Procedure for Assessing Truck Weight Shifts that Result from Changes in Legal Limits

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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 the alternative legislation that governs truck weight. Consequently, it has become implausible to try to forecast precisely the benefits and costs associated with changes in size and weight limits. In the past, various methodologies for projecting truck weight distribution patterns have been developed. Each methodology has made a contribution in the capability of a framework for assessing changes in truck size and weight patterns; however, improvement is needed to enhance the overall precision of these estimates. In June 1977 the Texas State Department of Highways and Public Transportation contracted the Center for Transportation Research to conduct a study on selected aspects of the truck size and weight issue. As a part of this 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, and it can be used to predict both gross vehicle weight and axle weight distributions. A brief review of available methodologies and a detailed discussion of the Texas Shift are presented. Illustrative applications of predicting gross vehicle weight and axle weight distributions as a result of changes in weight limits are presented. Comparison of the prediction results generated by all the available shifting methodologies is also included.

Given the national trend of increasing truck traffic on U.S. highways and the movement toward minimum size and weight standards for trucks operating on Federal-Aid highways, there has been a need for a methodology to aid highway engineers in assessing the effects of these changes on the highway infrastructure. Legislation has been introduced at the national level and among many states that would allow the "super truck" to operate under a range of provisions and limitations. These trends make the need for a procedure, which would predict future gross vehicle weight (GVW) and axle weight distributions and 18-kip equivalent single-axle load (KESAL) applications that result from changes in the legal size or weight limit, more compelling. An overview of the current methodologies is presented, and a new procedure--the Texas Shift--which is the result of ongoing truck size and weight research investigations in Texas, is described.

Because the prediction of future weight distributions is vital to the evaluation of impacts due to changes in legal weight limits, four major methodologies have been developed in the past:

1. First FHWA procedure,
2. Second FHWA procedure,
3. NCHRP procedure, and
4. Texas State Department of Highways and Public Transportation (TSDHPT) procedure.

Each of these procedures (in descending order) provided an increased level of confidence in their predicted results [for a review of these methodologies, see Larkin (1) and Walton and Yu (2)]; however, further studies indicated that a higher level of confidence may be achievable (3).

AVERAGE GVW FACTOR

From the recent detailed study of the average vehicle weight trends as replicated in the Texas data, the following observations were made:

1. Within the span of the same truck weight laws, changes in the average GVW for each truck type were gradual rather than abrupt.
2. No significant correlation on the average GVW among the four truck types (i.e., 2D, 3A, 3-S2, and 2-S1-2) was observed.
3. The average GVW factor is defined as the ratio between the average GVW and practical maximum GVW for a specific truck type. The variation of this ratio over the years for a specific truck type is insignificant.

The third item is the most significant finding. In this section the derivation and the significance of this average GVW factor are discussed. The data in Table 1 give the average truck weights and the ratios with respect to the practical maximum GVW by using the 3-S2 as an example. The ratio can be expressed mathematically as follows: Average GVW factor = average GVW ÷ practical maximum GVM. For each type of truck, a linear regression analysis was applied:

$$Y = AX$$

where

Y = average GVW,
X = practical maximum GVW, and
A = coefficient.

The statistical package MINITAB was used. The coefficient for each type of truck obtained from the analysis can be used as the recommended average GVW factor. These coefficients are given in Table 2.

T-values computed for the four types of trucks indicated that they are within the limits suggested

Table 1. Relation between average GVW and practical maximum GVW for 3-S2 on Texas Interstate rural highways.

Year	Avg Legal GVW	Practical Maximum GVW	Avg 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	45.54	72.00	0.63
1973	45.21	72.00	0.63
1974	41.32	72.00	0.57
1975[a]			
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 (df = 15); and two-sample T-test = -1.78 (df = 14).

[a]Texas weight limits changed.

Table 2. Recommended average GVW factors for four truck types operating on Texas Interstate rural highways.

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

Table 3. Practical maximum GVW for trucks in Texas.

	Practical Maximum GVW (kips) by Year		
Truck Type	1951 to 1959	1960 to 1974	1975 to Present
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

by the student t-distribution; hence, it can be concluded that the average GVW factors may be used to represent the relations between average and maximum GVW for the four truck types.

