STATEWIDE DETERMINATION OF HIGHWAY LOADINGS AND CONVERSION TO 18-KIP SINGLE AXLE LOAD EQUIVALENCE

MICHIGAN
HIGHWAY RESEARCH LABORATORY SECTION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

STATEWIDE DETERMINATION OF HIGHWAY LOADINGS AND CONVERSION TO 18-KIP SINGLE AXLE LOAD EQUIVALENCE

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CONTENTS

ABSTRACT

This study was initiated to develop a method for estimating both commercial traffic volumes and commercial traffic axle load characteristics. Sampling plans were developed for estimating commercial traffic numbers, vehicle types, and axle loads. Relationships between sample size, confidence levels, and precision of estimates are shown.

It was found that, for the most important commercial vehicle types, axle loads were relatively consistent, even between geographical locations. However, for estimating vehicle volumes and types, samples should be taken at any location where such information is desired.

Continuous records of commercial vehicle traffic passing through State Weigh Stations during 1960 through 1965 were used for developing a means of estimating annual commercial traffic volumes. Factors are provided so that 9 hour, 12 hour, and 24-hour sample counts can be expanded into estimates of annual commercial traffic volumes. Sampling units should span all quarters of a calender year because of seasonal fluctuations. Figure A shows the relationship between average precision of estimated annual volumes and the number of 24-hour sample counts used for the estimate.

Intensive sampling of commercial axle weights was carried out at eight permanent weigh stations. Because both between-station and within-station variances were relatively small for important types of vehicles, it appears that annual loadometer studies could be used to provide an estimate of axle loadings for each vehicle type.

Sampling to determine distributions of commercial vehicle types was periodically repeated over a two-year span at 22 locations throughout the State. The distribution of vehicle types was found to be not consistent between locations so each location must be sampled where an estimate of vehicle type characteristics is desired. Figure B shows the number of 24-hour sampling units that are required for any desired average precision of estimate. As with estimating commercial vehicle volumes, sampling units should be randomly selected from different quarters of a calender year because of seasonal variation. Sampling for both commercial vehicle volumes and their types can be carried out simultaneously.

