SHI02620
      END                                                               SHI02630
C                                                                       SHI02640
C                                                                       SHI02650
C*******************************************************                SHI02660
C                                                                       SHI02670
C         A SUBROUTINE STARTS AT THIS POINT                             SHI02680
C                                                                       SHI02690
C*******************************************************                SHI02700
C                                                                       SHI02710
C                                                                       SHI02720
      SUBROUTINE COEFFS                                                 SHI02730
C     THIS SUBROUTINE HANDLES COEFFICIENTS AND WEIGHT DISRIBUTION       SHI02740
C     GROUP ACCORDING TO STEP V - STEP VI                               SHI02750
```

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FILE: SHIFTIN  FORTRAN  B                     VM/SP CONVERSATIONAL MONITOR SYSTEM

C                                                                       SHI02760
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW                              SHI02770
      COMMON /VARIES/ WGTBASE(20),RAT(101)                              SHI02780
      COMMON /FLAGS/ IFLAG(10),NFLAGS                                   SHI02790
      COMMON/INDEX/ IVEH(3),IROAD(2),ISTATE(2),IFLG                     SHI02800
      COMMON/LIMITS/ AHIGH,ALOW,BHIGH,BLOW,CHIGH,CLOW                   SHI02810
      DIMENSION IFMT(5)                                                 SHI02820
C                                                                       SHI02830
C     READ IN COEFFICIENTS A,B,C                                        SHI02840
      READ (5,100) A,B,C                                                SHI02850
  100 FORMAT(3F10.4)                                                    SHI02860
C     READ IN LABELS OF DATA--  E.G. TRUCK TYPE, HWY SYS, AND STATE.    SHI02870
C                                                                       SHI02880
      READ 101,IYEAR,IROAD,IVEH,ISTATE,NA                               SHI02890
  101 FORMAT(I4,X,2A10,3A10,2A10,I5)                                    SHI02900
C     READ IN THE READING FORMAT OF INPUT DATA                          SHI02910
      READ (5,102) IFMT                                                 SHI02920
  102 FORMAT(8A10)                                                      SHI02930
C     READ IN TRUCK DISTRIBUTION GROUPS                                 SHI02940
      READ(5,IFMT) (WGTBASE(I),I = 1,NA)                                SHI02950
C     SET UP LIMITS FOR A,B,C, AND THEN RETURN TO /SHIFTIN/             SHI02960
C                                                                       SHI02970
      AHIGH = 2.0 * A                                                   SHI02980
      ALOW = 0.5 * A                                                    SHI02990
      BHIGH = 2.0 * B                                                   SHI03000
      BLOW = 0.5 * B                                                    SHI03010
      CHIGH = 2.0 * C                                                   SHI03020
      CLOW = 0.5 * C                                                    SHI03030
C                                                                       SHI03040
C                                                                       SHI03050
      RETURN                                                            SHI03060
      END                                                               SHI03070
C                                                                       SHI03080
C                                                                       SHI03090
C******************************************************                 SHI03100
C                                                                       SHI03110
C        A SUBROUTINE STARTS AT THIS POINT                              SHI03120
C                                                                       SHI03130
C******************************************************                 SHI03140
C                                                                       SHI03150
C                                                                       SHI03160
C                                                                       SHI03170
C                                                                       SHI03180
C******************************************************                 SHI03190
      SUBROUTINE RATIO                                                  SHI03200
C                                                                       SHI03210
C                                                                       SHI03220
C     THIS PROGRAM IS MODIFIED TO HANDLE THE RATIOS IN A                SHI03230
C     FINER MANNER.  THAT IS, INSTEAD OF USING 5 PERCENT                SHI03240
C     INTERVALS, IT USES 1 PERCENT INTERVAL.  THE REASON                SHI03250
C     OF USING 1 PERCENT INTERVAL IS TO OBTAIN A MORE                   SHI03260
C     PRECISE REGRESSION ANALYSIS AND A BETTER SHAPE OF                 SHI03270
C     ACCUMULATED FREQUENCY CURVES.  DATA:JUNE 18 1981.                 SHI03280
C                                                                       SHI03290
C                                                                       SHI03300
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C     THIS PROJECT IS A PART OF THE DEVELOPMENT OF A NEW                SHI03310
C     SHIFTING PROCEDURE FOR THE TRUCK STUDY.  THE ACCOUNT              SHI03320
C     NUMBER OF THE PROJECT IS 241.                                     SHI03330
                                                                        SHI03340
C                                                                       SHI03350
C                                                                       SHI03360
      COMMON /FLAGS/  IFLAG(10),NFLAGS                                  SHI03370
      COMMON /BASIC/ WDIST(35),SAMSIZ(35),N,NGROUP                      SHI03380
      COMMON /TKWGT/ VALUE(2,101),WGTPROJ(101)                          SHI03390
      COMMON /VARIES/ WGTBASE(20),RAT(101)                              SHI03400
      COMMON /INDEX/ IVEH(3),IROAD(2),ISTATE(2),IFLG                    SHI03410
      DIMENSION YSUM(35),Y(35),ACFREQ(101)                              SHI03420
      DIMENSION GVW(2,35),AXLE(2,16)                                    SHI03430
      DIMENSION IYEAR(2), I1(2),I2(2),ILIGHT(2),IHEAVY(2)               SHI03440
      DATA (GVW(1,I),I=1,30)/4.,10.,13.5,20.,22.,24.,26.,28.,30.,32.,   SHI03450
     +34.,36.,38.,40.,45.,50.,55.,60.,65.,70.,72.,75.,80.,              SHI03460
     +85.,90.,95.,100.,105.,110.,115./                                  SHI03470
      DATA (GVW(2,I),I=1,26)/10.,12.,14.,16.,18.,20.,22.,24.,26.,28.,30.SHI03480
     +,35.,40.,45.,50.,55.,60.,65.,70.,75.,80.,85.,90.,95.,100.,105./   SHI03490
      DATA (AXLE(1,I),I=1,13)/3.,7.,8.,12.,16.,18.,18.5,20.,22.,24.,26.,SHI03500
     +30.,35./                                                          SHI03510
      DATA (AXLE(2,I),I=1,16)/6.,12.,18.,24.,30.,32.,32.5,34.,36.,38.,  SHI03520
     +40.,42.,44.,46.,50.,55./                                          SHI03530
      DO 999 K=1,2                                                      SHI03540
      READ 51,IYEAR(K),IROAD,IVEH,ISTATE,N                              SHI03550
      IF(IYEAR(K).LE.2000) I2(K)=IYEAR(K)                               SHI03560
      IF(IYEAR(K).LE.2000)  GO TO 4                                     SHI03570
      I1(K)=IYEAR(K)/100                                                SHI03580
      I2(K)=IYEAR(K)-(I1(K)*100)                                        SHI03590
      I1(K)=I1(K) + 1900                                                SHI03600
      I2(K)=I2(K) + 1900                                                SHI03610
      IF(I1(K).LE.1958.AND.I2(K).GT.1958) PRINT 900                     SHI03620
  900 FORMAT(*1*,10X,*THE DISTRIBUTION GROUPS DO NOT FIT*               SHI03630
     .* FOR THE INPUT DATA.  SORRY.*)                                   SHI03640
      IF(I1(K).LE.1958.AND.I2(K).GT.1958) GO TO 9999                    SHI03650
    4 READ 51,IFLG                                                      SHI03660
      IF(IFLG.EQ.3000) GO TO 601                                        SHI03670
      IF(IFLG.EQ.6000) GO TO 602                                        SHI03680
      IF(IFLG.EQ.9000) GO TO 603                                        SHI03690
      READ 52,(WDIST(I),I=1,N)                                          SHI03700
      GO TO 5                                                           SHI03710
  601 DO 610 I=1,13                                                     SHI03720
  610 WDIST(I) = AXLE(1,I)                                              SHI03730
      NGROUP = 13                                                       SHI03740
      GO TO 5                                                           SHI03750
  602 DO 612 I=1,16                                                     SHI03760
  612 WDIST(I) = AXLE(2,I)                                              SHI03770
      NGROUP = 16                                                       SHI03780
      GO TO 5                                                           SHI03790
  603 IF(IYEAR(K).LE.1958) GO TO 620                                    SHI03800
      DO 613 I=1,30                                                     SHI03810
      WDIST(I) = GVW(1,I)                                               SHI03820
  613 CONTINUE                                                          SHI03830
      NGROUP = 30                                                       SHI03840
      GO TO 5                                                           SHI03850
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  620 DO 614 I=1,26                                                     SHI03860
  614 WDIST(I) = GVW(2,I)                                               SHI03870
      NGROUP = 26                                                       SHI03880
    3 READ 52,(SAMSIZ(J),J=1,N)                                         SHI03890
      ILIGHT(K)=0                                                       SHI03900
      DO 60 I=1,N                                                       SHI03910
      IF(ILIGHT(K).NE.0) GO TO 65                                       SHI03920
      IF(SAMSIZ(I).GT.0.0) ILIGHT(K)=I                                  SHI03930
   65 IF(SAMSIZ(I).GT.0.0) IHEAVY(K)=I                                  SHI03940
   60 CONTINUE                                                          SHI03950
      SUMB=0.0                                                          SHI03960
      DO 10 I=1,N                                                       SHI03970
   10 SUMB=SUMB + SAMSIZ(I)                                             SHI03980
      DO 11 I=1,N                                                       SHI03990
      Y(I) = SAMSIZ(I)/SUMB * 100.0                                     SHI04000
   11 CONTINUE                                                          SHI04010
      YSUM(1) = Y(1)                                                    SHI04020
      DO 12 I=2,N                                                       SHI04030
   12 YSUM(I) = YSUM(I-1) + Y(I)                                        SHI04040
      M=1                                                               SHI04050
      CHECK = 0.00000001                                                SHI04060
      I=1                                                               SHI04070
   20 IF(M.EQ.2) CHECK=CHECK - 0.00000001                               SHI04080
      IF (CHECK.GT.100.1) GO TO 999                                     SHI04090
      IF(I.EQ.N) GO TO 41                                               SHI04100
      IF(YSUM(I) - CHECK ) 40,41,42                                     SHI04110
   40 I=I+1                                                             SHI04120
      GO TO 20                                                          SHI04130
   41 VALUE(K,M) = WDIST (I)                                            SHI04140
      M=M+1                                                             SHI04150
      CHECK = CHECK + 1.0                                               SHI04160
      GO TO 20                                                          SHI04170
   42 YSUMI1=0.0                                                        SHI04180
      IF(I.GT.1) YSUMI1=YSUM(I-1)                                       SHI04190
      IF(YSUM(I)-YSUMI1) 20,20,43                                       SHI04200
   43 AIM1=0.0                                                          SHI04210
      IF(I.GT.1) AIM1= WDIST(I-1)                                       SHI04220
      VALUE(K,M) =AIM1 + (CHECK - YSUMI1)/                              SHI04230
     .(YSUM(I) - YSUMI1) * (WDIST(I) - AIM1)                            SHI04240
      M=M+1                                                             SHI04250
      CHECK =CHECK + 1.0                                                SHI04260
      GO TO 20                                                          SHI04270
  999 CONTINUE                                                          SHI04280
      DO 30 I=2,101                                                     SHI04290
   30 RAT(I) = VALUE(1,I)/VALUE(2,I)                                    SHI04300
                                                                        SHI04310
      IRETURN = 0                                                       SHI04320
      DO 32 I=1,NFLAGS                                                  SHI04330
      IF(IFLAG(I).EQ.'NORAT') IRETURN = 999                             SHI04340
   32 CONTINUE                                                          SHI04350
      IF(IRETURN.NE.0) GO TO 9999                                       SHI04360
      PRINT 499                                                         SHI04370
  499 FORMAT(*1*,//10X,*MULTIPLIERS OF THE INPUT TRUCK *                SHI04380
     +*WEIGHT DATA*/,10X,42(*=*)/)                                      SHI04390
      PRINT 500,IVEH                                                    SHI04400
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      PRINT 500,IROAD                                                   SHI04410
      PRINT 500,ISTATE                                                  SHI04420
 500  FORMAT(15X,8A10)                                                  SHI04430
      DO 35 K=1,2                                                       SHI04440
      IF(IYEAR(K).GT.4000) PRINT 510,K,I1(K),I2(K)                      SHI04450
      IF(IYEAR(K).LT.2000) PRINT 515,K,IYEAR(K)                         SHI04460
 35   CONTINUE                                                          SHI04470
      IF(IFLG.EQ.9000) PRINT 520                                        SHI04480
 520  FORMAT(/,17X,*ACCUMULATED*,6X,*YEAR(1)*,7X,*YEAR(2)*,             SHI04490
     .4X,*YEAR(1)/YEAR(2)*/,17X,*FREQUENCY*,8X,*GVW (KIPS)*,            SHI04500
     .4X,*GVW (KIPS)*/)                                                 SHI04510
      IF(IFLG.EQ.3000) PRINT 518                                        SHI04520
 518  FORMAT(/,17X,*ACCUMULATED*,6X,*YEAR(1)*,7X,*YEAR(2)*,             SHI04530
     .4X,*YEAR(1)/YEAR(2)*/,17X,*FREQUENCY*,8X,*SAW (KIPS)*,            SHI04540
     .4X,*SAW (KIPS)*/)                                                 SHI04550
      IF(IFLG.EQ.6000) PRINT 519                                        SHI04560
 519  FORMAT(/,17X,*ACCUMULATED*,6X,*YEAR(1)*,7X,*YEAR(2)*,             SHI04570
     .4X,*YEAR(1)/YEAR(2)*/,17X,*FREQUENCY*,8X,*TAW (KIPS)*,            SHI04580
     .4X,*TAW (KIPS)*/)                                                 SHI04590
      ACFREQ(1) = 0.0                                                   SHI04600
      PRINT 400,ACFREQ(1),VALUE(1,1),VALUE(2,1)                         SHI04610
      DO 50 I=1,20                                                      SHI04620
      ACFREQ(I) = ACFREQ(I-1) + 5.0                                     SHI04630
      I5 = 1 + I * 5                                                    SHI04640
      PRINT 400,ACFREQ(I),VALUE(1,I5),VALUE(2,I5),RAT(I5)               SHI04650
 50   CONTINUE                                                          SHI04660
      IL1=ILIGHT(1)                                                     SHI04670
      IL2=ILIGHT(2)                                                     SHI04680
      IH1=IHEAVY(1)                                                     SHI04690
      IH2=IHEAVY(2)                                                     SHI04700
      A11=0.0                                                           SHI04710
      IF(IL1.NE.1) A11=WDIST(IL1-1)                                     SHI04720
      A21=0.0                                                           SHI04730
      IF(IL2.NE.1) A21=WDIST(IL2-1)                                     SHI04740
      PRINT 522,A11,WDIST(IL1),A21,WDIST(IL2)                           SHI04750
      PRINT 521,WDIST(IH1-1),WDIST(IH1),WDIST(IH2-1),WDIST(IH2)         SHI04760
 400  FORMAT(9X,3F15.4,6X,F8.2)                                         SHI04770
 51   FORMAT(I4,X,2A10,3A10,2A10,I5)                                    SHI04780
 52   FORMAT(12F6.1)                                                    SHI04790
 510  FORMAT(/15X,*YEAR (*,I2,* ) = *,I4,* - *, I4)                     SHI04800
 515  FORMAT(/15X,*YEAR (*,I2,* ) = *,I4)                               SHI04810
 522  FORMAT(/9X,*THE LIGHTEST TRUCK*/9X                                SHI04820
     .,*RECORDED IS IN THE *,/9X,                                       SHI04830
     .*DISTRIBUTION GROUP: *,F5.1,*-*,F5.1,                             SHI04840
     .3X,F5.1,*-*,F5.1/)                                                SHI04850
 521  FORMAT(/9X,*THE HEAVISET TRUCK*/9X,                               SHI04860
     .*RECORDED IS IN THE *,/9X,                                        SHI04870
     .*DISTRIBUTION GROUP: *,F5.1,*-*,F5.1,                             SHI04880
     .3X,F5.1,*-*,F5.1)                                                 SHI04890
 9999 RETURN                                                            SHI04900
      END                                                               SHI04910
C                                                                       SHI04920
C*************************************************************          SHI04930
C                                                                       SHI04940
C          A SUBROUTINE STARTS AT THIS POINT                            SHI04950
```