In the regression of the average GVW and the practical maximum GVW, it was assumed that the relation between 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. The changes that occurred as a result of a 1975 weight law change were selected for testing.

The computed t-values for the two sample tests were within the allowable range of the t-distribution. A 95 percent confidence level was chosen for the test, and it was found that the variation of the means of the two samples was not significant at this level. Thus it was concluded that changes in weight laws in 1975 did not have a significant effect on the average GVW factors.

Note that the practical maximum GVW is used in the analysis instead of maximum allowable GVW. The use of the practical maximum GVW allows one to express the changes in both GVW and axle weight limits in a single parameter. If the maximum GVW were used, incorrect predictions would result in cases where weight law changes occurred only in either GVW or in axle weight.

For illustrative purposes, consider the 2D. The total truck weight is bounded by axle weight limits as well as considerations for safety. An increase in maximum GVW limit alone will not affect the weight trend of the 2D because the maximum possible GVW of 2D is controlled by its axle weight. Under both the pre-1975 limit and the current limit, 2D could never attain the 80,000 maximum GVW. Its GVW capacity is limited by the restrictions placed on its axle weight. Hence an erroneous shift would result if maximum GVW (currently 80,000 lb in Texas) is used to develop the average GVW factors.

Due to the operational safety consideration, the steering axles cannot be loaded to the maximum allowable single-axle weight. A review of the trends in steering axle weight distributions for 3A and 3-S2 indicates that there has not been any significant change in past years. The 2D and 2-S1-2 classes were not analyzed due to the difficulty in obtaining the data from FHWA's W-4 tables.

Based on the observation of historical data and review of the pertinent literature, four practical maximum steering axle weights for four types of trucks are recommended for use in the analyses of likely shifts. These weights are summarized in the table below.

Truck Type	Practical Maximum Steering Axle Limits (kip)
2D	7.22
3A	10.90
3-S2	12.00
2-S1-2	13.00

[The practical maximum steering axle limits for 2D and 3A suggested in the table were from Whiteside and others (4). The steering axle limits for 3-S2 and 2-S1-2 were values provided by the Texas Department of Highways and Public Safety.]

These steering axle limits are recommended to arrive at the values for practical maximum GVW limits. A summary of practical maximum GVW for Texas since 1951 is given in Table 3.

With the average GVW factors as a function of practical maximum GVW, engineers and planners may in turn estimate the future practical maximum GVW for any proposed law and by selected truck types. With the available average GVW factor provided in Table 2, the expected average truck weight under any proposed weight limits can be obtained. From the expected average truck weight, a shifted curve can be obtained by using the methodology to be presented.

The average GVW factors provided in Table 2 were derived from Texas weight survey data. Whether such factors are transferable to other states will require further verification.

THE TEXAS SHIFT

Shifting of Truck Weight Distribution Curve

The application of the Texas shift is summarized in Figure 1. The methodology is composed of three major parts:

1. Determining the expected mean and variance of the GVW distribution for a truck type under the proposed legal limit, which involves the analysis of historical data and the application of the average GVW;
2. Constructing a cumulative distribution curve from a set of representative truck weight data provided in the W-5 tables; and
3. Shifting the cumulative distribution curve, whereby the mean and variance of the shifted curve are within the acceptable tolerance of the parameters obtained in the first part of the procedure.

Statistical tests are used to facilitate the decision of whether to accept or reject a shifted curve. Once the tests are satisfied, the shifting procedure is complete and the projected truck weight distribution curve is obtained.