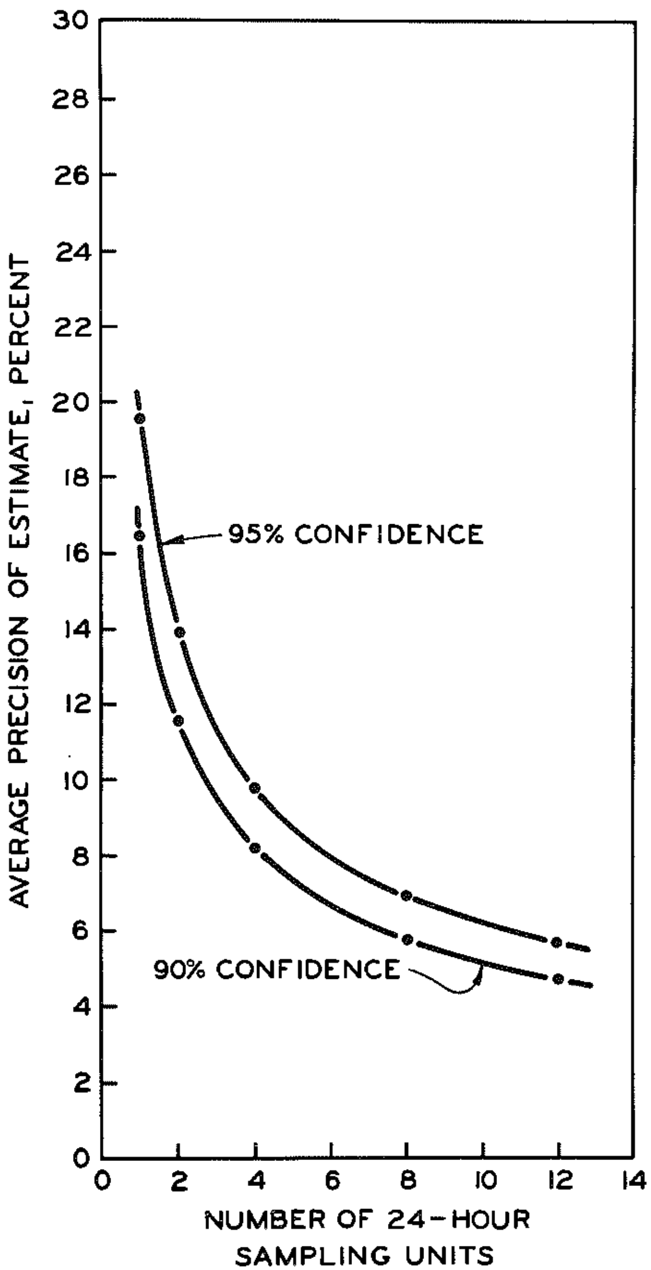
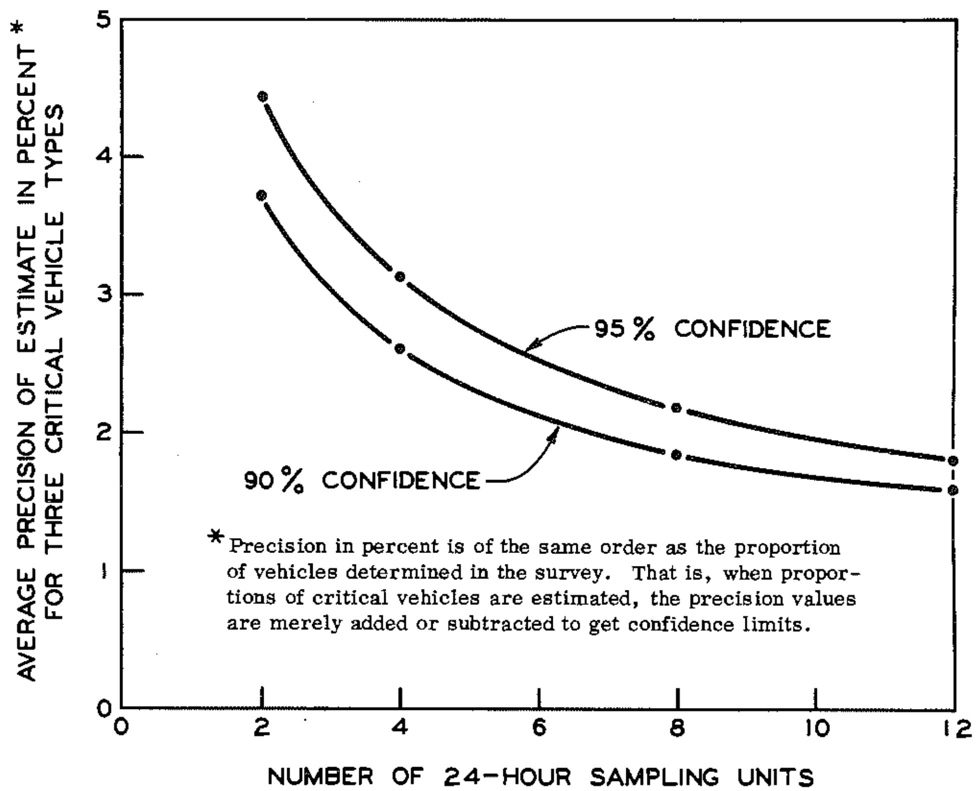


Figure A. Relationship between precision of estimated annual commercial vehicle volumes and sample size.

Figure B. Relationship between average precision of estimate of distribution of vehicle types and number of 24-hr sampling units.



INTRODUCTION

The service life of a pavement is a function of a number of variables; including vehicle axle loadings. The AASHO Road Test (1) showed how the service life of a pavement could be estimated using design parameters together with the magnitudes and cumulative repetitions of vehicle axle loads.

The investigation described in this report, of traffic loadings on Michigan highways, was financed from July 1, 1963 to June 30, 1966 by the Federal Highway Administration under the Highway Planning and Research program. The broad objective of this study as stated in the Proposal was to "... develop an improved system for estimating the magnitude and frequency of axle loads traveling over the entire Michigan Interstate and Primary Road network." Specifically, sampling plans were to be developed for estimating truck volumes, types, and axle loads traveling over any given pavement. Factors were to be developed for expanding sample truck volumes into weekly, monthly, or annual volumes. A systematic classification of pavements was to be attempted whereby commercial traffic characteristics could be related to such factors as geographical location, industrial environment, and cities joined by the highway under consideration.

As the investigation proceeded, it was logically separated into three phases:

1) Develop a method for expanding small sample counts of commercial vehicles into estimates of monthly and yearly volumes.

2) Determine the axle load characteristics for each type of commercial vehicle encountered on the Michigan trunkline system.

3) Determine the distribution of commercial vehicle types traveling on highways throughout the State.

By completing all three phases and integrating the results, a complete picture of the commercial traffic stream was to be developed for any Michigan highway. Further, by converting individual axle loads of each type vehicle to a common value, using AASHO Road Test results, a direct and simple comparison of traffic loadings on various roadways can be made. Separate discussions are included in this report for each of the three phases of the study.

Statistical terminology used throughout this report is defined in the Appendix.