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C                                                                       SHI04960
C*******************************************************                 SHI04970
C                                                                       SHI04980
      SUBROUTINE REGRESS                                                SHI04990
C                                                                       SHI05000
C     THIS SUBROUTINE DOES THE REGRESSION ANALYSIS FOR THE              SHI05010
C     MATHEMATICAL MODEL.  THE METHOD OF LEAST SQUARES IS               SHI05020
      COMMON /VARIES/ X(20),Y(101)                                      SHI05030
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW                              SHI05040
C     EMPLOYED IN REGRESSING LINEAR EQUATIONS                           SHI05050
C                                                                       SHI05060
      DIMENSION XREG(20),YREG(20),TRANX(20)                             SHI05070
     +,TRANY(20),AMAT(3,3),BVEC(3),CVEC(3),AINV(3,3)                    SHI05080
      COMMON/FLAGS/ IFLAG(10),NFLAGS                                    SHI05090
C                                                                       SHI05100
C     SELECT DATA FOR ANALYSIS, FIND THE MEAN AND STANDARD DEVIATION    SHI05110
C     OF VARIABLES --- SET UP CRITERIA TO ACCEPT OF REJECT              SHI05120
C                                                                       SHI05130
      SUMY = 0.0                                                        SHI05140
C     SELECT THE MIDDLE PART OF DISTRIBUTION AND USE DATA IN THE        SHI05150
C     REGION TO COMPUTE MEAN AND S.D.                                   SHI05160
C                                                                       SHI05170
      DO 10 I=5,19                                                      SHI05180
      I5 = 1 + I * 5                                                    SHI05190
      XREG(I) = X(I)                                                    SHI05200
      YREG(I) = Y (I5)                                                  SHI05210
      SUMY = SUMY + YREG(I)                                             SHI05220
   10 CONTINUE                                                          SHI05230
C     COMPUTE MEAN                                                      SHI05240
      YBAR = SUMY / 15.0                                                SHI05250
C     COMPUTE STANDARD DEVIATION OF Y'S                                 SHI05260
C                                                                       SHI05270
      YSQSUM = 0.0                                                      SHI05280
      DO 11 I= 5,19                                                     SHI05290
      YSQSUM = YSQSUM + (YREG(I)  - YBAR ) ** 2.0                       SHI05300
   11 CONTINUE                                                          SHI05310
      SD = SQRT (YSQSUM / 14.00)                                        SHI05320
C     SET UP LIMITS FOR ACCEPTANCE, 90% CONDIDENCE INTERVALS            SHI05330
      TOP = YBAR + 1.96 * SD                                            SHI05340
      BOTTOM = YBAR - 1.96 * SD                                         SHI05350
C                                                                       SHI05360
C     REJECT YREG VALUES THAT ARE NOT IN THE 90% CONFIDENCE INTERVALS   SHI05370
      IKT = 0                                                           SHI05380
C     THIS DO LOOP REJECT/ACCEPT VARIABLES THAT ARE TO BE REGRESSED     SHI05390
C                                                                       SHI05400
      DO 12 I=1,20                                                      SHI05410
      I5 = 1 + I* 5                                                     SHI05420
      IF(Y(I5).GT.TOP.OR.Y(I5).LT.BOTTOM) GO TO 12                      SHI05430
      IKT = IKT + 1                                                     SHI05440
      XREG(IKT) = X(I)                                                  SHI05450
      YREG(IKT) = Y(I5)                                                 SHI05460
   12 CONTINUE                                                          SHI05470
C                                                                       SHI05480
C     USE LEAST SQUARE METHOD TO FIND A,B, AND C                        SHI05490
C     FORM OF EQUATION:                                                 SHI05500
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C        YREG = A * (XREG ** B) * EXP (C * XREG)                        SHI05510
C     LINEAR FORM OF THE EQUATION:                                      SHI05520
C                                                                       SHI05530
C        LN(YREG) = LN(A) + B * LN(XREG) + (C * XREG)                   SHI05540
C                                                                       SHI05550
C     THIS DO LOOP SETS UP NATURAL LOG VALUES OF YREG AND XREG          SHI05560
C                                                                       SHI05570
      DO 13 I = 1,IKT                                                   SHI05580
      TRANX(I) = ALOG (XREG(I))                                         SHI05590
      TRANY(I) = ALOG (YREG(I))                                         SHI05600
 13   CONTINUE                                                          SHI05610
C                                                                       SHI05620
C     THE TRANSFORMED EQUATION IS REPRESENTED AS:                       SHI05630
C           T = A + BX + CY                                             SHI05640
C                                                                       SHI05650
C           WHERE  T = TRANY                                            SHI05660
C                  X = TRANX                                            SHI05670
C                  Y = XREG                                             SHI05680
C                                                                       SHI05690
C     THIS PORTION OF THE ROUTINE INITIALIZES THE PARAMETERS            SHI05700
      CUMX = 0.0                                                        SHI05710
      CUMY = 0.0                                                        SHI05720
      CUMT = 0.0                                                        SHI05730
      CUMXSQ = 0.0                                                      SHI05740
      CUMXY = 0.0                                                       SHI05750
      CUMXT = 0.0                                                       SHI05760
      CUMYT = 0.0                                                       SHI05770
      CUMYSQ = 0.0                                                      SHI05780
      CUMTSQ = 0.0                                                      SHI05790
C                                                                       SHI05800
C     THESE DO LOOPS SET UP THE 3X3 MATRIX                              SHI05810
C                                                                       SHI05820
      DO 14 I=1,IKT                                                     SHI05830
      CUMT = CUMT + TRANY(I)                                            SHI05840
      CUMX = CUMX + TRANX(I)                                            SHI05850
      CUMY = CUMY + XREG(I)                                             SHI05860
      CUMXSQ = CUMXSQ + TRANX(I)   * TRANX(I)                           SHI05870
      CUMXY = CUMXY + TRANX(I) * XREG(I)                                SHI05880
      CUMXT = CUMXT + TRANX(I) * TRANY(I)                               SHI05890
      CUMYT = CUMYT + XREG(I) * TRANY(I)                                SHI05900
      CUMYSQ = CUMYSQ + XREG(I) * XREG(I)                               SHI05910
      CUMTSQ = CUMTSQ + TRANY(I)  * TRANY(I)                            SHI05920
 14   CONTINUE                                                          SHI05930
C                                                                       SHI05940
C     THIS PART OF ROUTINE SETS UP MATRIX AND VECTOR                    SHI05950
C                                                                       SHI05960
      AMAT(1,1)  = FLOAT(IKT)                                           SHI05970
      AMAT(1,2)  = CUMX                                                 SHI05980
      AMAT(1,3)  = CUMY                                                 SHI05990
      AMAT(2,1)  = CUMX                                                 SHI06000
      AMAT(2,2)  = CUMXSQ                                               SHI06010
      AMAT(2,3)  = CUMXY                                                SHI06020
      AMAT(3,1)  = CUMY                                                 SHI06030
      AMAT(3,2)  = CUMXY                                                SHI06040
      AMAT(3,3)  = CUMYSQ                                               SHI06050
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      CVEC (1) = CUMT                                                   SHI06060
      CVEC (2) = CUMXT                                                  SHI06070
      CVEC (3) = CUMYT                                                  SHI06080
C                                                                       SHI06090
C     CALL /MATINV/ TO FIND THE INVERSE OF MATRIX AMAT                  SHI06100
C                                                                       SHI06110
      CALL MATINV (AMAT,3,AINV)                                         SHI06120
C                                                                       SHI06130
C     FIND THE UNKNOWNS BY MATRIX MULTIPLICATION                        SHI06140
C                                                                       SHI06150
C         (BVEC) = [AINV] * (CVEC)                                      SHI06160
C                                                                       SHI06170
      CALL MATMUL (AINV,CVEC,BVEC)                                      SHI06180
C                                                                       SHI06190
C     EQUATE VALUES FOR A,B,C,AND THEN COMPUTE THE R-SQ VALUE           SHI06200
C                                                                       SHI06210
      A = EXP (BVEC(1))                                                 SHI06220
      B = BVEC(2)                                                       SHI06230
      C = BVEC(3)                                                       SHI06240
C                                                                       SHI06250
C     ********************                                              SHI06260
C                                                                       SHI06270
C     INSERT THE R-SQ EQUATION HERE                                     SHI06280
C                                                                       SHI06290
C     ********************                                              SHI06300
C                                                                       SHI06310
C     CHECK PRINTING OPTIONS AND ACT ACCORDINGLY                        SHI06320
C                                                                       SHI06330
      IREG = 0                                                          SHI06340
      DO 15 I = 1,NFLAGS                                                SHI06350
                                                                        SHI06360
      IF(IFLAG(I).EQ.'NOREG') IREG = 10                                 SHI06370
   15 CONTINUE                                                          SHI06380
      IF(IREG.EQ.0) CALL REGOUT(AMAT,BVEC,CVEC,AINV,RSQ)                SHI06390
      RETURN                                                            SHI06400
      END                                                               SHI06410
C                                                                       SHI06420
C                                                                       SHI06430
C*******************************************************                SHI06440
C                                                                       SHI06450
C         A SUBROUTINE STARTS AT THIS POINT                             SHI06460
C                                                                       SHI06470
C*******************************************************                SHI06480
C                                                                       SHI06490
C                                                                       SHI06500
      SUBROUTINE REGOUT (AMAT,BVEC,CVEC,AINV,RSQ)                       SHI06510
C                                                                       SHI06520
C     THIS SUBROUTINE PRINTS OUTPUT FROM /REGRESS/                      SHI06530
C                                                                       SHI06540
      DIMENSION AMAT(3,3),BVEC(3),CVEC(3),AINV(3,3)                     SHI06550
C                                                                       SHI06560
      PRINT 100                                                         SHI06570
  100 FORMAT(*1*,//10X,*REGRESSION ANALYSIS TO FIT MULTIPLIERS *,       SHI06580
     +*INTO AN EQUATION*/,10X,55(*=*),//)                               SHI06590
      PRINT 101                                                         SHI06600
```