Preparation of a Cumulative Frequency Curve

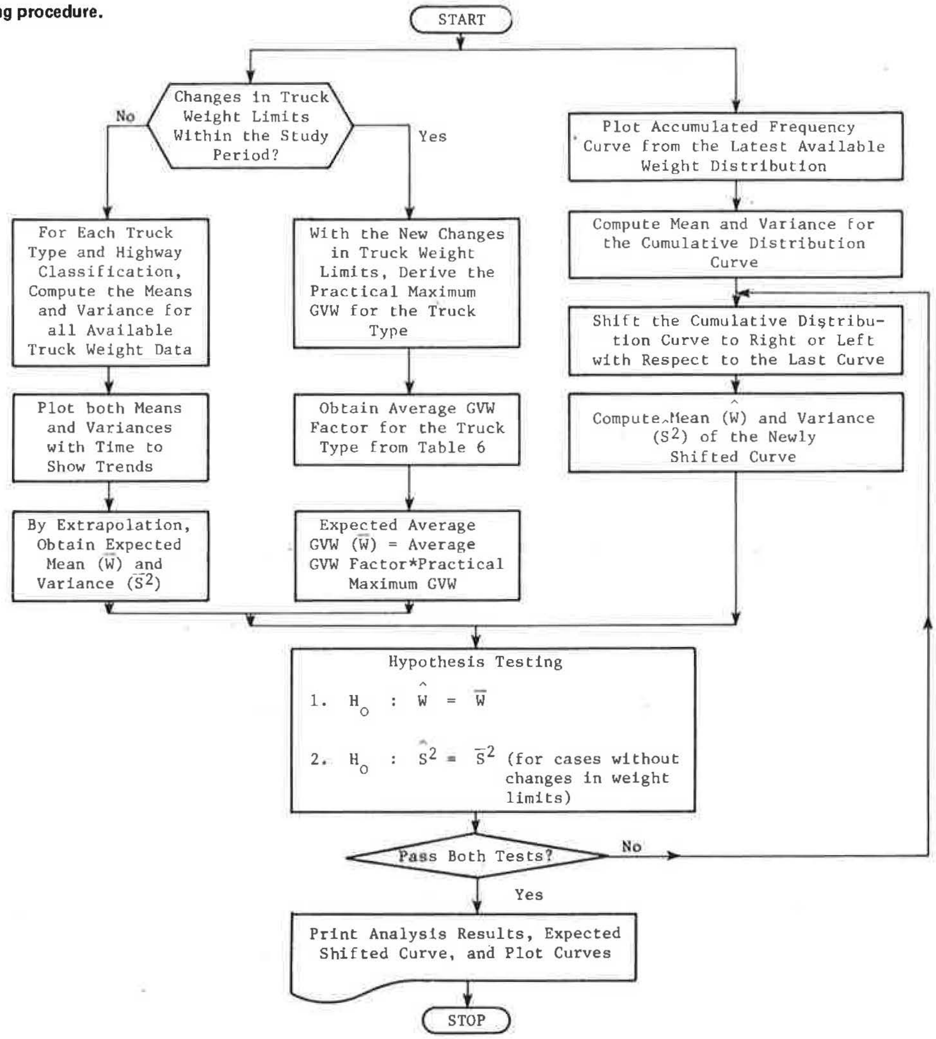
This part of the procedure provides a base curve from which shifting may occur. It is preferable to use statistically significant data from the most recent years.

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 for each interval.

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

Figure 1. Manual application of shifting procedure.



Shifting Curve to Obtain Expected Mean and Variance

It has been suggested by Larkin (1) that shifting for 2D and 3A starts at 50 percent and for 3-S2 and 2-S1-2 at 33.3 percent. However, these figures are based on Texas data. In the shifting procedure, users may start at any percentage that would factually or intuitively represent their case.

The shifting procedure is an iterative one. Obviously, the use of a computer to handle the shifting procedure will reduce the time consumed in performing the iterations (3). A manual step-by-step method is provided to illustrate the process.

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. The amount of shift should be according to the magnitude of the difference of the expected mean weight difference. The shifted curve should resemble the pattern of the unshifted curve (an S curve should be followed by another S curve).

Step 2: Compute the mean of the shifted curve. This can be done by taking the cumulative percentage of each weight interval of the original curve and the percentage for the corresponding interval in the newly shifted curve. The average weight for the shifted curve is the summation of the product of the mean weight for each weight interval with its 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 given in Table 4.

Step 4: To test the acceptability of the estimated curve, two statistical tests are used. The student t-test is used to determine whether the mean is within the 95 percent confidence intervals of the estimated future average truck weight. The chi-square test is used to determine the variance (5). If either the mean or variance of the estimated curve is outside the confidence intervals of the corresponding values, go back to step 1 and repeat the procedure. If both mean and variance are within an accountable limit, go to the next step.

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

The computation of mean and variance is given in Table 4. The example demonstrates the prediction for the 3-S2 truck weight curve in 1978. The base year is 1970, which was chosen because of the largeness of its sample size.