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PHASE I
ESTIMATING COMMERCIAL VEHICLE VOLUME

Purpose

The purpose of this phase of the project was to develop a method for estimating the volume of commercial traffic at any desired location during some given time period, such as a month or year.

Procedure

The first step was to develop a means for accurately determining historical traffic volumes for various time periods at several locations. Using relationships between known traffic quantities, factors were developed for estimating traffic volume for a large time period from small samples. Then, sampling plans were developed and tested for accuracy against the known volumes.

Weigh Station Reports

For several years, weighmasters at State Weigh Stations maintained hourly records of commercial vehicles passing over their scales. Only quantities of vehicles were counted, without regard to type or weight. Had these records been accurately and continuously maintained for any period ot time, the precise commercial traffic volume could have been determined for each weigh station. However, a number of problems were involved in using these reports. First, all commercial vehicles do not pass over the scales. Bypassing the weigh stations are such vehicles as buses, auto haulers, and certain delivery trucks. Second, weigh stations are closed down intermittently and at such times no records are kept. Third, it was observed that not all weighmasters were always conscientious in maintaining their records of vehicle counts.

In spite of these faults, however, it was decided that the weigh station reports were the best available data for commercial vehicle volume. Many thousands of individual daily weighmaster reports from 26 different locations spanning the years 1960 to 1965 were used in the study. Locations of the weigh stations are shown in Figure 1 and listed in Table 1.

One of the first tasks was to summarize annual commercial traffic volumes for each weigh station. To facilitate processing, traffic counts were grouped into 3-hr periods beginning at midnight. Where entries had been

TABLE 1
WEIGH STATIONS USED FOR COMPILING TRAFFIC VOLUME SURVEY DATA

No.	Station	Highway	Location
1*	Portland	I 96, WB	1-1/2 mi E of M 66
2*	Portland	I 96, EB	1-1/2 mi E of M 66
3	Pontiac	I 75, NB	1 mi W of US 10
4	Pontiac	I 75, SB	1 mi W of US 10
5	Pontiac	US 10, NB, SB	Just N of Drayton Plains
6	New Buffalo	US 12, NB	1/2 mi W of I 94
7	New Buffalo	US 12, SB	1-1/2 mi N of State Line
8	New Buffalo	I 94, NB	1-1/4 mi N of State Line
9	New Baltimore	I 94, NB	At 23 Mile Rd, Macomb Co.
10	New Baltimore	I 94, SB	At 23 Mile Rd, Macomb Co.
11	Lansing	M 78, NB, SB	At SW edge of City of Lansing
12*	Grass Lake	I 94, EB	2 mi W of E Co. Line
13*	Grass Lake	I 94, WB	2 mi W of E Co. Line
14	Fowlerville	I 96, EB	1 mi E of Co. Line
15	Fowlerville	I 96, WB	1 mi E of Co. Line
16*	Erie	I 75, SB	S of Luna Pier Rd
17*	Erie	I 75, NB	S of Luna Pier Rd
18*	Erie	US 24, NB, SB	7 mi N of State Line
19*	Cambridge Jct.	US 12, EB, WB M 50, NB, SB	NE corner M 50 and US 12
20	Birch Run	I 75, NB	N of Rathbun Rd
21	Birch Run	I 75, SB	N of Rathbun Rd
22	Powers	US 41, NB, SB US 2, NB, SB	US 2, US 41 intersection
	Weigh Stations Closed Since Survey		
23	Clio	US 10	At Clio Rd
24	Jackson	US 12	8 mi E of Jackson
25	Fowlerville	US 16	2 mi W of Fowlerville
26	Ionia	US 16	E of M 66

*Also used as an axle weight survey station.