```
 101  FORMAT(10X,* A - MATRIX [ 3 X 3 ]*/)                                  SHI06610
      DO 10 I=1,3                                                          SHI06620
      PRINT 102,(AMAT(I,J),J=1,3)                                          SHI06630
 102  FORMAT(10X,3F15.2)                                                   SHI06640
 10   CONTINUE                                                             SHI06650
      PRINT 103                                                            SHI06660
 103  FORMAT(/10X,*INVERSE  OF MATRIX A [3X3]*/)                           SHI06670
      DO 11 I = 1,3                                                        SHI06680
      PRINT 102, (AINV(I,J),J=1,3)                                         SHI06690
 11   CONTINUE                                                             SHI06700
      PRINT 104                                                            SHI06710
 104  FORMAT(/10X,* C- VECTOR*)                                            SHI06720
      DO 12 I = 1, 3                                                       SHI06730
      PRINT 102,CVEC(I)                                                    SHI06740
 12   CONTINUE                                                             SHI06750
      PRINT 105                                                            SHI06760
 105  FORMAT(/10X,*FORM OF MATRIX MULTIPLICATION*/,10X,29(*-*),            SHI06770
     +/10X,*[AINV](CVEC) = (BVEC)*//                                       SHI06780
     +,10X,*B-VECTOR (COEFFICIENTS A,B,AND C)*//)                          SHI06790
      PRINT 106,(BVEC(I),I=1,3)                                            SHI06800
 106  FORMAT(10X,*LN(A) = *,F10.4/14X,*B = *,F10.4,/14X,*C = *,            SHI06810
     +F10.4//)                                                             SHI06820
      RETURN                                                               SHI06830
      END                                                                  SHI06840
C                                                                          SHI06850
C                                                                          SHI06860
C*******************************************************                   SHI06870
C                                                                          SHI06880
C         A SUBROUTINE STARTS AT THIS POINT                                SHI06890
C                                                                          SHI06900
C*******************************************************                   SHI06910
C                                                                          SHI06920
C                                                                          SHI06930
      SUBROUTINE OPTMSE                                                    SHI06940
      COMMON /ONE/  X,Y,S,FX,FY,N,KOUNTS,LIN,NDRV,H,SIG,DELG               SHI06950
      DIMENSION     X(10),Y(10),S(10),SIG(10),DELG(10),H(10,10)            SHI06960
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW                                 SHI06970
      COMMON /WGTLIM/ SUMWGT,EXPWGT,SUMVAR,EXPVAR,CPT                      SHI06980
      COMMON /VARIES/ WGTBASE(20),RAT(101)                                 SHI06990
      COMMON /LIMITS/ AHIGH,ALOW,BHIGH,BLOW,CHIGH,CLOW                     SHI07000
C.....OPTIMIZATION BY THE POWELL METHOD.....                                SHI07010
C *** NDRV IS A REDUNDANT PARAMETER WITHIN THE POWELL METHOD               SHI07020
      KOUNTS=0                                                             SHI07030
      ICONVG=2                                                             SHI07040
      STEP=1.0                                                             SHI07050
      LIN=0                                                                SHI07060
      X(1) = A                                                             SHI07070
      X(2) = B                                                             SHI07080
      X(3) = C                                                             SHI07090
      PRINT 509                                                            SHI07100
 509  FORMAT(*1*/,10X,*RESULTS OBTAINED FROM THE POWELL METHOD*/           SHI07110
     +,10X,39(*=*)//)                                                      SHI07120
      CALL SECOND(A1)                                                      SHI07130
      CALL POWELL(STEP,ICONVG)                                             SHI07140
      ANEW = X(1)                                                          SHI07150
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      BNEW = X (2)                                                      SHI07160
      CNEW = X (3)                                                      SHI07170
      CALL SECOND(A2)                                                   SHI07180
      PRINT 600,A1                                                      SHI07190
      PRINT 601,KOUNTS,LIN,FX,(X(I),I=1,N)                              SHI07200
      PRINT 602,A2                                                      SHI07210
      PRINT 30, X(1),X(2),X(3),SUMWGT,SUMVAR                            SHI07220
 30   FORMAT(///10X,*COEFFICIENTS OF THE EQUATION*//20X,                SHI07230
     +* A = *,F10.4,/20X,* B = *,F10.4,/20X,* C = *,F10.4,              SHI07240
     +//20X,*AVERAGE WEIGHT = *,F10.4/,20X,*VARIANCE = *,F10.4//)       SHI07250
  600 FORMAT(14H TIME IS NOW =,F20.3)                                   SHI07260
  601 FORMAT (/// I10,48H FUNCTION EVALUATIONS WITHIN POWELL ROUTINE ANDSHI07270
     1 ,/        I10,47H FUNCTION EVALUATIONS DURING THE LINE SEARCHES. SHI07280
     2       //     18H FUNCTION VALUE = ,E20.8                         SHI07290
     3       //     18H VARIABLE VALUES:- / (X,5E20.8 ))                SHI07300
  602 FORMAT(/// 14H TIME IS NOW = , F20.8)                             SHI07310
      RETURN                                                            SHI07320
      END                                                               SHI07330
C                                                                       SHI07340
C*********************************************************              SHI07350
C                                                                       SHI07360
C        A SUBROUTINE STARTS AT THIS POINT                              SHI07370
C                                                                       SHI07380
C*********************************************************              SHI07390
C                                                                       SHI07400
      SUBROUTINE POWELL (STEP,ICONVG)                                   SHI07410
      COMMON /ONE/  X,Y,S,FX,FY,N,KOUNT,LIN,NDRV,DIRECT,BEFORE,FIRST    SHI07420
      DIMENSION     X(10),Y(10),S(10),DIRECT(10,10),BEFORE(10),FIRST(10)SHI07430
     1              ,W(10),SECND(10)                                    SHI07440
      EQUIVALENCE    (W,SECND)                                          SHI07450
C *** N = THE NUMBER OF VARIABLES.                                      SHI07460
C     KOUNT = THE NUMBER OF FUNCTIONS EVALUATIONS NOT IN LINEAR SEARCH. SHI07470
C     ICONVG = THE FINAL CONVERGENCE TEST DESIRED.                      SHI07480
C            = 1, TERMINATE AS SOON AS TESTING IS SATISFIED.            SHI07490
C            = 2, AS SOON AS THE TESTING CRITERIA ARE SATISFIED INCREASESHI07500
C                 ALL THE VARIABLES BY 10*ACC AND SOLVE PROBLEM AGAIN.  SHI07510
C     THEN PERFORM A LINE SEARCH BETWEEN THE SOLUTIONS IF DIFFERENT     SHI07520
C     SOLUTIONS ARE DEEMED TO BE FOUND.                                 SHI07530
C     STEP = THE INITIAL STEP SIZE.                                     SHI07540
C     ACC = THE REQUIRED ACCURACY IN THE FUNCTION AND VECTOR VALUES.    SHI07550
C     INSERT IPRINT= 1 FOR COMPLETE PRINT OUT OR IPRINT = 2 FINAL       SHI07560
C    1ANSWER ONLY                                                       SHI07570
      ACC = .0001                                                       SHI07580
      IPRINT=1                                                          SHI07590
      NTRY=1                                                            SHI07600
      N1=N-1                                                            SHI07610
      STEPA=STEP                                                        SHI07620
C *** SET UP THE INITIAL DIRECTION MATRIX (USING UNIT VECTORS).         SHI07630
      DO 2  I=1,N                                                       SHI07640
      DO 1  J=1,N                                                       SHI07650
    1 DIRECT(J,I)=0.                                                    SHI07660
    2 DIRECT(I,I)=1.                                                    SHI07670
C *** EVALUATED THE FUNCTION AT THE INITIAL VARIABLE VALUES.            SHI07680
   30 CALL FUN(X,FX)                                                    SHI07690
      KOUNT=KOUNT+1                                                     SHI07700
```

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C *** SAVE THE FINAL FUNCTION VALUE (F1) AND THE FINAL VARIABLE VALUES  SHI07710
C     (BEFORE) FROM THE PREVIOUS CYCLE.                                 SHI07720
      PRINT 36                                                          SHI07730
   36 FORMAT(8X,*FX*,12X,*X(1)*,14X,*X(2)*,12X,*X(3)*/)                 SHI07740
    3 F1=FX                                                             SHI07750
      DO 4  I=1,N                                                       SHI07760
    4 BEFORE(I)=X(I)                                                    SHI07770
      GO TO (801,802), IPRINT                                           SHI07780
  801 PRINT 901,FX,(X(I),I=1,N)                                         SHI07790
  901 FORMAT (/(5E16.8))                                                SHI07800
C *** START SEARCHING HERE.                                             SHI07810
  802 SUM=0.                                                            SHI07820
C     AT THE END OF THE CYCLE, SUM WILL CONTAIN THE MAXIMUM CHANGE IN   SHI07830
C     THE FUNCTION VALUE FOR ANY SEARCH DIRECTION, AND ISAVE INDICATES  SHI07840
C     THE DIRECTION VECTOR TO WHICH IT CORRESPONDS.                     SHI07850
      DO 9  I=1,N                                                       SHI07860
C     S CONTAINS THE INITIAL STEP SIZES IN THE I-TH DIRECTION.          SHI07870
      DO 5  J=1,N                                                       SHI07880
    5 S(J)=DIRECT(J,I)*STEP                                             SHI07890
C     FIND THE MINIMUM IN THE I-TH DIRECTION, AND THE CHANGE IN FUNCTIONSHI07900
C     VALUE.                                                            SHI07910
      CALL COGGIN                                                       SHI07920
      A=FX-FY                                                           SHI07930
      IF(A-SUM) 7,7,6                                                   SHI07940
    6 ISAVE=I                                                           SHI07950
      SUM=A                                                             SHI07960
C     TRANSFER THE NEW FUNCTION AND VARIABLE VALUES TO FX AND X.        SHI07970
    7 DO 8  J=1,N                                                       SHI07980
    8 X(J)=Y(J)                                                         SHI07990
    9 FX=FY                                                             SHI08000
C *** NOW INVESTIGATE WHETHER A NEW SEARCH DIRECTION SHOULD BE INCORPOR-SHI08010
C     ATED INSTEAD OF THE ISAVE DIRECTION.                              SHI08020
      F2=FX                                                             SHI08030
      DO 10  I=1,N                                                      SHI08040
   10 W(I)=2.0*X(I)-BEFORE(I)                                           SHI08050
      CALL FUN(W,F3)                                                    SHI08060
      KOUNT=KOUNT+1                                                     SHI08070
      A=F3-F1                                                           SHI08080
      IF(A) 11,19,19                                                    SHI08090
   11 A=2.0*(F1-2.0*F2+F3)*((F1-F2-SUM)/A)**2                           SHI08100
      IF(A-SUM) 12,19,19                                                SHI08110
C *** A NEW SEARCH DIRECTION IS REQUIRED. FIRST REMOVE ROW ISAVE.       SHI08120
   12 IF(ISAVE-N) 13,15,15                                              SHI08130
   13 DO 14  I=ISAVE,N1                                                 SHI08140
      II=I+1                                                            SHI08150
      DO 14  J=1,N                                                      SHI08160
   14 DIRECT(J,I)=DIRECT(J,II)                                          SHI08170
C     SET THE N-TH DIRECTION VECTOR EQUAL TO THE NORMALISED DIFFERENCE  SHI08180
C     BETWEEN THE INITIAL AND FINAL VARIABLE VALUES FOR LAST CYCLE.     SHI08190
   15 A=0.                                                              SHI08200
      DO 16  J=1,N                                                      SHI08210
      DIRECT(J,N)=X(J)-BEFORE(J)                                        SHI08220
   16 A=DIRECT(J,N)**2+A                                                SHI08230
      A=1.0/SQRT(A)                                                     SHI08240
      DO 17  J=1,N                                                      SHI08250
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FILE: SHIFIN   FORTRAN  B                VM/SP CONVERSATIONAL MONITOR SYSTEM

      DIRECT(J,N)=DIRECT(J,N)*A                                         SHI08260
   17 S(J)=DIRECT(J,N)*STEP                                             SHI08270
      CALL COGGIN                                                       SHI08280
      FX=FY                                                             SHI08290
      DO 18  I=1,N                                                      SHI08300
   18 X(I)=Y(I)                                                         SHI08310
C *** TEST FOR CONVERGENCE.                                             SHI08320
   19 CALL TEST(F1,FX,BEFORE,X,FLAG,N,ACC)                              SHI08330
      IF(FLAG)  22,22,20                                                SHI08340
C *** CONVERGENCE NOT YET ACHEIVED. COMPUTE A NEW STEP SIZE AND         SHI08350
C     GO BACK TO 3.                                                     SHI08360
   20 IF(F1-FX) 121,120,120                                             SHI08370
  121 STEP=-0.4*SQRT(ABS(F1-FX))                                        SHI08380
      GO TO 123                                                         SHI08390
  120 STEP=0.4*SQRT(F1-FX)                                              SHI08400
  123 IF(STEPA-STEP)  21,3,3                                            SHI08410
   21 STEP=STEPA                                                        SHI08420
      GO TO 3                                                           SHI08430
C *** CONVERGENCE ACHEIVED. IF ICONVG=2, INCREASE ALL VARIABLES BY      SHI08440
C     10*ACC AND GO BACK TO 3.                                          SHI08450
   22 GO TO (23,24),ICONVG                                              SHI08460
   23 RETURN                                                            SHI08470
   24 GO TO (25,27),NTRY                                                SHI08480
   25 NTRY=2                                                            SHI08490
      DO 26  I=1,N                                                      SHI08500
      FIRST(I)=X(I)                                                     SHI08510
   26 X(I)=X(I)+ACC*10.                                                 SHI08520
      FFIRST=FX                                                         SHI08530
      GO TO 100                                                         SHI08540
C *** CONVERGENCE ATTAINED USING TWO DIFFERENT STARTING POINTS. CONSTRUCSHI08550
C     UNIT VECTOR BETWEEN SOLUTIONS AND SEARCH DIRECTION FOR A MINIMUM. SHI08560
   27 FSECND=FX                                                         SHI08570
      A=0.                                                              SHI08580
      DO 28  I=1,N                                                      SHI08590
      SECND(I)=X(I)                                                     SHI08600
      S(I)=FIRST(I)-SECND(I)                                            SHI08610
   28 A=A+S(I)**2                                                       SHI08620
      IF(A)  23,23,29                                                   SHI08630
   29 A=STEP/SQRT(A)                                                    SHI08640
      DO 30  I=1,N                                                      SHI08650
   30 S(I)=S(I)*A                                                       SHI08660
      CALL COGGIN                                                       SHI08670
C *** TEST IF NEW POINT IS SUFFICIENTLY CLOSE TO EITHER OF THE TWO      SHI08680
C     SOLUTIONS. IF SO RETURN.                                          SHI08690
      CALL TEST(FFIRST,FY,FIRST,Y,FLAG,N,ACC)                           SHI08700
      IF(FLAG)  32,32,31                                                SHI08710
   31 CALL TEST(FSECND,FY,SECND,Y,FLAG,N,ACC)                           SHI08720
      IF(FLAG)  32,32,34                                                SHI08730
   32 DO 33  I=1,N                                                      SHI08740
   33 X(I)=Y(I)                                                         SHI08750
      FX=FY                                                             SHI08760
      RETURN                                                            SHI08770
C *** FINAL SOLUTION NOT ACCURATE ENOUGH.  REPLACE THE FIRST DIRECTION  SHI08780
C     VECTOR BY INTER-SOLUTION VECTOR (NORMALISED) AND RECYCLE          SHI08790
   34 A=A/STEP                                                          SHI08800
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      DO 35  I=1,N                                                      SHI08810
      DIRECT(I,1)=(FIRST(I)-SECND(I))*A                                 SHI08820
   35 FIRST(I)=SECND(I)                                                 SHI08830
      GO TO 3                                                           SHI08840
      END                                                               SHI08850
      SUBROUTINE TEST(FI,FF,RI,RF,FLAG,N,ACC)                           SHI08860
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW                              SHI08870
      DIMENSION  RI(10),RF(10)                                          SHI08880
      FLAG=+2.                                                          SHI08890
      IF(ABS(FI)-ACC) 2,2,1                                             SHI08900
    1 IF(ABS((FI-FF)/FI)-ACC) 3,3,7                                     SHI08910
    2 IF(ABS(FI-FF)-ACC) 3,3,7                                          SHI08920
    3 DO 6  I=1,N                                                       SHI08930
      IF(ABS(RI(I))-ACC) 5,5,4                                          SHI08940
    4 IF(ABS((RI(I)-RF(I))/RI(I))-ACC) 6,6,7                            SHI08950
    5 IF(ABS(RI(I)-RF(I))-ACC) 6,6,7                                    SHI08960
    6 CONTINUE                                                          SHI08970
      FLAG=-2.                                                          SHI08980
    7 RETURN                                                            SHI08990
      END                                                               SHI09000
C                                                                       SHI09010
C*******************************************************                 SHI09020
C                                                                       SHI09030
C         A SUBROUTINE STARTS AT THIS POINT                             SHI09040
C                                                                       SHI09050
C*******************************************************                 SHI09060
C                                                                       SHI09070
      SUBROUTINE COGGIN                                                 SHI09080
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW                              SHI09090
      COMMON /ONE/  X,Y,S,FX,FY,N,KOUNTS,LIN,NDRV,H,SIG,DELG            SHI09100
      DIMENSION     X(10),Y(10),S(10),SIG(10),DELG(10),H(10,10)         SHI09110
C *** THE INITIAL VARIABLE VALUES ARE IN X, AND THE CORRESPONDING       SHI09120
C *** FUNCTION VALUE IS FX.                                             SHI09130
C *** THE SEARCH DIRECTION VECTOR IS S, AND THE INITIAL STEP SIZE STEP. SHI09140
C *** LIN IS USED TO COUNT THE NUMBER OF FUNCTION EVALUATIONS AND N IS  SHI09150
C *** THE NUMBER OF VARIABLES.                                          SHI09160
      FA=FB=FC=FX                                                       SHI09170
      DA=DB=DC=0.                                                       SHI09180
      STEP=1.0                                                          SHI09190
      D=STEP                                                            SHI09200
      K=-2                                                              SHI09210
      M=0                                                               SHI09220
C *** START THE SEARCH THE BOUND THE MINIMUM                            SHI09230
    1 DO 2  I=1,N                                                       SHI09240
    2 Y(I)=X(I)+D*S(I)                                                  SHI09250
      CALL FUN(Y,F)                                                     SHI09260
      K=K+1                                                             SHI09270
      LIN=LIN+1                                                         SHI09280
      IF(F-FA) 5,3,6                                                    SHI09290
C *** NO CHANGE IN FUNCTION VALUE.  RETURN WITH VECTOR CORRESPONDING TO SHI09300
C     FUNCTION VALUE OF FA, BECAUSE IF THE FUNCTION VALUE IS INDEPENDENTSHI09310
C     OF THIS SEARCH DIRECTION, THEN CHANGES IN THE VARIABLE VALUES MAY SHI09320
C     UPSET THE MAIN PROGRAM CONVERGENCE TESTING.                       SHI09330
    3 DO 4  I=1,N                                                       SHI09340
    4 Y(I)=X(I)+DA*S(I)                                                 SHI09350
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      FY=FA                                                             SHI09360
      RETURN                                                            SHI09370
C *** THE FUNCTION IS STILL DECREASING.  INCREASE THE STEP SIZE BY      SHI09380
C     DOUBLE THE PREVIOUS INCREASE IN STEP SIZE.                        SHI09390
    5 FC=FB  $  FB=FA  $  FA=F                                          SHI09400
      DC=DB  $  DB=DA  $  DA=D                                          SHI09410
      D=2.0*D+STEP                                                      SHI09420
      GO TO 1                                                           SHI09430
C *** MINIMUM IS BOUNDED IN AT LEAST ONE DIRECTION.                     SHI09440
    6 IF (K) 7,8,9                                                      SHI09450
C     MINIMUM IS BOUNDED IN ONE DIRECTION ONLY.  REVERSE THE SEARCH     SHI09460
C     DIRECTION AND RECYCLE.                                            SHI09470
    7 FB=F                                                              SHI09480
      DB=D  $  D=-D  $  STEP=-STEP                                      SHI09490
      GO TO 1                                                           SHI09500
C     MINIMUM IS BOUNDED IN BOTH DIRECTIONS AFTER ONLY TWO FUNCTION     SHI09510
C     EVALUATIONS [ONE EITHER SIDE OF THE ORIGIN].  PROCEED TO THE      SHI09520
C     PARABOLIC INTERPOLATION.                                          SHI09530
    8 FC=FB  $  FB=FA  $  FA=F                                          SHI09540
      DC=DB  $  DB=DA  $  DA=D                                          SHI09550
      GO TO 21                                                          SHI09560
C     THE MINIMUM IS BOUNDED AFTER AT LEAST TWO FUNCTION EVALUATIONS IN SHI09570
C     THE SAME DIRECTION.  EVALUATE THE FUNCTION AT STEP SIZE=(DA+DB)/2.SHI09580
C     THIS WILL YEILD 4 EQUALLY SPACED POINTS BOUNDING THE MINIMUM.     SHI09590
    9 DC=DB  $  DB=DA  $  DA=D                                          SHI09600
      FC=FB  $  FB=FA  $  FA=F                                          SHI09610
   10 D=0.5*(DA+DB)                                                     SHI09620
      DO 11  I=1,N                                                      SHI09630
   11 Y(I)=X(I)+D*S(I)                                                  SHI09640
      CALL FUN(Y,F)                                                     SHI09650
      LIN=LIN+1                                                         SHI09660
C *** NOW HAVE THAT  FA>FB<FC  AND THAT  FA>F<FC  ASSUMING THAT THE     SHI09670
C     FUNCTION IS UNIMODAL.  REMOVE EITHER POINT A OR POINT B IN SUCH A SHI09680
C     WAY THAT THE FUNCTION IS BOUNDED AND  FA>FB<FC  [THE CORRESPONDINGSHI09690
C     STEP SIZES ARE  DA>DB>DC  OR  DA<DB<DC  ].                        SHI09700
   12 IF ((DC-D)*(D-DB)) 15,13,18                                       SHI09710
C *** LOCATION OF MINIMUM IS LIMITED BY ROUNDING ERRORS. RETURN WITH B. SHI09720
   13 DO 14  I=1,N                                                      SHI09730
   14 Y(I)=X(I)+DB*S(I)                                                 SHI09740
      FY=FB                                                             SHI09750
      RETURN                                                            SHI09760
C *** THE POINT D IS IN THE RANGE DA TO DB.                             SHI09770
   15 IF(F-FB) 16,13,17                                                 SHI09780
   16 FC=FB  $  FB=F                                                    SHI09790
      DC=DB  $  DB=D                                                    SHI09800
      GO TO 21                                                          SHI09810
   17 FA=F                                                              SHI09820
      DA=D                                                              SHI09830
      GO TO 21                                                          SHI09840
C *** THE POINT D IS IN THE RANGE DB TO DC                              SHI09850
   18 IF(F-FB) 19,13,20                                                 SHI09860
   19 FA=FB  $  FB=F                                                    SHI09870
      DA=DB  $  DB=D                                                    SHI09880
      GO TO 21                                                          SHI09890
   20 FC=F                                                              SHI09900
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      DC=D                                                              SHI09910
C *** NOW PERFORM THE PARABOLIC INTERPOLATION.                          SHI09920
   21 A=FA*(DB-DC)+FB*(DC-DA)+FC*(DA-DB)                                SHI09930
      IF(A) 22,30,22                                                    SHI09940
   22 D=0.5*((DB*DB-DC*DC)*FA+(DC*DC-DA*DA)*FB+(DA*DA-DB*DB)*FC)/A      SHI09950
C     CHECK THAT THE POINT IS GOOD. IF SO, EVALUATE THE FUNCTION.       SHI09960