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

1. GVW = 72 to 80 kips,
2. Tandem-axle weight = 32 to 34 kips, and
3. Single-axle weight = 18 to 20 kips.

Table 4. Computation of mean and variance from an estimated cumulated distribution curve.

GVW Distribution Intervals	(B) Mid-GVW Intervals	(C) No. of Trucks	B x C	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	33.5	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	78,256	4,240,727.88

Notes: Mean = 78,256/1,605 = 48.76.
Variance = {4,240,727.88 - [$(78,256)^2$/1,605]} = 265.06.
Standard deviation = 16.28.

Based on the 1975 weight laws, the practical maximum GVW was estimated to be 80.0 kips. As noted from the data in Table 2, the average GVW factor for 3-S2 is 0.66. Thus the average GVW after the weight law changes is 52.80 kips.

When the average GVW factors were derived, only legal vehicles were included in the computation of average GVW. Overloaded vehicles can be accounted for by using a violation factor. For example, if the violation population is estimated to be approximately 5 percent of the total population of a particular type of truck, the violation factor is then equal to 1.05. For the above example, the adjusted GVW is 52.8 x 1.05, or 55.44 kips.

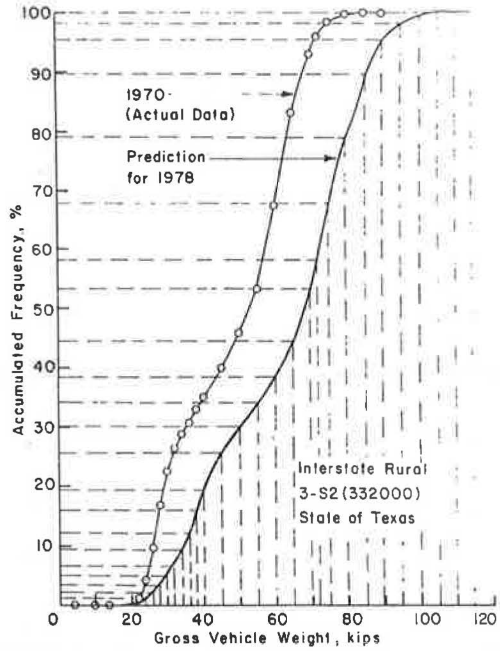
As shown in Table 1, the average GVW for 1970 is 47.65 kips. From the 1970 weight distribution curve, a first shifting was attempted (Figure 2). From the shifted curve, an average GVW of 62.5 kips was obtained. A comparison of this figure with the expected average GVW (55.44 kips) indicates that the second curve is too much to the right and should be between the unshifted and the first shifted curve. A new plotting is attempted. From the new shifted curve, a mean of 55.09 and a variance of 352.33 are obtained. The standard deviation of the curve is 18.79. The computation of mean, standard deviation, and variance is given in Table 4.

Because 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. Hence statistical tests are used to set bounds for the predicted values. The student t-test and chi-squared test are applied to the mean and variance, respectively.

From the example, the parameters of the shifted curve are mean = 55.09, variance = 353.23, and standard deviation = 18.79. The expected mean based on the average GVW factors is, however, 55.44.

The student t-test is applied in order to accept

Figure 2. First trial shifting from 1970 data for projection of 1978 GVW distribution.



or reject the shifted curve. The t-value for the shifted curve is

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

It should be pointed out that, in response to weight law changes, only the average truck weight is used to predict a shifted curve.

A chi-sqaure test was conducted by using available 1978 truck weight data. With a confidence level of 0.05 and 29 degrees of freedom, the chi-square value obtained is 42.56 (5). Because the computed chi-square value (1.47) is much lower than 42.56, it indicates that the projection is acceptable.

From the experience gained in the use of this procedure, a few suggestions can be made that should enhance its use by others. 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 whether the next curve should be shifted to the right or left of the first shifted curve. If the mean weight of the first shifted curve is above the expected weight 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 shifts.

PREDICTIONS OF AXLE WEIGHT DISTRIBUTION AND 18-KESAL

In the estimation of highway maintenance and rehabilitation cost, an important input is the prediction of total 18-KESAL. The axle weight distribution directly affects the computation of total 18-KESAL. A method for predicting axle weight distributions for selected vehicle classes was developed.