      IF((DA-D)*(D-DC)) 13,13,23                                        SHI09970
   23 DO 24  I=1,N                                                      SHI09980
   24 Y(I)=X(I)+D*S(I)                                                  SHI09990
      CALL FUN(Y,F)                                                     SHI10000
      LIN=LIN+1                                                         SHI10010
C *** CHECK FOR CONVERGENCE.  IF NOT ACHEIVED, RECYCLE.                 SHI10020
      IF(ABS(FB)-0.00001) 25,25,26                                      SHI10030
   25 A=1.0  $  GO TO 27                                                SHI10040
   26 A=1.0/FB                                                          SHI10050
   27 IF(ABS((FB-F)*A)-.0001) 28,28,12                                  SHI10060
C *** CONVERGENCE ACHEIVED.  RETURN WITH THE SMALLER OF F AND FB.       SHI10070
   28 IF(F-FB) 29,13,13                                                 SHI10080
   29 FY=F                                                              SHI10090
      RETURN                                                            SHI10100
C *** THE PARABOLIC INTERPOLATION WAS PREVENTED BY THE DIVISOR BEING    SHI10110
C     ZERO.  IF THIS IS THE FIRST TIME THAT IT HAS HAPPENED, TRY AN     SHI10120
C     INTERMEDIATE STEP SIZE AND RECYCLE; OTHERWISE GIVE UP AS IT LOOKS SHI10130
C     LIKE A LOST CAUSE.                                                SHI10140
   30 IF(M) 31,31,13                                                    SHI10150
   31 M=M+1                                                             SHI10160
      GO TO 10                                                          SHI10170
      END                                                               SHI10180
      BLOCK DATA                                                        SHI10190
      COMMON /ONE/  X,Y,S,FX,FY,N,KOUNTS,LIN,NDRV,H,SIG,DELG            SHI10200
      DIMENSION      X(10),Y(10),S(10),SIG(10),DELG(10),H(10,10)        SHI10210
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW                              SHI10220
      DATA N /3/                                                        SHI10230
      END                                                               SHI10240
C                                                                       SHI10250
C*******************************************************                SHI10260
C                                                                       SHI10270
C         A SUBROUTINE STARTS AT THIS POINT                             SHI10280
C                                                                       SHI10290
C*******************************************************                SHI10300
C                                                                       SHI10310
      SUBROUTINE FUN(X,FX)                                              SHI10320
      DIMENSION X(10)                                                   SHI10330
C     THIS SUBROUTINE PROVIDE THE EQUATION AND RESTRAINTS               SHI10340
C     FOR THE MAIN PROGRAM.  THE EQUATION IS                            SHI10350
C                                                                       SHI10360
C                                                                       SHI10370
C              Y = A * X ** B * EXP ( C * X )                           SHI10380
C                                                                       SHI10390
C                                                                       SHI10400
C                 X(1)  =  A                                            SHI10410
C                 X(2)  =  B                                            SHI10420
C                 X(3)  =  C                                            SHI10430
C                                                                       SHI10440
C                                                                       SHI10450
```

```
      COMMON /WGTLIM/ SUMWGT,EXPWGT,SUMVAR,EXPVAR,CPT                   SHI10460
      COMMON /VARIES/ WGTBASE(20),RAT(101)                              SHI10470
      COMMON /PLOTD/ ACCFR(35),B(35)                                    SHI10480
      COMMON /BASIC/ A(35),SAMSIZ(35),NA,NGROUP                         SHI10490
      COMMON /PASS/ NPASS                                               SHI10500
      DIMENSION A1(35),A2(35),FACT(101)                                 SHI10510
      COMMON /TKWGT/ TKWGT(2,101),WGTPROJ(101)                          SHI10520
      IFLG = 0                                                          SHI10530
      IF(IFLG.EQ.0) GO TO 100                                           SHI10540
      FX = ABS ( 10000000000.00 / X(1) * X(2) / X(3) )                  SHI10550
      GO TO 999                                                         SHI10560
 100  DO 10 I = 2, 95                                                   SHI10570
      PI = FLOAT(I+1)                                                   SHI10580
      IF(PI.LE.CPT) GO TO 5                                             SHI10590
      FACT(I) = X(1)*(TKWGT(2,I) ** X(2)) * EXP(TKWGT(2,I) * X(3))      SHI10600
      WGTPROJ(I) = TKWGT(2,I) * FACT(I)                                 SHI10610
      GO TO 10                                                          SHI10620
 5    FACT(I) = RAT(I)                                                  SHI10630
      WGTPROJ(I) = TKWGT(2,I) * FACT(I)                                 SHI10640
 10   CONTINUE                                                          SHI10650
      DO 11 I = 96,101                                                  SHI10660
      FACT(I) = 0.5 * (FACT(90) + FACT(95))                             SHI10670
      WGTPROJ(I) = TKWGT(2,I) * FACT(I)                                 SHI10680
 11   CONTINUE                                                          SHI10690
      SUMWGT = 0.0                                                      SHI10700
      SUMVAR = 0.0                                                      SHI10710
      NPASS = 0                                                         SHI10720
      CALL SCURVE                                                       SHI10730
C                                                                       SHI10740
C     CALCULATE THE VARIANCE OF S-CURVE                                 SHI10750
      SUMB = 0.0                                                        SHI10760
      SUMAB1 = 0.0                                                      SHI10770
      SUMAB = 0.0                                                       SHI10780
      SUMA2B = 0.0                                                      SHI10790
      MC = NGROUP /2                                                    SHI10800
      AMIDPT = A (MC)                                                   SHI10810
      DO 16 I=1, NGROUP                                                 SHI10820
      IF(I.EQ.1) A1(1) = A(1) / 2.0                                     SHI10830
      IF(I.NE.1) A1(I) = (A(I-1) + A(I)) / 2.0                          SHI10840
      A2(I) = A1(I) - AMIDPT                                            SHI10850
      SUMB = SUMB + B(I)                                                SHI10860
      SUMAB1= SUMAB1 + A1(I) * B(I)                                     SHI10870
      SUMAB = SUMAB + A2(I) * B(I)                                      SHI10880
      SUMA2B = SUMA2B + A2(I) * A2(I) * B(I)                            SHI10890
 16   CONTINUE                                                          SHI10900
      SUMWGT = SUMAB1 / SUMB                                            SHI10910
      SUMVAR = (SUMA2B - SUMAB * SUMAB / SUMB)/ SUMB                    SHI10920
      FX = ABS (SUMWGT - EXPWGT)                                        SHI10930
 999  RETURN                                                            SHI10940
      END                                                               SHI10950
C                                                                       SHI10960
C                                                                       SHI10970
C*******************************************************               SHI10980
C                                                                       SHI10990
C          A SUBROUTINE STARTS AT THIS POINT                            SHI11000
```

```
C                                                                       SHI11010
C********************************************************               SHI11020
C                                                                       SHI11030
C                                                                       SHI11040
C     THIS SUBROUTINE IS TO FIND THE MATRIX-INVERSE                     SHI11050
      SUBROUTINE MATINV(AA,N,AINV)                                      SHI11060
      DIMENSION AA(3,3),AINV(3,3),A(10,20),ID(10)                       SHI11070
      NN=N+1                                                            SHI11080
      N2=2*N                                                            SHI11090
      DO 200 I=1,N                                                      SHI11100
      DO 200 J=1,N                                                      SHI11110
  200 A(I,J) = AA(I,J)                                                  SHI11120
      K=1                                                               SHI11130
      DO 1 I=1,N                                                        SHI11140
      DO 1 J=NN,N2                                                      SHI11150
      A(I,J) = 0.                                                       SHI11160
    1 CONTINUE                                                          SHI11170
      DO 21 I=1,N                                                       SHI11180
      A(I,N+I) = 1.                                                     SHI11190
   21 ID(I) = I                                                         SHI11200
    2 CONTINUE                                                          SHI11210
      KK=K+1                                                            SHI11220
      IS=K                                                              SHI11230
      IT=K                                                              SHI11240
      B=ABS(A(K,K))                                                     SHI11250
      DO 3 I=K,N                                                        SHI11260
      DO 3 J=K,N                                                        SHI11270
      IF(ABS(A(I,J))-B)3,3,31                                           SHI11280
   31 IS=I                                                              SHI11290
      IT=J                                                              SHI11300
      B=ABS(A(I,J))                                                     SHI11310
    3 CONTINUE                                                          SHI11320
      IF(IS-K)  4,4,41                                                  SHI11330
   41 DO 42 J=K,N2                                                      SHI11340
      C=A(IS,J)                                                         SHI11350
      A(IS,J)=A(K,J)                                                    SHI11360
   42 A(K,J)=C                                                          SHI11370
    4 CONTINUE                                                          SHI11380
      IF(IT-K)5,5,51                                                    SHI11390
   51 IC=ID(K)                                                          SHI11400
      ID(K)=ID(IT)                                                      SHI11410
      ID(IT)=IC                                                         SHI11420
      DO 52 I=1,N                                                       SHI11430
      C=A(I,IT)                                                         SHI11440
      A(I,IT)=A(I,K)                                                    SHI11450
   52 A(I,K)=C                                                          SHI11460
    5 CONTINUE                                                          SHI11470
      IF(A(K,K))  6,120,6                                               SHI11480
    6 CONTINUE                                                          SHI11490
      DO 7 J=KK,N2                                                      SHI11500
      A(K,J)=A(K,J)/A(K,K)                                              SHI11510
      DO 7 I=KK,N                                                       SHI11520
      W=A(I,K)*A(K,J)                                                   SHI11530
      A(I,J)=A(I,J)-W                                                   SHI11540
      IF(ABS(A(I,J))-.0001*ABS(W))71,7,7                                SHI11550
```

```
 71    A(I,J)=0.                                                        SHI11560
 7     CONTINUE                                                         SHI11570
       N=KK                                                             SHI11580
       IF(K-N) 2,81,120                                                 SHI11590
 81    IF(A(N,N))8,120,8                                                SHI11600
 8     CONTINUE                                                         SHI11610
       DO 9 J=NN,N2                                                     SHI11620
       A(N,J)=A(N,J)/A(N,N)                                             SHI11630
 9     CONTINUE                                                         SHI11640
       N1=N-1                                                           SHI11650
       DO 10 M=1,N1                                                     SHI11660
       I=N-M                                                            SHI11670
       II=I+1                                                           SHI11680
       DO 10 K=II,N                                                     SHI11690
       DO 10 J=NN,N2                                                    SHI11700
       A(I,J)=A(I,J)-A(I,K)*A(K,J)                                      SHI11710
 10    CONTINUE                                                         SHI11720
       DO 11 I=1,N                                                      SHI11730
       DO 11 J=1,N                                                      SHI11740
       IF(ID(J)-I) 11,111,11                                            SHI11750
 111   DO 112 K=NN,N2                                                   SHI11760
 112   AINV(I,K-N)=A(J,K)                                               SHI11770
 11    CONTINUE                                                         SHI11780
       RETURN                                                           SHI11790
 120   WRITE(2,1000)                                                    SHI11800
       WRITE(3,1000)                                                    SHI11810
       RETURN                                                           SHI11820
 1000  FORMAT(10X,19H MATRIX IS SINGULAR)                               SHI11830
       END                                                              SHI11840
C                                                                       SHI11850
C                                                                       SHI11860
C*******************************************************                SHI11870
C                                                                       SHI11880
C         A SUBROUTINE STARTS AT THIS POINT                             SHI11890
C                                                                       SHI11900
C*******************************************************                SHI11910
C                                                                       SHI11920
C                                                                       SHI11930
       SUBROUTINE MATMUL (AINV,CVEC,BVEC)                               SHI11940
C                                                                       SHI11950
C      THIS SUBROUTINE DOES MATRIX-MULTIPLICATION.                      SHI11960
C      ONLY [3X3](3) = (3) OPERATIONS CAN BE DONE IN THIS SUBROUTINE    SHI11970
C                                                                       SHI11980
       DIMENSION AINV(3,3),CVEC(3),BVEC(3)                              SHI11990
C      THIS DO LOOPS OPERATES MATRIX MULTIPLICATION                     SHI12000
C                                                                       SHI12010
       DO 10 I=1,3                                                      SHI12020
         BVEC(I) = 0.0                                                  SHI12030
         DO 11 J=1,3                                                    SHI12040
           BVEC(I) = BVEC(I) + AINV(I,J) * CVEC(J)                      SHI12050
 11     CONTINUE                                                        SHI12060
 10    CONTINUE                                                         SHI12070
       RETURN                                                           SHI12080
       END                                                              SHI12090
C                                                                       SHI12100
```

```
C                                                                       SHI12110
C*******************************************************                SHI12120
C                                                                       SHI12130
C         A SUBROUTINE STARTS AT THIS POINT                             SHI12140
C                                                                       SHI12150
C*******************************************************                SHI12160
C                                                                       SHI12170
C                                                                       SHI12180
      SUBROUTINE XSQUARE (NSTCP)                                        SHI12190
      COMMON /FLAGS/ IFLAG(10),NFLAGS                                   SHI12200
      COMMON /BASIC/ WDIST(35),SAMSIZ(35),NA,NGROUP                     SHI12210
      DIMENSION IFMT(8),CHISQ(35),YEXP(20),COL3(20),COL4(20),COL5(20),  SHI12220
     + X(20),Y(20)                                                      SHI12230
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW                              SHI12240
      COMMON /VARIES/ WGTBASE(20),RAT(101)                              SHI12250
      DATA (CHISQ(I),I=1,30)/ 3.841,5.991,7.815,9.488,11.070,12.592,    SHI12260
     .14.067,15.507, 16.910, 18.307, 19.75, 21.026, 22.362, 23.685,     SHI12270
     .24.996,26.296,27.587, 28.869, 30.144, 31.410, 32.671, 33.924,     SHI12280
     .35.172, 36.415, 37.652, 38.885, 40.113, 41.337, 42.557, 43.773/   SHI12290
      NP = 20                                                           SHI12300
      DO 10 I = 1, 20                                                   SHI12310
      I5 = 1 + I*5                                                      SHI12320
      X(I) = WGTBASE(I)                                                 SHI12330
      Y(I) = RAT(I5)                                                    SHI12340
   10 CONTINUE                                                          SHI12350
      DO 20 I=1,20                                                      SHI12360
      YEXP(I) = A * X(I) ** B * EXP (X(I) *C)                           SHI12370
   20 CONTINUE                                                          SHI12380
      SUMCOL5=0.0                                                       SHI12390
      DO 25 J=1,NP                                                      SHI12400
      COL3(J) = YEXP(J) - Y(J)                                          SHI12410
      COL4(J) = COL3(J) * COL3(J)                                       SHI12420
      COL5(J) = COL4(J) / YEXP(J)                                       SHI12430
      SUMCOL5 = SUMCOL5 + CCL5(J)                                       SHI12440
   25 CONTINUE                                                          SHI12450
      NXSQ = 10                                                         SHI12460
      DO 26 I=1,NFLAGS                                                  SHI12470
      IF(IFLAG(I).EQ.'NOCHI') NXSQ = 0                                  SHI12480
   26 CONTINUE                                                          SHI12490
      IF(NXSQ.EQ.0) GO TO 990                                           SHI12500
      PRINT 500                                                         SHI12510
  500 FORMAT(*1*,/10X,*CHI-SQUARE TESTING ON GOODNESS-OF-FIT OF *,      SHI12520
     +*THE MULTIPLIER EQUATION*/,10X,64(*=*),//)                        SHI12530
      PRINT 505                                                         SHI12540
  505 FORMAT(10X,*EQUATION FITTED:*,10X,                                SHI12550
     + 35HYEXP = A * (X ** B) * EXP (X * C)              ,/)            SHI12560
      PRINT 510,A,B,C                                                   SHI12570
  510 FORMAT(/10X,*WHERE      A = *,F10.4/                              SHI12580
     + 20X,*B = *,F10.4,/20X,*C = *,F10.4/)                             SHI12590
      PRINT 515                                                         SHI12600
  515 FORMAT(18X,*(1)*,12X,*(2)*,12X,*(3)*,12X,*(4)*,12X,*(5)*,         SHI12610
     ./18X,*ACTUAL*,9X,*EXPECTED*,7X,*(1) - (2)*,6X,*(3)X(3)*,8X,       SHI12620
     .*(4)/(2)*,/18X,*VALUES*,9X,*VALUES*//)                            SHI12630
      DO 30 J=1,NP                                                      SHI12640
      PRINT 520,J,Y(J),YEXP(J),COL3(J),COL4(J),COL5(J)                  SHI12650
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 30   CONTINUE                                                          SHI12660
 520  FORMAT(7X,I3,5(F13.6,3X)/)                                        SHI12670
      PRINT 525,SUMCOL5                                                 SHI12680
 525  FORMAT(51X,*CHI-SQUARE VALUE = *,F15.6/)                          SHI12690
      NDEG = 18                                                         SHI12700
      IF(SUMCOL5.GT.CHISQ(NDEG))                                        SHI12710
     .PRINT 535                                                         SHI12720
      IF(SUMCOL5.GT.CHISQ(NDEG))                                        SHI12730
     +NSTOP = 10                                                        SHI12740
      IF(SUMCOL5.LE.CHISQ(NDEG)) PRINT 540                              SHI12750
 535  FORMAT(10X,*THE CHI-SQUARE VALUE EXCEEDS THE 5% SIGNIFICANT VALUE*SHI12760
     .,/10X,*THE COEFFICIENTS GIVEN SHOULD NOT BE RELIED UPON.*/)       SHI12770
 540  FORMAT(10X,*THE CHI-SQUARE VALUE IS WITHIN THE 5 PERCENT SIGNI*,  SHI12780
     .*FICIENT *,                                                       SHI12790
     .*VALUE.*,/10X,*THUS,THE COEFFICIENTS MAY BE USED FOR THE EQUATION*SHI12800
     ./)                                                                SHI12810
 990  CONTINUE                                                          SHI12820
      RETURN                                                            SHI12830
      END                                                               SHI12840
                                                                        SHI12850
                                                                        SHI12860
                                                                        SHI12870
C                                                                       SHI12880
C                                                                       SHI12890
C*******************************************************                 SHI12900
C                                                                       SHI12910
C        A SUBROUTINE STARTS AT THIS POINT                              SHI12920
C                                                                       SHI12930
C*******************************************************                 SHI12940
C                                                                       SHI12950
C                                                                       SHI12960
      SUBROUTINE CALWGT                                                 SHI12970
C     THIS SUBROUTINE PRODUCES W-4 OF W-5 TABLES FOR THE                SHI12980
C     WEIGHT DISTRIBUTION                                               SHI12990
C                                                                       SHI13000
      COMMON /VARIES/ WGTBASE(20),RAT(101)                              SHI13010
      COMMON /WGTLIM/ SUMWGT,EXPWGT,SUMVAR,EXPVAR,CPT                   SHI13020
      COMMON /CONSTS/ A,B,C,ANEW,BNEW,CNEW                              SHI13030
      COMMON /TKWGT/ TKWGT(2,101),WGTPROJ(101)                          SHI13040
      DIMENSION FACT(101)                                               SHI13050
C                                                                       SHI13060
C     THIS DO LOOP CALCULATES THE PROJECTED WEIGHT AT 1 %               SHI13070
C     INTERVALS AND COMPUTES THE AVERAGE WEIGHT                         SHI13080
C                                                                       SHI13090
      PROJWGT = 0.0                                                     SHI13100
      DO 10 I = 2, 95                                                   SHI13110
      FACT(I) = ANEW * (TKWGT(2,I) ** BNEW) * EXP(TKWGT(2,I) * CNEW)    SHI13120
      PT = FLOAT(I+1)                                                   SHI13130
      IF(PT.LE.CPT) GO TO 5                                             SHI13140
      WGTPROJ(I) = TKWGT(2,I) * FACT(I)                                 SHI13150
      GO TO 10                                                          SHI13160
 5    FACT(I) = RAT(I)                                                  SHI13170
      WGTPROJ(I) = TKWGT(2,I) * FACT(I)                                 SHI13180
 10   CONTINUE                                                          SHI13190
C                                                                       SHI13200
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C       FOR 95 - 100%, THE FACTORS USED ARE BASED ON THE AVERAGE          SHI13210
C       OF FACT(90) AND FACT(95).  THE MATHEMATICAL MODEL TENDS           SHI13220
C       TO GIVE LOWER VALUES AT THE 95 PERCENTILE AND UPWARDS.            SHI13230
C                                                                         SHI13240
        DO 11 I= 96,101                                                   SHI13250
        FACT(I) = 0.5 * (FACT(90) + FACT(95))                             SHI13260
        WGTPROJ(I) = TRWGT(2,I) * FACT(I)                                 SHI13270
 11     CONTINUE                                                          SHI13280
C       PRINT OUTPUTS                                                     SHI13290
        WRITE(6,600)                                                      SHI13300
 600    FORMAT(*1*,//10X*PROJECTED TRUCK WEIGHT DISTRIBUTION *,           SHI13310
       +15H (5% INTERVALS)                          /10X,50(*=*)//)       SHI13320
        WRITE(6,601)                                                      SHI13330
 601    FORMAT(10X,*ACC.FREQ.*,10X,*FACTORS*,10X,                         SHI13340
       +*WEIGHT*/10X,*(PERCENT)*,27X,*(KIPS)*//)                          SHI13350
        DO 12 I= 1,20                                                     SHI13360
        PERCT = I * 5.0                                                   SHI13370
        I5 = 1 + I * 5                                                    SHI13380
        WRITE(6,602) PERCT,FACT(I5),WGTPROJ(I5)                           SHI13390
 602    FORMAT(1X,F15.4,5X,2F15.4)                                        SHI13400
 12     CONTINUE                                                          SHI13410
        RETURN                                                            SHI13420
        END                                                               SHI13430
C                                                                         SHI13440
C                                                                         SHI13450
C                                                                         SHI13460
C                                                                         SHI13470
C*****************************************************                    SHI13480
C                                                                         SHI13490
C           A SUBROUTINE STARTS AT THIS POINT                             SHI13500
C                                                                         SHI13510
C*****************************************************                    SHI13520
C                                                                         SHI13530
C                                                                         SHI13540
        SUBROUTINE SPLOT                                                  SHI13550
        DIMENSION XAXIS(4),YAXIS(4),TITLE(5)                              SHI13560
        INTEGER XAXIS,YAXIS,TITLE                                         SHI13570
        COMMON /BASIC/ WDIST(35),SAMSIZ (35),N,NGROUP                     SHI13580
        COMMON /INDEX/ IVEH(3),IROAD(2),ISTATE(2),IFLG                    SHI13590
        COMMON /PLOTD/ ACCFR(35),PERCENT(35)                              SHI13600
C       THIS SUBROUTINE PLOTS A TITLE PAGE                                SHI13610
C       INITIATE ZETAPLOT                                                 SHI13620
C                                                                         SHI13630
        CALL PLOTS(0,0,4LPLOT)                                            SHI13640
C       GET THE CURRENT DATE INFORMATION                                  SHI13650
        CALL DATE(IDATE)                                                  SHI13660
C       MOVE PEN TO A NEW POSITION AND SET ORIGIN                         SHI13670
        CALL PLOT(1.0,2.0,-3)                                             SHI13680
        CALL SYMBOL (0.85,7.,.4,12HTRUCK WEIGHT,0.,12)                    SHI13690
        CALL SYMBOL (0.85,6.3,.4,12HDISTRIBUTION,0.,12)                   SHI13700
        CALL SYMBOL (1.65,5.6,.4,8HSHIFTING,0.,8)                         SHI13710
        CALL SYMBOL (1.05,4.9,.4,11HMETHODOLOGY,0.,11)                    SHI13720
        CALL SYMBOL (2.0,3.,.25,IDATE,0.,10)                              SHI13730
        CALL SYMBOL (-.13,-.5,.2,34HCENTER FOR TRANSPORTATION RESEARCH,   SHI13740
       + 0.,34)                                                           SHI13750
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      CALL SYMBOL (1.5,-.8,.2,13HAUGUST 1,1981,0.,13)                   SHI13760
      CALL PLOT(0.,0.,999)                                              SHI13770
C     GO TO NEXT PAGE AND PLCT CURVE                                    SHI13780
      ENLARG = 1.0                                                      SHI13790
      REDUCE = 0.9                                                      SHI13800
      IF(IFLG.EQ.3000.OR.IFLG.EQ.6000) ENLARG=2.0                       SHI13810
      SIZE1=.14                                                         SHI13820
      SIZE2= .11                                                        SHI13830
      FATOR = 1./ENLARG                                                 SHI13840
C     TO CALL ZETAPLOT SUBROUTINES -- INITIATE                          SHI13850
      CALL PLOTS (0,0,4HPLOT)                                           SHI13860
C     TO MOVE PEN TO THE ALLCCATED ORIGIN                               SHI13870
      CALL PLOT (1.8,1.5,-3)                                            SHI13880
      CALL FACTOR (REDUCE)                                              SHI13890
C     TO PLOT A 7 INCH AXIS WITH TICK MARKS AND ANNOTATIONS             SHI13900
      X=0.0                                                             SHI13910
      Z=0.0                                                             SHI13920
      DO 100 I=1,12                                                     SHI13930
      CALL PLOT (X,0.0,3)                                               SHI13940
      X = X + 0.5                                                       SHI13950
      Z = Z + 10.0*FATOR                                                SHI13960
      CALL PLOT (X, 0.0, 2)                                             SHI13970
      CALL PLOT (X, 0.1,2)                                              SHI13980
      CALL NUMBER (X-0.09,-.25, 0.105,Z,0.0,-1)                         SHI13990
 100  CONTINUE                                                          SHI14000
      X = 0.0                                                           SHI14010
      DO 310 I=1,120                                                    SHI14020
      CALL PLOT (X,0.0,3)                                               SHI14030
      CALL PLOT (X,0.05,2)                                              SHI14040
      X = X +0.05                                                       SHI14050
  310 CONTINUE                                                          SHI14060
C     TO WRITE THE TITLE FOR THE PLOT                                   SHI14070
      CALL SYMBOL(0.0,-1.0,SIZE1,                                       SHI14080
     +44HTRUCK WEIGHT DISTRIBUTION SHIFTING PROCEDURE  ,0.,44)          SHI14090
C     TO WRITE SYMBOLS FOR X-AXIS                                       SHI14100
      IF(IFLG.EQ.3000) CALL SYMBOL (0.75,-.5,SIZE1,                     SHI14110
     +28H SINGLE AXLE WEIGHT (KIPS)   ,0.,28)                           SHI14120
      IF(IFLG.EQ.6000) CALL SYMBOL (0.75,-.5,SIZE1,                     SHI14130
     +28H TANDEM AXLE WEIGHT (KIPS)    , 0.,28)                         SHI14140
      IF(IFLG.EQ.9000) CALL SYMBOL (0.75,-.5,SIZE1,                     SHI14150
     +28H GROSS TRUCK WEIGHT (KIPS)   ,0.,28)                           SHI14160
C     TO PLOT AN 8-INCH Y-AXIS WITH TICK MARKS AND NO.                  SHI14170
      Y = 0.0                                                           SHI14180
      W= 0.0                                                            SHI14190
      DO 101 I=1,10                                                     SHI14200
      CALL PLOT (0.0,Y,3)                                               SHI14210
C     SCALE THE Y-AXIS                                                  SHI14220
      Y = Y + 0.8                                                       SHI14230
      W = W + 1.0                                                       SHI14240
      CALL PLOT (0.0,Y,2)                                               SHI14250
      CALL PLOT (0.1,Y,2)                                               SHI14260
C     PUT NUMBERS UNDER TICK MARKS ( NUMBER = XXX.XX)                   SHI14270
      IDIGIT = 0                                                        SHI14280
      CALL NUMBER (-0.15,Y-.1, 0.105,10.*W,90.0,IDIGIT)                 SHI14290
 101  CONTINUE                                                          SHI14300
```

```
      Y = 0.0                                                           SHI14310
      DO 311 I =1,100                                                   SHI14320
      Y = Y + 0.08                                                      SHI14330
      CALL PLOT (0.0,Y,3)                                               SHI14340
      CALL PLOT ( 0.05,Y,2)                                             SHI14350
 311  CONTINUE                                                          SHI14360
C     TO PLOT SYMBOLS FOR Y-AXIS                                        SHI14370
      CALL SYMBOL (-.4,1.5,SIZE1,                                       SHI14380
     +30H ACCUMULATED FREQUENCY (%)       ,90.,30)                      SHI14390
C     TO PRINT THE HIGHWAY TYPE                                         SHI14400
      X=1.2                                                             SHI14410
      Y=9.0                                                             SHI14420
      CALL SYMBOL(0.,Y,SIZE1,IROAD,0.,20)                               SHI14430
      Y=Y-.25                                                           SHI14440
C     TO PRINT THE VEHICLE TYE                                          SHI14450
      CALL  SYMBOL(0.,Y,SIZE1,IVEH,0.,30)                               SHI14460
      Y=Y-.25                                                           SHI14470
C     PRINT THE STATE                                                   SHI14480
      CALL SYMBOL(0.,Y,SIZE1,ISTATE,0.,20)                              SHI14490
C     DEFINE THE SCALE FOR THE GRAPH                                    SHI14500
      XSCALE = 20. * FATOR                                              SHI14510
      N = NGROUP                                                        SHI14520
      WDIST(N+1)  = 0.                                                  SHI14530
      WDIST(N+2)  = XSCALE                                              SHI14540
      ACCFR(N+1)  = 0.                                                  SHI14550
      ACCFR(N+2)  = 12.5                                                SHI14560
      CALL LINE  (WDIST(1),ACCFR(1),N,1,1,1)                            SHI14570
      CALL PLOT(0.,0.,999)                                              SHI14580
      RETURN                                                            SHI14590
      END                                                               SHI14600
C                                                                       SHI14610
C                                                                       SHI14620
C*******************************************************               SHI14630
C                                                                       SHI14640
C          A SUBROUTINE STARTS AT THIS POINT                            SHI14650
C                                                                       SHI14660
C*******************************************************               SHI14670
C                                                                       SHI14680
C                                                                       SHI14690
      SUBROUTINE SCURVE                                                 SHI14700
C     THIS SUBROUTINE CONVERTS CUTPUT INTO W-4 OR W-5 TABLES            SHI14710
C                                                                       SHI14720
      COMMON /PLOTD/ ACCFR(35),PERCENT(35)                              SHI14730
      COMMON /IKWGT/ IKWGT(2,101),WGTPROJ(101)                          SHI14740
      COMMON /BASIC/ WDIST(35),SAMSIZ(35),NA,NGROUP                     SHI14750
      COMMON /WGTLIM/ SUMWGT,EXPWGT,SUMVAR,EXPVAR,CPT                   SHI14760
      COMMON /PASS/ NPASS                                               SHI14770
C                                                                       SHI14780
      WGTPROJ(1)  = 0.0                                                 SHI14790
      M = 1                                                             SHI14800
      I = 2                                                             SHI14810
  5    IF(M.EQ.NGROUP) GO TO 13                                         SHI14820
      IF(I.GT.101) GO TO 13                                             SHI14830
      IF(WGTPROJ(I) - WDIST(M))  10,11,12                               SHI14840
 10   I = I + 1                                                         SHI14850
```

```
      GO TO 5                                                           SHI14860
 11   ACCFR(M) = (I-1) * 1.0                                            SHI14870
      I = I + 1                                                         SHI14880
      M = M + 1                                                         SHI14890
      GO TO 5                                                           SHI14900
 12   ACCFR(M) = ((WDIST(M) - WGTPROJ(I-1))/(WGTPROJ(I)-WGTPROJ(I-1))   SHI14910
     . + (I - 2) ) * 1.0                                                SHI14920
      M = M + 1                                                         SHI14930
      GO TO 5                                                           SHI14940
 13   DO 14 I = M, NGROUP                                               SHI14950
      ACCFR (I) = 100.0                                                 SHI14960
 14   CONTINUE                                                          SHI14970
      PERCENT(1) = ACCFR(1)                                             SHI14980
C     THIS DO LOOP CALCULATES THE PERCENTAGE OF THE DISTRIBUTION        SHI14990
C                                                                       SHI15000
      DO 15 I = 2, NGROUP                                               SHI15010
      PERCENT(I) = ACCFR(I) - ACCFR(I-1)                                SHI15020
 15   CONTINUE                                                          SHI15030
      IF(NPASS.EQ.0) GO TO 99                                           SHI15040
C                                                                       SHI15050
C     PRINT OUTPUTS                                                     SHI15060
C                                                                       SHI15070
      WRITE(6,600)                                                      SHI15080
 600  FORMAT(*1*,/                                                      SHI15090
     +/10X,*PROJECTED WEIGHT DISTRIBUTION*,/10X,29(*=*)//)              SHI15100
      WRITE(6,601)                                                      SHI15110
 601  FORMAT(10X,*WEIGHT*,15X,*PERCENTAGE*,10X,                         SHI15120
     +*ACCUMULATED*/7X,*DISTRIBUTION*,33X,*FREQUENCY*//)                SHI15130
C                                                                       SHI15140
C     THIS DO LOOP PRINTS THE OUTPUT                                    SHI15150
C                                                                       SHI15160
      DO 16 I = 1,NGROUP                                                SHI15170
      WRITE(6,602) WDIST(I), PERCENT(I), ACCFR(I)                       SHI15180
 16   CONTINUE                                                          SHI15190
 602  FORMAT(10X,F10.4,10X,F10.4,10X,F10.4)                             SHI15200
      WRITE(6,603) SUMWGT , SUMVAR                                      SHI15210
 603  FORMAT(//10X,*AVEAGE WEIGHT = *,F10.4/,                           SHI15220
     +         10X,*  VARIANCE    = *,F10.4/)                           SHI15230
 99   NPASS = 10                                                        SHI15240
      RETURN                                                            SHI15250
      END                                                               SHI15260
C     SUBROUTINE                                                        SHI15270
C                                                                       SHI15280
C                                                                       SHI15290
C*******************************************************                SHI15300
C                                                                       SHI15310
C         A SUBROUTINE STARTS AT THIS POINT                             SHI15320
C                                                                       SHI15330
C*******************************************************                SHI15340
C                                                                       SHI15350
      SUBROUTINE INPROG (COMMAND)                                       SHI15360
      COMMON /FLAGS/ IFLAG(10),NFLAGS                                   SHI15370
      COMMON /WGTLIM/ SUMWGT,EXPWGT,SUMVAR,EXPVAR,CPT                   SHI15380
      INTEGER COMMAND(1)                                                SHI15390
      READ(5,100) COMMAND                                               SHI15400
```

```
 100  FORMAT(A7)                                                        SHI15410
      I = 0                                                             SHI15420
 1    I = I + 1                                                         SHI15430
      NFLAGS=I                                                          SHI15440
      IF(NFLAGS.GT.10) GO TO 2                                          SHI15450
      READ(5,110) IFLAG(I)                                              SHI15460
      IF(IFLAG(I).EQ.'     ') GO TO 2                                   SHI15470
      GO TO 1                                                           SHI15480
 2    READ(5,120) EXPWGT,EXPVAR,CPT                                     SHI15490
 110  FORMAT(A5)                                                        SHI15500
 120  FORMAT(3F10.5)                                                    SHI15510
      RETURN                                                            SHI15520
      END                                                               SHI15530
                                                                        SHI15540
                                                                        SHI15550
                                                                        SHI15560
C                                                                       SHI15570
C******************************************************                 SHI15580
C                                                                       SHI15590
C         A SUBROUTINE STARTS AT THIS POINT                             SHI15600
C                                                                       SHI15610
C******************************************************                 SHI15620
C                                                                       SHI15630
      SUBROUTINE CONCLUD                                                SHI15640
C                                                                       SHI15650
C     THIS SUBROUTINE MAKES THE CONCLUSION OF ANALYSIS                  SHI15660
C                                                                       SHI15670
      COMMON /WGTLIM/ SUMWGT,EXPWGT,SUMVAR,EXPVAR,CPT                   SHI15680
      COMMON /BASIC/ A(35),SAMSIZ(35),NA,NGROUP                         SHI15690
C                                                                       SHI15700
      WRITE(6,600)                                                      SHI15710
 600  FORMAT(*1*,//10X,*CONCLUSION OF ANALYSIS*/10X,22(*=*)/)           SHI15720
      WRITE(6,610) EXPWGT,EXPVAR                                        SHI15730
 610  FORMAT(/10X,*INPUT ESTIMATORS:*//                                 SHI15740
     +12X,*EXPECTED MEAN     = *F10.2,/                                 SHI15750
     +12X,*EXPECTED VARIANCE = *F10.2/)                                 SHI15760
      WRITE(6,620) SUMWGT,SUMVAR                                        SHI15770
 620  FORMAT(/10X,*COMPUTED ESTIMATORS:*//                              SHI15780
     +12X,* MEAN     = *F10.2,/                                         SHI15790
     +12X,* VARIANCE = *F10.2/)                                         SHI15800
C                                                                       SHI15810
C                                                                       SHI15820
C     COMPUTE THE T- AND CHISQ-VALUES                                   SHI15830
C                                                                       SHI15840
C     REFERENCE:                                                        SHI15850
C        R.J.LARSEN, M.L.MARX                                           SHI15860
C        AN INTRODUCTION TO MATHEMATICAL STATISTICAL AND ITS            SHI15870
C        APPLICATION                                                    SHI15880
C                                PRENTICE HALL   1980                   SHI15890
C        T-TEST: PG 324;  CHISQ-TEST: PG 288                            SHI15900
C                                                                       SHI15910
C        T = ABS(XBAR - YBAR) / (SDEV / SQRT(N))                        SHI15920
C                                                                       SHI15930
C                                                                       SHI15940
      RT = NGROUP * 1.0                                                 SHI15950
```

```
      T = ABS (EXPWGT - SUMWGT) / SQRT (SUMVAR / RT)
C
C     COMPUTE THE CHISQ VALUE
C
C     CHISQ = (N-1) * COMPUTED VARIANCE / EXPECTED VARIANCE
C
      CHISQ = (NA - 1) * SUMVAR / EXPVAR
      DF = FLOAT (NA)
C
C     PRINT COMMENTS AND RESULTS
      WRITE (6,630) T,CHISQ,DF
  630 FORMAT(//10X,*STATISTICAL TESTING*/,10X,19(*-*)//,
     +10X,*T-TEST (TO TEST THE ACCEPTABILITY OF THE COMPUTED MEAN)*/
     +10X,*CHISQ-TEST (TO TEST THE ACCEPTABILITY OF THE VARIANCE)*/
     +//10X,*T-TEST*//
     +12X,*NULL HYPOTHESIS      : COMPUTED MEAN = EXPECTED MEAN*/
     +/12X,*ALTERNATE HYPOTHESIS: THEY ARE NOT EQUAL*/
     +/15X,*T-VALUE = *,F10.4//
     +10X,*CHISQ-TEST*//
     +12X,*NULL HYPOTHESIS      : COMPUTED VARIANCE  = EXPECTED VARIANCE*
     +/12X,*ALTERNATE HYPOTHESIS: THEY ARE NOT EQUAL*//
     +15X,*CHISQ-VALUE = *,F10.4//
     +15X,*DEGREE OF FREEDOM = *,F10.0//)
      WRITE (6,640)
  640 FORMAT(//,
     +10X,*ENGINEERS ARE RESPONSIBLE TO CHECK BOTH THE*/
     +10X,*T-AND CHISQ-VALUES WITH THE T-AND CHISQ-DISTRIBUTION*/
     +10X,*TABLES RESPECTIVELY.*/
     +10X,*IF BOTH HYPOTHESES ARE ACCEPTABLE, THE COMPUTED*/
     +10X,*WEIGHT DISTRIBUTION CURVE SHOULD BE ACCEPTABLE.*/
     +10X,*IF ONE OF THE HYPOTHESES IS REJECTED, THEN IT*/
     +10X,*IS UP TO THE ENGINEERS TO USE THEIR OWN JUDGEMENT*/
     +10X,*TO ACCEPT OR REJECT THE DISTRIBUTION CURVE.*//)
C
C
      RETURN
      END
C
C*******************************************************
C
C         A SUBROUTINE STARTS AT THIS POINT
C
C*******************************************************
C
      SUBROUTINE HISTOGM
C
C     THIS SUBROUTINE PLOTS A HISTOGRAM TO SHOW THE DISRIBUTION OF
C     TRUCK WEIGHT
C
      COMMON /INDEX/ IVEH(3),IROAD(2),ISTATE(2),IFLG
      COMMON /BASIC/ D(35),SAMSIZ(35),NA,NGROUP
      COMMON /PLOTD/ ACCPR(35),PERCENT(35)
C
      CALL PLOTS(0,0,4HPLOT)
      CALL PLOT(1.5,2.5,-3)
```

```
      SIZE1=0.14                                                        SHI16510
      SIZE2=0.10                                                        SHI16520
C     DEFINE LENGTH OF X-AXIS                                           SHI16530
      XLONG = 0.25 * (NGROUP +4)                                        SHI16540
C     LOCATE THE STARTING POINT OF X-AXIS HEADING                       SHI16550
      XLOC = 0.5 * (XLONG - (SIZE1 * 25.0))                             SHI16560
C     DEFINE SIZE OF LETTERS IN TITLE                                   SHI16570
      TSIZE = XLONG / 46.0                                              SHI16580
C     DRAW A LINE FOR X-AXIS                                            SHI16590
      CALL PLOT(XLONG,0.0,2)                                            SHI16600
      CALL PLOT(0.0,0.0,3)                                              SHI16610
      XGO = 0.25                                                        SHI16620
      CALL PLOT(XGO,0.0,3)                                              SHI16630
      CALL PLOT(XGO,0.05,2)                                             SHI16640
      XVALUE = 0.0                                                      SHI16650
      CALL NUMBER (0.2,-0.15,SIZE2,XVALUE,0.0,-1)                       SHI16660
      CALL PLOT(XGO,0.0,3)                                              SHI16670
      DO 10 I= 1,NGROUP                                                 SHI16680
      XGO = XGO + 0.25                                                  SHI16690
      CALL PLOT(XGO,0.0,3)                                              SHI16700
      CALL PLOT(XGO,0.05,2)                                             SHI16710
      CALL NUMBER (XGO-0.1,-0.15,SIZE2,D(I),0.0,-1)                     SHI16720
   10 CONTINUE                                                          SHI16730
      IF(IFLG.EQ.3000) CALL SYMBOL                                      SHI16740
     +(XLOC,-0.5,SIZE1,25HSINGLE AXLE WEIGHT (KIPS) ,0.0,25)            SHI16750
      IF(IFLG.EQ.6000) CALL SYMBOL                                      SHI16760
     +(XLOC,-0.5,SIZE1,25HTANDEM AXLE WEIGHT (KIPS) ,0.0,25)            SHI16770
      IF(IFLG.EQ.9000) CALL SYMBOL                                      SHI16780
     +(XLOC,-0.5,SIZE1,25HGROSS TRUCK WEIGHT (KIPS) ,0.0,25)            SHI16790
      CALL SYMBOL(0.0,-1.5,TSIZE,                                       SHI16800
     +47HTRUCK WEIGHT DISTRIBUTION SHIFTING METHODOLOGY ,0.0,47)        SHI16810
      CALL PLOT(0.0,0.0,3)                                              SHI16820
      CALL PLOT(0.0,5.0,2)                                              SHI16830
      DO 15 I=1,10                                                      SHI16840
      YVALUE = I * 5.0                                                  SHI16850
      YGO = I * 0.5                                                     SHI16860
      CALL PLOT(0.0,YGO,3)                                              SHI16870
      CALL PLOT(0.05,YGO,2)                                             SHI16880
      CALL NUMBER(-0.6,YGO,SIZE2,YVALUE,0.0,1)                          SHI16890
   15 CONTINUE                                                          SHI16900
      CALL SYMBOL (-1.0,1.8,SIZE1,10HPERCENTAGE ,90.0,10)               SHI16910
      CALL SYMBOL(0.0,6.5,SIZE1,IROAD,0.0,20)                           SHI16920
      CALL SYMBOL(0.0,6.2,SIZE1,IVEH,0.0,30)                            SHI16930
      CALL SYMBOL(0.0,5.9,SIZE1,ISTATE,0.0,20)                          SHI16940
      CALL PLOT(0.0,0.0,3)                                              SHI16950
      DO 20 I=1,NGROUP                                                  SHI16960
      XGO = 0.25 * I                                                    SHI16970
      CALL PLOT(XGO,0.0,3)                                              SHI16980
      YGO = PERCENT(I)/10.0                                             SHI16990
      CALL PLOT(XGO,YGO,2)                                              SHI17000
      CALL NUMBER(XGO+0.1,YGO+0.1,SIZE2,PERCENT(I),90.0,1)              SHI17010
      CALL PLOT(XGO,YGO,3)                                              SHI17020
      CALL PLOT(XGO+0.25,YGO,2)                                         SHI17030
      CALL PLOT(XGO+0.25,0.0,2)                                         SHI17040
   20 CONTINUE                                                          SHI17050
```

```
FILE: SHIFTIN  FORTRAN  B                       VM/SP CONVERSATIONAL MONITOR SYSTEM

      CALL PLOT(0.0,0.0,999)                                                   SHI17060
      RETURN                                                                   SHI17070
      END                                                                      SHI17080
```