Estimation of Tandem-Axle Weight Distribution

The procedure was developed in order to focus on two types of trucks: 3A and 3-S2. Axle weight predictions for 2D and 2-S1-2 were eliminated because the available data sources for truck weights (W-4 tables) do not allow distinction between loaded axle distributions (i.e., steering axle versus rear or loaded axles). For 3A and 3-S2, the axle weight distributions given in the W-4 tables allowed separation of the steering axles from the loading axles. An investigation of steering-axle weight distribution facilitated a new approach for the vehicle classes.

For the single-unit truck symbolized by 3A, the single-axle data given in the W-4 tables are the steering-axle data, whereas the tandem-axle data are for loading axles. Therefore, the GVW is

$$GVW = SAW + TAW$$

where SAW is single-axle weight and TAW is tandem-axle weight. For the 3-S2, which has one single axle (steering axle) and two tandem axles, the GVW may be expressed as

$$GVW = SAW + \Sigma(TAW) \quad (1)$$

Attempts were made to relate the GVW, SAW, and TAW weight distribution data for 3A and 3-S2. The approach was to explore the relation among GVW, SAW, and TAW for 3A and 3-S2 so that a TAW distribution could be predicted directly from the GVW distribution.

Therefore, let GVW(i%), SAW(i%), and TAW(i%) be the GVW, SAW, and TAW at i percent along the truck weight cumulated percentage curves for either 3A or 3-S2. For the single-unit trucks represented by 3A, prediction of TAW(i%) was based on

$$TAW_{3A}(i\%) = GVW(i\%) - SAW(i\%) \quad (2)$$

and for 3-S2,

$$TAW_{3\text{-}S2}(i\%) = GVW(i\%) - SAW(i\%) \quad (3)$$

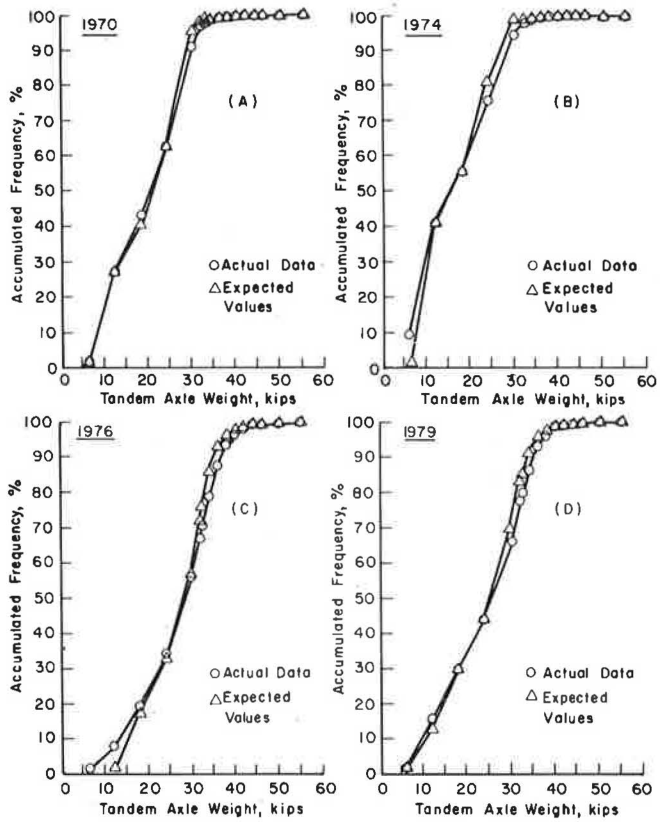
In the analysis, predicted TAW values were compared with data collected in the annual Texas weighing operation. Once the TAW(i%) values were obtained, a predicted cumulative percentage curve was constructed. The predicted TAWs and the actual TAWs were plotted in a graph for comparison. Data collected over a period of several years were used to test the relations stated in Equations 2 and 3. The years selected represent a spectrum of different conditions. 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 a significant increase in truck weights after the 1975 change. Year 1979 was used to reflect the latest trends. The distribution curves for 3-S2 are shown in Figure 3. Along with the distribution curves, the predicted and actual TAW distribution data were also analyzed for the goodness-of-fit with the chi-squared values given in the following tables. The first table gives the chi-squared values for the 3A:

Year	Chi-Squared Value
1970	20.68
1974	75.06
1976	19.58
1979	18.24

The next table gives the chi-squared values for the 3-S2:

Year	Chi-Squared Value
1970	9.08
1974	33.85
1976	12.87
1979	10.35

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



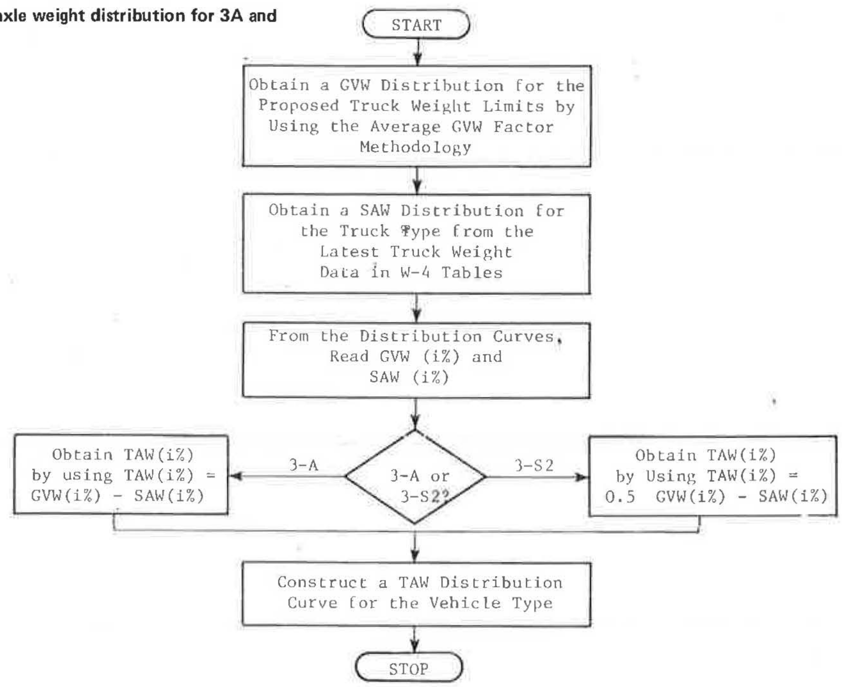
Both the graphics and the chi-squared values indicate that the predicted TAW distribution agrees closely with actual field data.

From the study of GVW and axle weight distributions, it can be concluded that a simple relation of GVW, SAW, and TAW for a single truck is applicable to the weight distribution data. The relations stated in Equations 1 and 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 for predicting TAW distributions and 18-KESAL as a result of a change in the legal truck size or 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 GVW limits in 1975 did not change the distribution of steering-axle weight. This observation is based on the analysis of steering-axle weight distribution curves. Because of practical consideration and concern for operational safety, the steering-axle weight distribution did not change, even though the weight laws changed. Thus, for prediction purposes, it is suggested that the current steering-axle weight distribution be used as an estimate of the future steering-axle weight distribution under the changed legal limits. Similarly, 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 previously. The procedures are shown in Figure 4.

Figure 4. Flowchart for predicting tandem-axle weight distribution for 3A and 3-S2.



The procedures used to predict the tandem-axle weight distribution are as follows:

1. When the previously stated methodology is employed, use the average GVW factor to obtain the GVW distribution curve under a proposed truck weight limit.
2. Obtain the SAW distribution for the truck type from the latest weight data in the W-4 tables.
3. Read the GVW(i%) and SAW(i%) values from the GVW and SAW distribution curves.
4. Use the appropriate equation for each truck type; i.e., for 3-S2,

$$TAW(i\%) = 0.5\ [GVW(i\%) - SAW(i\%)]$$

and for 3A,

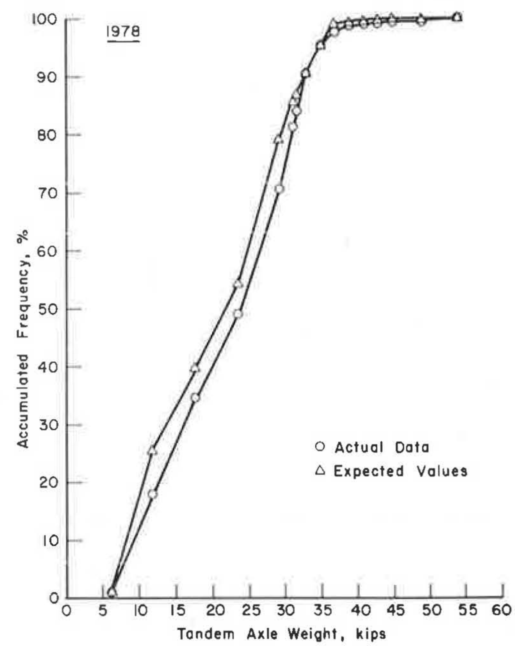
$$TAW(i\%) = GVW(i\%) - SAW(i\%)$$

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

To illustrate the application of the procedure, an example that uses the 3-S2 on Texas Interstate highways is provided in the next section.