APPENDIX 3

SOURCE PROGRAM OF "TAWEXP"——SHIFTING PROGRAM FOR TANDEM AXLE WEIGHT DISTRIBUTION

```
      PROGRAM IAWEXP(INPUT,OUTPUT,PLOT)
C     THIS PROGRAM IS USED TO ANALYZE THE PREDICTION FOR
C     TANDEM AXLE DISTRIBUTION.  IT CAN BE APPLIED TO 2
C     TYPES OF TRUCKS ONLY -- 3-A AND 3-S2.  THE SEQUENCE
C     OF INPUT DATA SHOULD BE ACCORDING TO THE FOLLOWING
C     ORDER :
C          1. GROSS VEHICLE WEIGHT DISTRIBUTION DATA
C          2. SINGLE AXLE WEIGHT DIST.DATA OF THE SAME YEAR,
C          3. TANDEM AXLE WEIGHT DIST.DATA OF THE SAME YEAR.
C
C     THE RESULT OF THE ANALYSIS IS PRESENTED IN ACTUAL
C     AND PREDICTED TANDEM AXLE WEIGHT DISTRIBUTION AND
C     THE CHI-SQUARE VALUE TO SHOW THEIR GOODNESS OF FIT.
C
C     DATE OF FIRST VERSION: OCTOBER 12,1981.
C     WRITTEN BY PAUL NG FOR THE CENTER FOR TRANSP.RESEARCH.
C
      DIMENSION VALUE(3,101),TAWE(101)
      COMMON /BASIC/ WDIST(35),SAMSIZ  (35),N,NGROUP
      COMMON /PLOTD/ ACCFR(2,35)
      COMMON /INDEX/ IVEH(3),IROAD(2),ISTATE(2),IPLG,IYEAR
      DIMENSION YSUM(35),Y(35)
      DIMENSION GVW(2,35),AXLE(2,16)
      DATA (GVW(1,I),I=1,30)/4.,10.,13.5,20.,22.,24.,26.,28.,30.,32.,
     +34.,36.,38.,40.,45.,50.,55.,60.,65.,70.,72.,75.,80.,
     +85.,90.,95.,100.,105.,110.,115./
      DATA (GVW(2,I),I=1,26)/10.,12.,14.,16.,18.,20.,22.,24.,26.,28.,30.
     +,35.,40.,45.,50.,55.,60.,65.,70.,75.,80.,85.,90.,95.,100.,105./
      DATA (AXLE(1,I),I=1,13)/3.,7.,8.,12.,16.,18.,18.5,20.,22.,24.,26.,
     +30.,35./
      DATA (AXLE(2,I),I=1,16)/6.,12.,18.,24.,30.,32.,32.5,34.,36.,38.,
     +40.,42.,44.,46.,50.,55./
      DO 999 K=1,3
      READ 51,IYEAR,IROAD,IVEH,ISTATE,N
      DENOM = 1.0
      IF(IVEH(1).EQ.'3-S2(33200') DENOM =2.0
      IF(IVEH(1).EQ.'3-A(230000') DENOM = 1.0
      READ 51,IFLG
      IF(IFLG.EQ.3000) GO TO 601
      IF(IFLG.EQ.6000) GO TO 602
      IF(IFLG.EQ.9000) GO TO 603
      READ 52,(WDIST(I),I=1,N)
      GO TO 5
 601  DO 610 I=1,13
 610  WDIST(I) = AXLE(1,I)
      NGROUP = 13
      GO TO 5
 602  DO 612 I=1,16
 612  WDIST(I) = AXLE(2,I)
      NGROUP = 16
      GO TO 5
 603  IF(IYEAR.LE.1958) GO TO 620
      DO 613 I=1,30
      WDIST(I) = GVW(1,I)
```

```
 613  CONTINUE
      NGROUP = 30
      GO TO 5
 620  DO 614 I=1,26
 614  WDIST(I) = GVW(2,I)
      NGROUP = 26
  5   READ 52,(SAMSIZ(J),J=1,N)
      SUMB=0.0
      DO 10 I=1,N
 10   SUMB=SUMB + SAMSIZ(I)
      DO 11 I=1,N
      Y(I) = SAMSIZ(I)/SUMB * 100.0
 11   CONTINUE
      YSUM(1) = Y(1)
      DO 12 I=2,N
 12   YSUM(I) = YSUM(I-1) + Y(I)
      M=1
      CHECK = 0.0000001
      I=1
 20   IF(M.EQ.2) CHECK=CHECK - 0.00000001
      IF (CHECK.GT.100.1) GO TO 999
      IF(I.EQ.N) GO TO 41
      IF(YSUM(I) - CHECK ) 40,41,42
 40   I=I+1
      GO TO 20
 41   VALUE(K,M) = WDIST (I)
      M=M+1
      CHECK = CHECK + 1.0
      GO TO 20
 42   YSUMI1=0.0
      IF(I.GT.1) YSUMI1=YSUM(I-1)
      IF(YSUM(I)-YSUMI1) 20,20,43
 43   AIM1=0.0
      IF(I.GT.1) AIM1= WDIST(I-1)
      VALUE(K,M) =AIM1 + (CHECK - YSUMI1)/
     .(YSUM(I) - YSUMI1) * (WDIST(I) - AIM1)
      M=M+1
      CHECK =CHECK + 1.0
      GO TO 20
 999  CONTINUE
      XSQ = 0.0
      DO 30 I=2,101
      TAWE(I) = (VALUE(1,I) - VALUE(2,I))/DENOM
      DIFF = TAWE(I) - VALUE(3,I)
      DIFFSQ = DIFF * DIFF
      CONST = DIFFSQ / TAWE(I)
      XSQ = XSQ + CONST
 30   CONTINUE
C     PUT ACTUAL DATA INTO VALUE(1,I),AND EXPECTED VALUES INTO VALUE(2,I)
      DO 31 I = 2,101
      VALUE(2,I) = TAWE(I)
      VALUE(1,I) = VALUE(3,I)
 31   CONTINUE
      K = 1
 101  M = 1
```

```
      VALUE(K,1)  = 0.0
      I = 2
 105  IF(M.EQ.26) GO TO 113
      IF(I.GT.101) GO TO 113
      K1 = K + 1
      IF(VALUE(K,I)- AXLE(2,M)) 110,111,112
 110  I = I + 1
      GO TO 105
 111  ACCFR(K,M)  = (I - 1 ) * 1.0
      I = I + 1
      M = M + 1
      GO TO 105
 112  ACCFR(K,M)  = ((AXLE(2,M) - VALUE(K,I-1))/
     . (VALUE(K,I) - VALUE(K,I-1)) + (I-2)) * 1.0
      M = M + 1
      GO TO 105
 113  DO 114 I = M,16
      ACCFR(K,I)  = 100.0
 114  CONTINUE
      K = K + 1
      IF (K.EQ.2) GO TO 101
      PRINT 500,IYEAR,IROAD,ISTATE,IVEH
 500  FORMAT(*1*,//10X,*AXLE WEIGHT DISTRIBUTION ANALYSIS*//
     +10X,I4,/10X,2A10,/10X,2A10,/10X,3A10////)
      PRINT 503
 503  FORMAT(10X,*TANDEM*,4X,*ACUTAL*,8X,*EXPECTED*/
     +10X,* AXLE *,3X,*CUMMULATED*,5X,*CUMMULATED*/
     +10X,*WEIGHT*,3X,*PERCENTAGE*,5X,*PERCENTAGE*/)
      DO 499 I=1,16
 499  PRINT 501,AXLE(2,I),ACCFR(1,I),ACCFR(2,I)
      PRINT 502,XSQ
 501  FORMAT(6X,F10.2,3X,F10.2,3X,F10.2)
 502  FORMAT(//10X,*CHI-SQUARE VALUE = *,F10.4/)
 51   FORMAT(I4,X,2A10,3A10,2A10,I5)
 52   FORMAT(12F6.1)
      CALL SPLOT
      STOP
      END
      SUBROUTINE SPLOT
      DIMENSION XAXIS(4),YAXIS(4),TITLE(5),ACC(35)
      INTEGER XAXIS,YAXIS,TITLE
      COMMON /BASIC/ WDIST(35),SAMSIZ (35),N,NGROUP
      COMMON /INDEX/ IVEH(3),IROAD(2),ISTATE(2),IFLG,IYEAR
      COMMON /PLOTD/ ACCFR(2,35)
C     THIS SUBROUTINE PLOTS A TITLE PAGE
C     INITIATE ZETAPLOT
C
      ENLARG = 1.0
      REDUCE = 0.9
      IF(IFLG.EQ.3000.OR.IFLG.EQ.6000) ENLARG=2.0
      SIZE1=.14
      SIZE2= .11
      FATOR = 1./ENLARG
C     TO CALL ZETAPLOT SUBROUTINES -- INITIATE
      CALL PLOTS (0,0,4LPLOT)
```

```
C      TO MOVE PEN TO THE ALLOCATED ORIGIN
       CALL PLOT (1.8,1.5,-3)
       CALL FACTOR (REDUCE)
C      TO PLOT A 7 INCH AXIS WITH TICK MARKS AND ANNOTATIONS
       X=0.0
       Z=0.0
       DO 100 I=1,12
       CALL PLOT (X,0.0,3)
       X = X + 0.5
       Z = Z + 10.0*FATOR
       CALL PLOT (X, 0.0, 2)
       CALL PLOT (X, 0.1,2)
       CALL NUMBER (X-0.09,-.25, 0.105,Z,0.0,-1)
 100   CONTINUE
       X = 0.0
       DO 310 I=1,120
       CALL PLOT (X,0.0,3)
       CALL PLOT (X,0.05,2)
       X = X +0.05
  310  CONTINUE
C      TO WRITE THE TITLE FOR THE PLOT
       CALL SYMBOL(0.0,-1.0,SIZE1,
      +44H AXLE WEIGHT DISTRIBUTION SHIFTING PROCEDURE  ,0.,44)
C      TO WRITE SYMBOLS FOR X-AXIS
        CALL SYMBOL (0.75,-.5,SIZE1,
      +28H TANDEM AXLE WEIGHT (KIPS)    , 0.,28)
C      TO PLOT AN 8-INCH Y-AXIS WITH TICK MARKS AND NO.
       Y = 0.0
       W = 0.0
       DO 101 I=1,10
       CALL PLOT (0.0,Y,3)
C      SCALE THE Y-AXIS
       Y = Y + 0.8
       W = W + 1.0
       CALL PLOT (0.0,Y,2)
       CALL PLOT (0.1,Y,2)
C      PUT NUMBERS UNDER TICK MARKS ( NUMBER = XXX.XX)
       IDIGIT = 0
       CALL NUMBER (-0.15,Y-.1, 0.105,10.*W,90.0,IDIGIT)
 101   CONTINUE
       Y = 0.0
       DO 311 I =1,100
       Y = Y + 0.08
       CALL PLOT (0.0,Y,3)
       CALL PLOT ( 0.05,Y,2)
 311   CONTINUE
C      TO PLOT SYMBOLS FOR Y-AXIS
       CALL SYMBOL (-.4,1.5,SIZE1,
      +30H  ACCUMULATED FREQUENCY (%)       ,90.,30)
C      TO PRINT THE HIGHWAY TYPE
       X=1.2
       Y=9.0
       CALL SYMBOL(0.,Y,SIZE1,IROAD,0.,20)
       Y=Y-.25
C      TO PRINT THE VEHICLE TYE
```

```
      CALL  SYMBOL(0.,Y,SIZE1,IVEH,0.,30)
      Y=Y-.25
C     PRINT THE STATE
      CALL SYMBOL(0.,Y,SIZE1,ISTATE,0.,20)
C     PRINT THE YEAR
      Y = Y -.25
      YEAR = FLOAT(IYEAR)
      CALL NUMBER(0.,Y,SIZE1,YEAR,0.,-1)
C     DEFINE THE SCALE FOR THE GRAPH
      XSCALE = 20. * FATOR
      N = NGROUP
      DO 312 I=1,2
      DO 313 K = 1,N
       ACC(K)  = ACCPR(I,K)
 313  CONTINUE
      WLIST(N+1)  = 0.
      WLIST(N+2)  = XSCALE
      ACC(N+1)  = 0.
      ACC(N+2)  = 12.5
      CALL LINE  (WLIST(1),ACC(1),N,1,1,I)
      IF(I.EQ.1)  CALL SYMBOL  (4.0,2.0,.11,I,0.,-1)
      IF(I.EQ.1)  CALL SYMBOL  (4.4,2.0,.11,11HACTUAL DATA  ,0.0,11)
      IF(I.EQ.2)  CALL SYMBOL  (4.0,1.8,.11,I,0.,-1)
      IF(I.EQ.2)  CALL SYMBOL  (4.4,1.8,.11,15HEXPECTED VALUES   ,0.0,15)
 312  CONTINUE
      CALL PLOT(0.,0.,999)
      RETURN
      END
```

APPENDIX 4

SOURCE PROGRAM FOR SHIFTING OF TRUCK WEIGHT DISTRIBUTION BASED ON NCHRP/SDHPT PROCEDURE

```
      PROGRAM NCHRP (INPUT,OUTPUT)
C     THIS PROGRAM PROJECTS THE SHIFTING OF TRUCK WEIGHT DISTRIBUTION
C     CURVES.  THE METHODOLOGY USED IS BASED UPON NCHRP 141 PROCEDURE
C     OR THE SDHPT PROCEDURE DEVELOPED BY TEXAS HIGHWAY DEPARTMENT.
      DIMENSION IROAD(2),IVEH(3),ISTATE(2),SAMSIZ(30),GVW(30),
     +YSUM(30),Y(30),VALUE(105),ACCFR(30),PERCT(30)
      DATA (GVW(I),I=1,30)/4.,10.,13.5,20.,22.,24.,26.,28.,30.,32.,
     +34.,36.,38.,40.,45.,50.,55.,60.,65.,70.,72.,75.,80.,
     +85.,90.,95.,100.,105.,110.,115./
      READ 50,SGVW,PMGVWP,PMGVWF
 50   FORMAT(3F10.3)
      READ 51,IYEAR,IROAD,IVEH,ISTATE,N
      READ 51,IFLAG
 51   FORMAT(I4,X,2A10,3A10,2A10,I5)
      READ 52,(SAMSIZ(I),I=1,N)
 52   FORMAT(12F6.1)
      SUMB = 0.0
      DO 10 I=1,N
 10   SUMB = SUMB + SAMSIZ(I)
      DO 11 I=1,N
      Y(I) =SAMSIZ(I) / SUMB * 100.0
 11   CONTINUE
      YSUM(1) = Y(1)
      DO 12 I= 2,N
 12   YSUM (I) = YSUM(I-1) + Y (I)
      M = 1
      CHECK = 0.000001
      I = 1
 20   IF(M.EQ.2) CHECK = CHECK - 0.000001
      IF (CHECK.GT.100.1) GO TO 999
      IF(I.EQ.N) GO TO 41
      IF(YSUM(I) - CHECK) 40,41,42
 40   I = I + 1
      GO TO 20
 41   VALUE(M) = GVW(I)
      M = M + 1
      CHECK = CHECK + 1.0
      GO TO 20
 42   YSUMI1 = 0.0
      IF (I.GT.1) YSUMI1 = YSUM(I - 1)
      IF(YSUM(I) - YSUMI1) 20,20,43
 43   AIM1 = 0.0
      IF(I.GT.1) AIM1 = GVW(I-1)
      VALUE(M) = AIM1 + (CHECK - YSUMI1) /
     .(YSUM(I) - YSUMI1) * (GVW(I) - AIM1)
      M = M + 1
      CHECK = CHECK + 1.0
      GO TO 20
 999  DO 150 I=1,100
      IF(VALUE(I).LT.SGVW) GO TO 150
      IF(VALUE(I).GT.SGVW.AND.VALUE(I).LT.PMGVWP)
     +VALUE(I) = VALUE(I) * (1.0 +(PMGVWF/PMGVWP - 1.0)/
     +(PMGVWP - SGVW) * (VALUE(I) - SGVW))
      IF(VALUE(I) .GE. PMGVWP)
```

```
     +VALUE(I) = VALUE(I) * PMGVWP /PMGVWP
150   CONTINUE
C
C     THIS PART OF PROGRAM CONVERTS VALUES BACK TO PERCENTAGE
C
      VALUE(1) = 0.0
      M = 1
      I = 2
 105  IF(M.EQ.30) GO TO 113
      IF(I.GT.101) GO TO 113
      IF(VALUE(I) - GVW(M))  110,111,112
 110  I = I + 1
      GO TO 105
 111  ACCFR(M) = (I - 1 ) * 1.0
      I = I + 1
      M = M + 1
      GO TO 105
 112  ACCFR(M) = ((GVW(M) - VALUE(I-1))/(VALUE(I) - VALUE(I-1))
     . + (I-2)) * 1.0
      M = M + 1
      GO TO 105
 113  DO 114 I=M,30
      ACCFR(I) = 100.0
 114  CONTINUE
      PERCT(1) = ACCFR(1)
      SAMSIZ(1) = PERCT(1) * SUMB / 100.0
      DO 115 I=2,30
      PERCT(I) = ACCFR(I) - ACCFR(I-1)
      SAMSIZ(I) = PERCT(I) * SUMB / 100.0
 115  CONTINUE
C     THIS PART PRINTS THE OUTPUT
C
      PRINT 600,IYEAR , IROAD,IVEH,ISTATE
 600  FORMAT(*1*,10X,*PROJECTION BY NCHRP/SDHPT METHODOLOGY*//,
     +10X,I4,/10X,2A10,/10X,3A10,/10X,2A10/)
      PRINT 601
 601  FORMAT(10X,*GVW INTERVALS*,10X,*ACCUMULATED FREQUENCY*/)
      DO 116 I=1,30
      PRINT 602,GVW(I),ACCFR(I)
 116  CONTINUE
      NA = 30
      PRINT 117,IYEAR,IROAD,IVEH,ISTATE,NA
 117  FORMAT(*1*,/I4,X,2A10,3A10,2A10,I5)
      PRINT 119,IFLAG
 119  FORMAT(I4)
      PRINT 118,(SAMSIZ(I),I=1,NA)
 118  FORMAT(12F6.1)
 602  FORMAT(10X,F10.4,15X,F10.4)
      STOP
      END
```

APPENDIX 5

INPUT FORMAT AND ILLUSTRATION FOR "MEANWGT"

INPUT FORMAT FOR "MEANWGT"

1. First card——Description of Data I

Format: (I4, X, 2A10, 3A10, 2A10, I5)

a.	YEAR	Year in which data was collected
b.	IROAD	Highway system in which the truck weighing stations were located
c.	IVEH	Vehicle type
d.	ISTATE	State in which data was collected
e.	N	Number of distribution intervals contained in the data

2. Second card—Description of Data II

Format: (I4)

a.	IFLAG	To indicate the type of truck weight i.e., 3000 for single axle weight 6000 for tandem axle weight 9000 for gross vehicle weight

3. Third card to Fifth card——Sample sizes for corresponding truck weight distribution groups (one to three cards)

Format: (12F6.1)

a.	[SAMSIZ(i), I = 1, N]	Number of trucks recorded in the corresponding truck weight distribution groups

Note: Repeat the above sequence to compute for more years.
Leave a blank card to terminate.

```
FILE: APENDC   DATA     B                 VM/SP CONVERSATIONAL MONITOR SYSTEM

....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....

1970.INTERSTATE RURAL    3-S2(332000)                  STATE OF TEXAS         2
9000.GROSS VEHICLE WEIGHT
    0.    0.    0.    2.   15.   51.   85.  117.   92.   61.   37.   31.
   39.   32.   79.   95.  117.  229.  254.  157.   48.   39.   20.    4.
    1.
1971.INTERSTATE RURAL    3-S2(332000)                  STATE OF TEXAS         2
9000.GROSS VEHICLE WEIGHT
    0.    0.    0.   14.   41.   95.  125.  114.   77.   48.   54.   33.
   35.   27.  127.  128.  201.  278.  217.   94.   12.    1.    3.    1.
    1.
1972.INTERSTATE RURAL    3-S2(332000)                  STATE OF TEXAS         2
9000.GROSS VEHICLE WEIGHT
   -0.   -0.   -0.    2.    5.   17.   23.   13.   16.    9.    2.    6.
    5.    6.   17.   19.   32.   51.   38.   15.    2.    2.    2.   -0.
    0.    1.
1973.INTERSTATE RURAL    3-S2(332000)                  STATE OF TEXAS         2
9000.GROSS VEHICLE WEIGHT
   -0.   -0.   -0.    2.    7.   17.   30.   21.   15.   11.    7.   10.
    4.    4.   14.   18.   27.   59.   33.   24.    8.    3.    2.    1.
1974.INTERSTATE RURAL    3-S2(332000)                  STATE OF TEXAS         2
9000.GROSS VEHICLE WEIGHT
   -0.   -0.   -0.    4.   16.   46.   39.   23.   16.   15.    8.   12.
   10.    6.   12.   27.   33.   58.   34.   22.    0.    1.    5.    1.
1976.INTERSTATE RURAL    3-S2(332000)                  STATE OF TEXAS         3
9000.GROSS VEHICLE WEIGHT
    0.    0.    0.    0.    0.    0.    2.    9.   29.   25.   53.   32.
   36.   18.   67.   62.   91.  130.  138.  146.   90.  138.  206.  101.
   42.   20.   11.    1.    3.    1.
1978.INTERSTATE RURAL    3-S2(332000)                  STATE OF TEXAS         3
9000.GROSS VEHICLE WEIGHT
    0.    0.    0.    2.    3.    5.   36.   94.  155.  121.  103.   74.
   57.   54.  131.  119.  149.  173.  157.  316.  159.  196.  165.   58.
   32.   13.    2.    1.    1.    0.
1979.INTERSTATE RURAL    3-S2(332000)                  STATE OF TEXAS         2
9000.GROSS VEHICLE WEIGHT
    0.    0.    0.    0.    0.    5.   24.   54.   92.   82.   74.   54.
   41.   45.   91.   96.  112.  126.  154.  221.  112.  159.  171.   99.
   31.    9.    7.    3.
```

APPENDIX 6

INPUT FORMAT AND ILLUSTRATION FOR "SHIFTIN"

INPUT FORMAT AND ILLUSTRATION FOR "SHIFTIN"

(1) Nature of data	(one card) Format: (A7)
(a) [COEFF]	COEFFICIENTS for a linearized curve. The coefficients are the ln (A), B, and C of the following equation. $\ln Y = \ln A + B \ln x + Cx$ The input of COEFFICIENTS will provide a base for the program to start shifting.
(b) [RAWDATA]	To identify that the data provided in the file is drawn from raw field data. Regression analysis is required before actual shifting can be started.
(2) Optional commands	(up to five cards) Format: (A5)

These optional commands can be used to suppress certain outputs. These options are:

(a) [NORATIO]	To suppress the output from the subroutine /RATIO/, which is to compute the ratios of truck weight for two years at five percent interval.
(b) [NOREGRE]	To suppress the output from the subroutine /REGRESS/, which is to perform a regression analysis and to fit the ratios obtained from subroutine /RATIO/ to a straight line.
(c) [NOCHISQ]	To suppress the output from the subroutine /CHISQ/, which is to perform a CHI-SQUARE analysis on the curve fitted by /REGRESS/ and the actual data.
(d) [NOPLOT]	To suppress the plotting routine from generating an accumulated frequency truck weight distribution curve (shifted curve).
(e) [NOHISTO]	To suppress the plotting routine from generating a histogram for the shifted truck weight curve.

NOTE: Leave a blank card to terminate options.

INPUT FORMAT AND ILLUSTRATION FOR "SHIFTIN" (cont.)

(3) Estimator—Input card (one card)

Format: (5F10.5)

This card contains three parameters. The sequence of the parameters are:

(a)	[EXPWGT]	Expected average weight for the predicted year. The expected average weight is obtained either from historical trend analysis or from an average GVW factor.
(b)	[EXPVAR]	Expected variance for the predicted year. The variance for truck weight is obtained from historical trend analysis. To project a weight distribution curve for a new set of proposed truck weight limits, EXPVAR should be ≃ 10-15 percent higher than the latest available distribution.
(c)	[CPT]	Critical point from which shifting starts to occur. It is expressed in terms of percentage, i.e. for 10 percent input CPT = 10.0.

(4) Latest truck weight distribution data (three to five cards)

(a) First card——description of data I

Format: (I4, x, 2A10, 3A10, 2A10, I5)

(i)	IYEAR	Year in which data was collected.
(ii)	IROAD	Highway system in which the truck weighing stations were located.
(iii)	IVEH	Vehicle type.
(iv)	ISTATE	State in which data was collected.
(v)	N	Number of distribution intervals contained in the data.

(b) Second card——description of data II

Format: (I4)

(i) IFLG To indicate the type of truck weight,

i.e. 3,000 single axle weight
6,000 tandem axle weight
9,000 gross vehicle weight

INPUT FORMAT AND ILLUSTRATION FOR "SHIFTIN" (cont.)

(c) Third card——Fifth card——sample sizes for corresponding truck weight distribution groups (one to three cards)

Format: (12F6.1)

(i) [SAMSIZ (I), I=1,N] The number of trucks recorded in the corresponding truck weight distribution groups. The distribution weights are input inside the program in DATA statements. Check W-4 or W-5 tables for the weights of the distribution groups. Each card should not contain more than 12 numbers

(5) Base year truck weight distribution data (three to five cards)

Format:

Description of this item is exactly the same as than in item 4. The importance of this item is that the general shape of curve of the base year affects the shape of the predicted years. Thus, it is important to choose data with a large sample size for the base year data. Any unsmoothness in a curve due to scarcity of sample will sacrifice the accuracy of prediction.

A sample input is shown on the next page. This sample is the actual input data used for the shifting of truck weight distribution curve for 1978 for the truck 3-S2 on Texas highways. The output of the shifting is shown in the latter part of the appendix.

```
FILE: APENDA2  DATA     B                    VM/SP CONVERSATIONAL MONITOR SYSTEM

....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....

RAWDATA

 14.58      100.0       0.0
1974.INTERSTATE RURAL    2D(220000)                        STATE OF TEXAS        1.
9000.GROSS VEHICLE WEIGHT
   -0.   15.   10.   15.    4.    3.    0.    1.    0.    0.    0.    1.
1978.INTERSTATE RURAL    2D(220000)                        STATE OF TEXAS        1.
9000.GROSS VEHICLE WEIGHT
    0.  131.  144.  120.   51.   36.   19.    7.    3.    0.    1.    1.
```

```
FILE: APENDA   DATA      B                 VM/SP CONVERSATIONAL MONITOR SYSTEM

....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....

RAWDATA

 55.44       400.0       0.0
1974.INTERSTATE RURAL     3-S2(332000)                     STATE OF TEXAS       2
9000.GROSS VEHICLE WEIGHT
    0.      0.      0.      4.     16.     46.     39.     23.     16.     15.      8.     12.
   10.      6.     12.     27.     33.     58.     34.     22.      0.      1.      5.      1.
1970.INTERSTATE RURAL     3-S2(332000)                     STATE OF TEXAS       2
9000.GROSS VEHICLE WEIGHT
    0.      0.      0.      2.     15.     51.     65.    117.     92.     61.     37.     31.
   39.     32.     79.     95.    117.    229.    254.    157.     48.     39.     20.      4.
    1.
```

APPENDIX 7

INPUT FORMAT AND ILLUSTRATION FOR "TAWEXP"

INPUT FORMAT FOR "TAWEXP"

Three sets of data are to be arranged in the following order:

1. predicted GVW distribution for the interested year,
2. actual SAW distribution from the latest available year,
3. optional: actual TAW distribution to be compared with the output.