An illustration of the actual and predicted values by using TAWEXP, a program that predicts tandem-axle weight for 3A and 3-S2 by using the previously mentioned procedures, is shown in Figure 5. A chi-square test of the actual and predicted curve was performed and found to be acceptable.

Figure 5. Comparison of actual and predicted tandem-axle weight distributions for 3-S2 on Texas Interstate rural highways.



Calculation of 18-KESAL

To assess the pavement impact due to changes in legal weight limits, the 18-KESAL applications have to be computed under the current and proposed weight limits. The data source used in the computation of the total number of 18-KESAL 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 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" (6).

The 18-KESAL applications for the proposed weight limits can be computed from the shifted axle weight distribution curve. 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 Figure 6 summarizes the procedure.

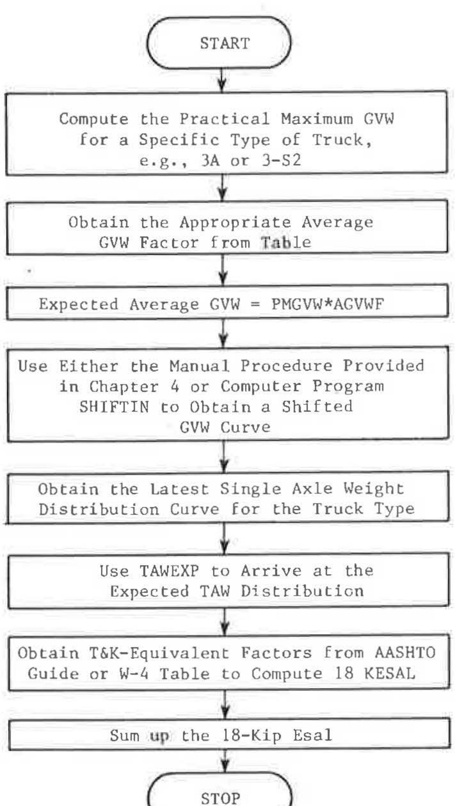
For illustrative purposes, the predicted tandem-axle weight distribution obtained earlier is again used to compute the equivalent 18-kip axle load. Both flexible and rigid pavement 18-KESAL for actual and predicted axle weight distributions are given in Table 5. The differences between the actual and predicted 18-KESAL are less than 1 percent for both the rigid and flexible pavements.

Comment on 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 shift for TAW distribution depends on both GVW and SAW distributions. Therefore, the accuracy of the prediction of future axle weight distributions depends on the quality of current axle weight distribution data and the sample size.

To remedy the deficiency in sample size, users may combine data of the same truck type from different years. This may be significant for the steering-axle distribution of 3A and 3-S2 because the SAW distribution curves did not shift significantly throughout the years. Hence combining the data will improve the accuracy of prediction.

Figure 6. Shifting procedure and computation of 18-KESAL.



SUMMARY AND RECOMMENDATIONS

The objective of this study was to develop a shifting methodology that could be used to predict future GVW and axle weight distributions and 18-KESAL applications in response to changes in laws governing the size and weight of trucks.

While developing the Texas Shift, the following concepts were introduced to facilitate more precise predictions.

1. Extensive use of historical data in projecting future distribution: Several computer programs were written to facilitate analysis and modeling.
2. Use of statistical methods in analyzing historical data: Statistical tests such as the chi-square test and student t-tests are used extensively in the procedure. Computer statistical packages such as the Statistical Package for the Social Sciences (SPSS) and MINITAB were used in data sorting and analysis.
3. Computer application in conducting the shifting procedure: Due to the large amount of historical data and a large number of required input parameters, use of computers became a necessity.
4. Concept of using mean and variance to predict future distribution: Both the mean and variance for the weight distribution curves usually suggest specific trends over a period of time that can be represented by regression models. By using these models these two parameters may be predicted for future truck weight distributions. The suggested shifting procedure enables one to obtain a future weight distribution curve with acceptable precision.
5. Concept of using an average GVW factor for projecting average GVW under a proposed limit: The average GVW factor is used to relate a known param-

Table 5. Computation of actual and predicted 18-KESAL for flexible pavement for 3-S2 on Texas Interstate highways.