For each set of data, input format is similar to that listed for "MEANWGT." The third set of data is optional. If no comparison is expected, leave a blank card to terminate the data set.

```
FILE: APENDB   DATA     B                    VM/SP CONVERSATIONAL MONITOR SYSTEM

....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....

1978.INTERSTATE RURAL    3-S2(332000)                       STATE OF TEXAS        3
9000.GROSS VEHICLE WEIGHT
.163  .2445 .1426 .2649 .0815 .0815 3.016 7.181 8.350 5.554 3.120 2.234
2.463 2.031 4.639 5.002 5.454 7.410 9.669 9.965 3.823 4.332 5.457 5.961
2.296 .3880 .3354 .3354 .0078 0.000
1974.INTERSTATE RURAL    3-S2(332000)                       STATE OF TEXAS
3000.SINGLE AXLE
    1.    13.    69.   301.     8.
1978.INTERSTATE RURAL    3-S2(332000)                       STATE OF TEXAS        1
6000.TANDEM AXLE
    1.  846.   790.  676.  1019.  519.   135.   312.   222.   116.    53.    32.
   13.     4.     2.     2.
```

APPENDIX 8

SAMPLE OUTPUT FROM "SHIFTIN"

```
MULTIPLIERS OF THE INPUT TRUCK *WEIGHT DATA
==========================================

      3-S2(332000)
      INTERSTATE RURAL
      STATE OF TEXAS

      YEAR ( 1 ) = 1974

      YEAR ( 2 ) = 1970

        ACCUMULATED        YEAR(1)        YEAR(2)     YEAR(1)/YEAR(2)
        FREQUENCY          GVW (KIPS)     GVW (KIPS)

               0           13.5000        13.5000
          5.0000           21.9250        24.2882            .90
         10.0000           22.8174        26.1282            .87
         15.0000           23.6609        27.5000            .86
         20.0000           24.5949        29.1087            .84
         25.0000           25.5897        31.2869            .82
         30.0000           26.9913        35.3871            .76
         35.0000           28.9750        39.9844            .72
         40.0000           31.4933        45.0526            .70
         45.0000           35.2667        49.2763            .72
         50.0000           39.6667        52.8419            .75
         55.0000           46.1852        55.6496            .83
         60.0000           49.7778        57.4017            .87
         65.0000           52.7576        59.1539            .89
         70.0000           55.3966        60.8169            .91
         75.0000           57.0699        62.3967            .91
         80.0000           58.7414        63.9764            .92
         85.0000           60.7059        65.8997            .92
         90.0000           63.5588        68.4554            .93
         95.0000           67.1818        71.3229            .94
        100.0000           85.0000        90.0000            .94

THE LIGHTEST TRUCK
RECORDED IS IN THE
DISTRIBUTION GROUP:  13.5- 20.0     13.5- 20.0


THE HEAVISET TRUCK
RECORDED IS IN THE
DISTRIBUTION GROUP:  80.0- 85.0     85.0- 90.0
```

```
REGRESSION ANALYSIS TO FIT MULTIPLIERS INTO AN EQUATION
=======================================================


 A - MATRIX [ 3 X 3 ]

          20.00          77.24          1015.93
          77.24         301.10          4052.58
        1015.93        4052.58         57748.10

INVERSE  OF MATRIX A [3X3]

          91.23         -32.48              .67
         -32.48          11.62             -.24
            .67           -.24              .01

 C- VECTOR
          -3.31
         -12.56
        -153.52

FORM OF MATRIX MULTIPLICATION
------------------------------
[AINV](CVEC) = (BVEC)

B-VECTOR (COEFFICIENTS A,B,AND C)


LN(A) =      1.9122
    B =      -.7876
    C =       .0190
```

```
CHI-SQUARE TESTING ON GOODNESS-OF-FIT OF THE MULTIPLIER EQUATION
================================================================

EQUATION FITTED:          YEXP = A * (X ** B) * EXP (X * C)

WHERE      A =      6.7680
           B =      -.7876
           C =       .0190

           (1)            (2)            (3)            (4)            (5)
           ACTUAL         EXPECTED       (1) - (2)      (3)X(3)        (4)/(2)
           VALUES         VALUES

  1        .902700        .869907        -.032794       .001075        .001236

  2        .873286        .850462        -.022824       .000521        .000613

  3        .860395        .838407        -.021989       .000484        .000577

  4        .844932        .826539        -.018393       .000338        .000409

  5        .817906        .813817        -.004090       .000017        .000021

  6        .762744        .798336         .035592       .001267        .001587

  7        .724658        .791197         .066539       .004427        .005596

  8        .699034        .792905         .093870       .008812        .011113

  9        .715692        .800512         .084820       .007194        .008987

 10        .750667        .810678         .060011       .003601        .004442

 11        .829929        .820867        -.009062       .000082        .000100

 12        .867182        .828143        -.039039       .001524        .001840

 13        .891869        .836097        -.055772       .003111        .003720

 14        .910874        .844257        -.066617       .004438        .005257

 15        .914616        .852547        -.062069       .003853        .004519

 16        .918173        .861354        -.056819       .003228        .003748

 17        .921186        .872762        -.048424       .002345        .002687

 18        .928470        .889074        -.039397       .001552        .001746

 19        .941939        .908922        -.033017       .001090        .001199

 20        .944444       1.078565         .134120       .017988        .016678

                                         CHI-SQUARE VALUE =            .076075

THE CHI-SQUARE VALUE IS WITHIN THE 5 PERCENT SIGNIFICTENT VALUE.
THUS,THE COEFFICIENTS MAY BE USED FOR THE EQUATION
```

```
          RESULTS OBTAINED FROM THE POWELL METHOD
          ======================================


       FX              X(1)              X(2)              X(3)


  .14322279E+02   .67679738E+01  -.78756438E+00   .18970216E-01

  .82483325E-06   .91262080E+01  -.78756438E+00   .18970214E-01
       FX              X(1)              X(2)              X(3)


  .33066588E+01   .91272080E+01  -.78656438E+00   .19970214E-01

  .26806692E-05   .91272080E+01  -.80129808E+00   .19970214E-01
IME IS NOW =                  6.218


         6 FUNCTION EVALUATIONS WITHIN POWELL ROUTINE AND
       266 FUNCTION EVALUATIONS DURING THE LINE SEARCHES.

UNCTION VALUE =          .26806692E-05

ARIABLE VALUES:-
      .91272080E+01       -.80129808E+00       .19970214E-01


IME IS NOW =           8.1790000


          COEFFICIENTS OF THE EQUATION

                    A =      9.1272
                    B =      -.8013
                    C =       .0200

                   AVERAGE WEIGHT =    55.4400
                   VARIANCE =   427.4632
```

```
PROJECTED TRUCK WEIGHT DISTRIBUTION  (5↓ INTERVALS)
=================================================

ACC.FREQ.             FACTORS            WEIGHT
(PERCENT)                                (KIPS)


  5.0000               1.1585            27.9428
 10.0000               1.1257            29.4123
 15.0000               1.1105            30.5381
 20.0000               1.0957            31.8934
 25.0000               1.0801            33.7924
 30.0000               1.0621            37.5844
 35.0000               1.0557            42.2104
 40.0000               1.0616            47.8272
 45.0000               1.0750            52.9712
 50.0000               1.0915            57.6756
 55.0000               1.1075            61.6326
 60.0000               1.1188            64.2218
 65.0000               1.1311            66.9073
 70.0000               1.1436            69.5488
 75.0000               1.1562            72.1445
 80.0000               1.1696            74.8276
 85.0000               1.1869            78.2165
 90.0000               1.2115            82.9369
 95.0000               1.2204            87.0309
100.0000               1.2204           109.8328
```

```
     PROJECTED WEIGHT DISTRIBUTION
    ==============================


     WEIGHT                  PERCENTAGE            ACCUMULATED
  DISTRIBUTION                                      FREQUENCY


        4.0000                  .1534                 .1534
       10.0000                  .2301                 .3835
       13.5000                  .1342                 .5177
       20.0000                  .2492                 .7669
       22.0000                  .0767                 .8436
       24.0000                  .0767                 .9203
       26.0000                  .0767                 .9970
       28.0000                 4.1951                5.1920
       30.0000                 7.4323               12.6243
       32.0000                 7.7321               20.3565
       34.0000                 5.0849               25.4414
       36.0000                 2.8658               28.3071
       38.0000                 2.1443               30.4514
       40.0000                 2.3744               32.8258
       45.0000                 4.7136               37.5394
       50.0000                 4.6244               42.1638
       55.0000                 4.9262               47.0900
       60.0000                 5.3416               52.4316
       65.0000                 9.0353               61.4669
       70.0000                 9.4139               70.8808
       72.0000                 3.8445               74.7253
       75.0000                 5.5897               80.3150
       80.0000                 6.6054               86.9204
       85.0000                 5.1828               92.1033
       90.0000                 5.3254               97.4287
       95.0000                 1.6190               99.0476
      100.0000                  .3210               99.3687
      105.0000                  .3210               99.6897
      110.0000                  .3103              100.0000
      115.0000                      0              100.0000

     AVEAGE WEIGHT =    55.4400
       VARIANCE    =   427.4632
```

```
CONCLUSION OF ANALYSIS
======================


INPUT ESTIMATORS:

  EXPECTED MEAN     =       55.44
  EXPECTED VARIANCE =      400.00


COMPUTED ESTIMATORS:

   MEAN     =       55.44
   VARIANCE =      427.46



STATISTICAL TESTING
-------------------

T-TEST (TO TEST THE ACCEPTABILITY OF THE COMPUTED MEAN)
CHISQ-TEST (TO TEST THE ACCEPTABILITY OF THE VARIANCE)


T-TEST

  NULL HYPOTHESIS      : COMPUTED MEAN = EXPECTED MEAN

  ALTERNATE HYPOTHESIS: THEY ARE NOT EQUAL

     T-VALUE =        .0000

CHISQ-TEST

  NULL HYPOTHESIS      : COMPUTED VARIANCE  = EXPECTED VARIANCE
  ALTERNATE HYPOTHESIS: THEY ARE NOT EQUAL

     CHISQ-VALUE =    30.0911

     DEGREE OF FREEDOM =        30.

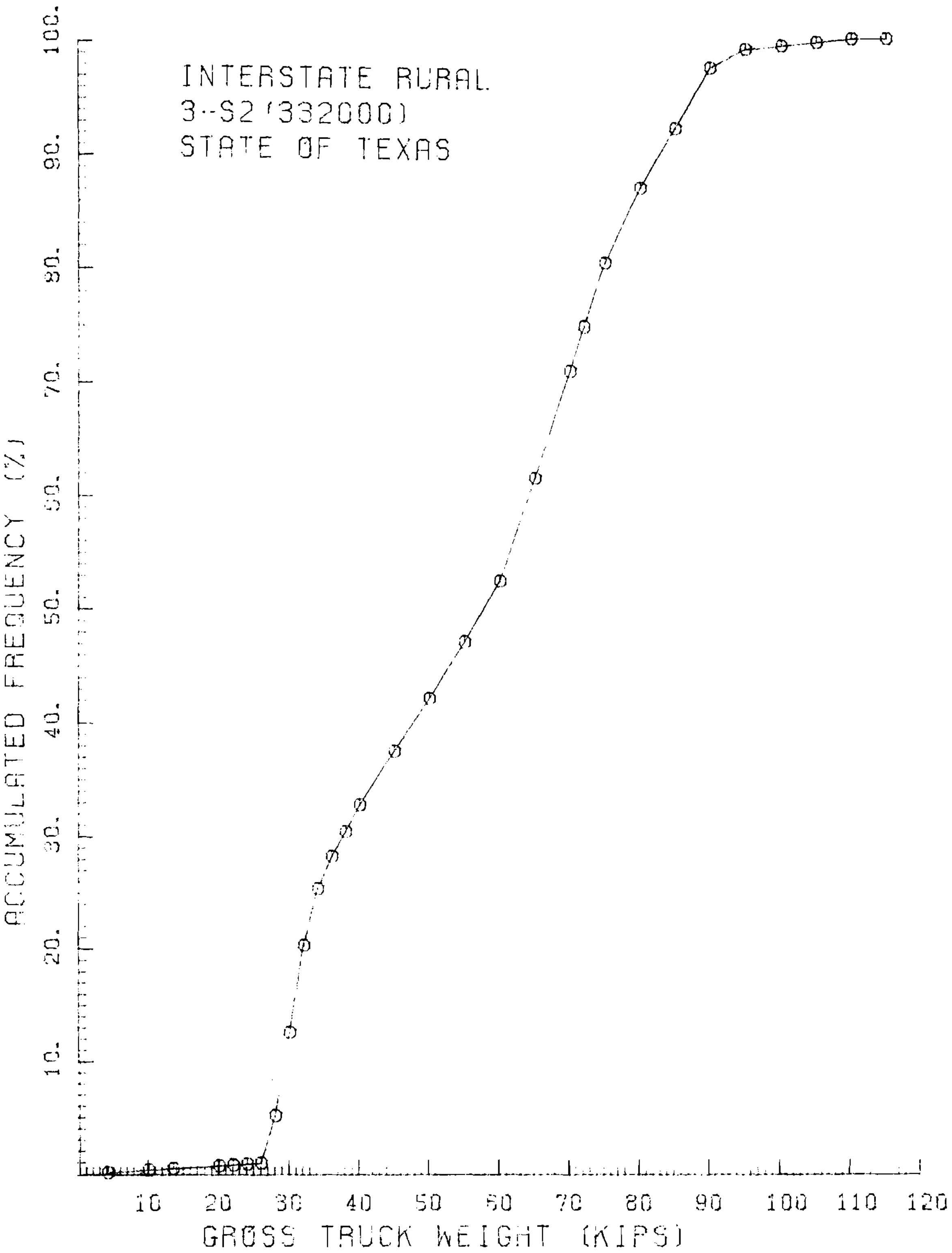


ENGINEERS ARE RESPONSIBLE TO CHECK BOTH THE
T-AND CHISQ-VALUES WITH THE T-AND CHISQ-DISTRIBUTION
TABLES RESPECTIVELY.
IF BOTH HYPOTHESES ARE ACCEPTABLE, THE COMPUTED
WEIGHT DISTRIBUTION CURVE SHOULD BE ACCEPTABLE.
IF ONE OF THE HYPOTHESES IS REJECTED, THEN IT
IS UP TO THE ENGINEERS TO USE THEIR OWN JUDGEMENT
TO ACCEPT OR REJECT THE DISTRIBUTION CURVE.
```

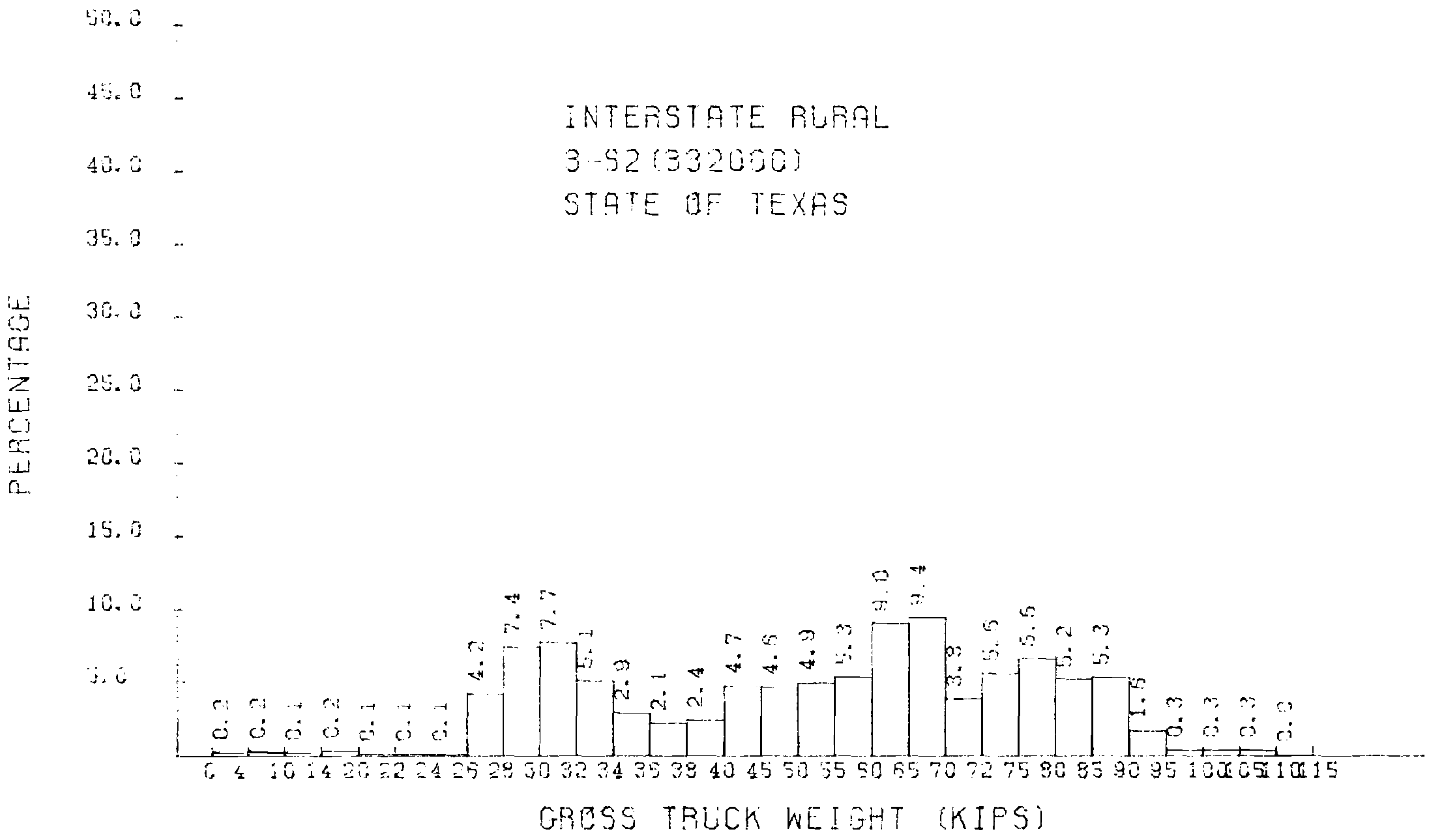
TRUCK WEIGHT DISTRIBUTION SHIFTING METHODOLOGY

22 APR 82

CENTER FOR TRANSPORTATION RESEARCH
AUGUST 1, 1981



TRUCK WEIGHT DISTRIBUTION SHIFTING PROCEDURE



TRUCK WEIGHT DISTRIBUTION SHIFTING METHODOLOGY