Weight Groups	Observed Sample	Predicted Sample	Flexible Pavement 18-KESAL 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	1,019	1,962.2	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
Σ	4,744	4,744.0		2,092.00	2,217.0

Note: Δ = (2,217 - 2,092)/2,092 = 5.98 percent.

eter to an unknown parameter (for example, the future maximum GVW to the future average GVW). From the proposed truck weight limits, the future maximum practical GVW may be derived for a certain truck type. By multiplying the future maximum practical GVW with a given average GVW factor, the estimated average GVW for that truck type under the proposed limits may be obtained. Once the future average GVW is obtained, a future truck weight distribution may be projected by using the shifting methodology suggested herein.

Although the main data set came from the Texas Interstate system, the shifting procedure can be used for other types of highway systems and is considered applicable to other states. For a long-term investment on the existing federal and state highway systems, it is strongly recommended that truck weighing activities be intensified and operating efficiency be improved.

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This paper reflects our views, and we are responsible for the contents, facts, and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of TSDHPT. This report does not constitute a standard, specification, or regulation.

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Truck Size and Weight Enforcement: A Case Study

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In this paper the current state regulations affecting motor vehicle sizes and weights, the agencies involved directly or indirectly in the enforcement of these regulations, the characteristics of oversize and overweight vehicle movements within the state (both legal and illegal), and the cost of these vehicle movements to the state are discussed. The characterization of oversize and overweight movements in Texas is emphasized. To study the economic effects to the state, a 100 percent compliance case was set up to compare with the actual case. The case study of Texas showed that, although the current oversize and overweight movements may save the trucking industry up to $1.4 billion over the next 20 years at current conditions, these movements are estimated to cost the state an additional $261 million over the same 20-year period. Similarly, enforcement of the state laws is estimated to result in only $84 million if the current fine and permit fee structure is maintained. It was recommended that the current fine and fee structure be revised to discourage violation.

Due to the growth of truck traffic, interest in the effects of change in motor vehicle size and weights, and the challenge of perpetuating the nation's highway infrastructure, Texas has sponsored a series of truck size and weight investigations. These studies have focused on gaining a better appreciation of these trends and how to best integrate them into a rational decision framework for future highway programs and activities. The issues of legal limits, enforcement, and permitting were combined into a case study of the Texas experience, which may provide information and assistance to other states.

Almost two-thirds of all Texas communities depend entirely on trucks for service, and 98 percent of the fresh fruits and vegetables and 99 percent of the livestock are transported to principal markets by trucks (1). The importance of load limits and highway design practices was recognized early in the history of highway development. This interrelation led directly to limitations on vehicle loads, and laws were enacted in many states to establish maximum allowable motor vehicle sizes and weights (2). The first such law in Texas was enacted in 1929 (3). Since then the law has been modified several times. The most recent major changes of the law occurred in 1975, when the maximum gross vehicle weight was raised to 80,000 lb, the maximum single-axle load to 20,000 lb, and the maximum tandem-axle load to 34,000 lb.

As the highway system in Texas matured and there was a shift in emphasis from construction to maintenance and rehabilitation, the enforcement of motor vehicle size and weight laws became a highlighted issue. Strict enforcement of motor vehicle size and weight laws is a step toward reducing motor vehicle size and weight violations, heavy truck accidents, and, even more, highway maintenance and rehabilitation expenditures.

The various governmental units in Texas that are involved in regulating or enforcing the regulations on motor vehicle sizes and weights include the Department of Public Safety (DPS), the Texas State Department of Highways and Public Transportation (TSDHPT), the Office of the Attorney General (AG), the Texas Railroad Commission (RRC), and the Justices of the Peace (or the county court system). Among these governmental units, the DPS has the most direct role in enforcing size and weight laws.

A study was undertaken to summarize the current size- and weight-related activities in Texas and to