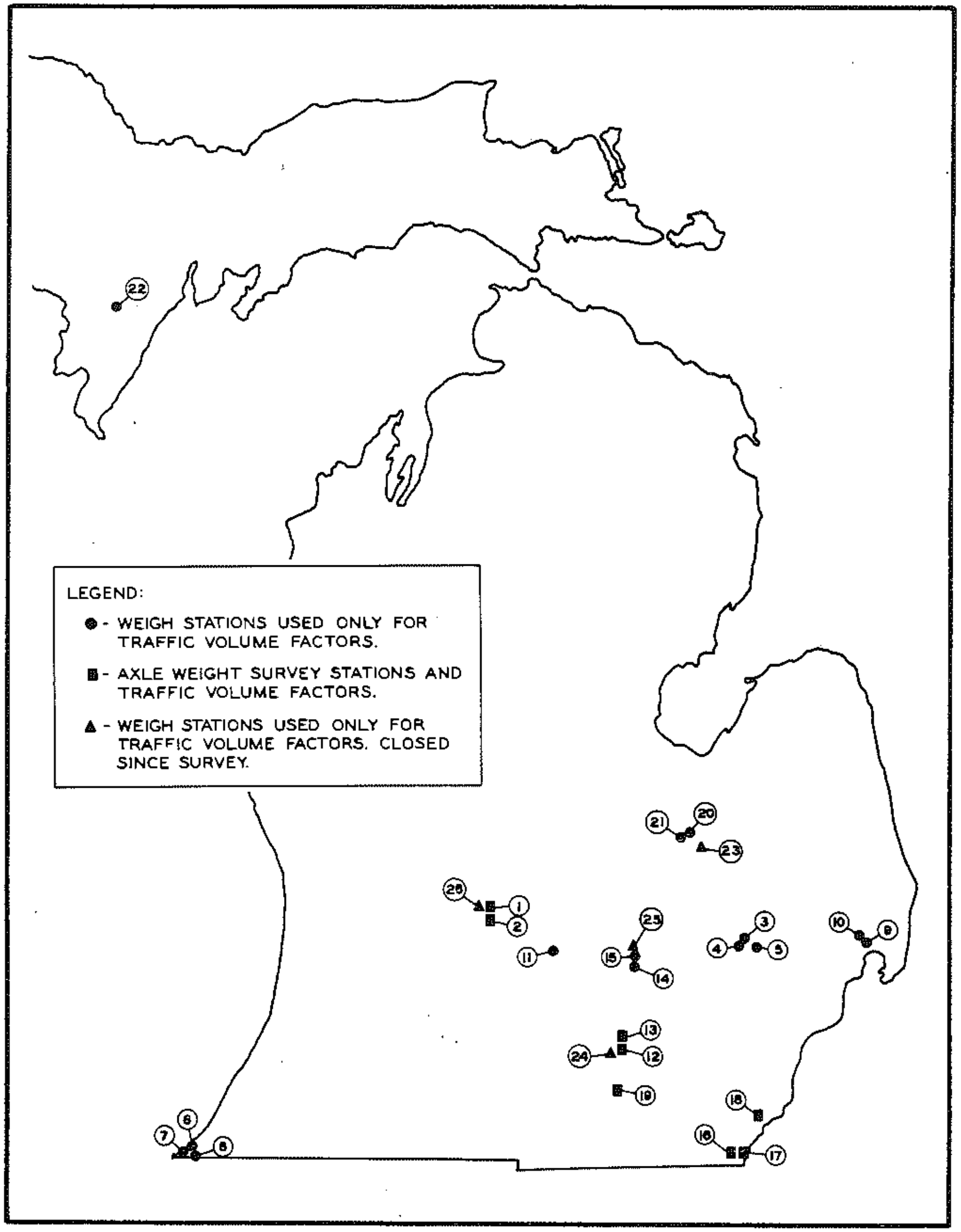


Figure 1. Locations of weigh stations used in the study.

omitted for brief periods, an estimated value was inserted. These values were estimated for each station as the mean average of similar 3-hr periods within the same quarter year. In most cases, omissions were on weekends when traffic volume was light; therefore, errors from estimating missing data would have a minor effect on annual volumes. However, for a number of stations, reports for an entire year were discarded because of excessive omissions. Finally, a total of 86 station-years (Table 2) was judged to be acceptable and used in the analysis.

Annual traffic volumes were computed for each station by summing all 3-hr time periods during a year. Similarly, daily, weekly, and monthly volumes were computed. For example, monthly volume expansion factors (K) were computed as follows:

$$K_i = \frac{V_a}{V_{mi}}$$

where: V_a = annual traffic volume
V_{mi} = monthly traffic volume for month i
K_i = expansion factor for month i

Thus, expansion factors were computed for each station applicable to each month. The product of a monthly traffic volume and its respective expansion factor would be the annual commercial traffic volume for a particular location.

Evaluation of the Three-Hour Samples

In similar fashion, factors were developed for expanding 3-hr time period volumes to weekly volumes, and weekly volumes to monthly volumes. Thus, using appropriate factors, a 3-hr sample traffic count could be expanded into an estimate of annual volume. Individual stations now had an expansion factor for each 3-hr period for each year where data were available. To be useable, however, thousands of expansion factors had to be reduced down to a relative few.

As a first step, 3-hr factors (for expanding to estimates of weekly volumes) for similar time periods were averaged over all days and years within each station. This meant that each 3-hr factor, say the one for 3 a.m. to 6 a.m., was pooled to one average value regardless of which day of the week it occurred. Standard deviations and coefficients of variation were also computed. Figure 2 shows graphically how individual factors were dispersed around their respective means for several of the stations used in the study. Coefficients of variation (standard deviation x 100 ÷ mean) were almost all well under 10 percent. This suggests that pooling the 3-hr factors does not introduce a large error.

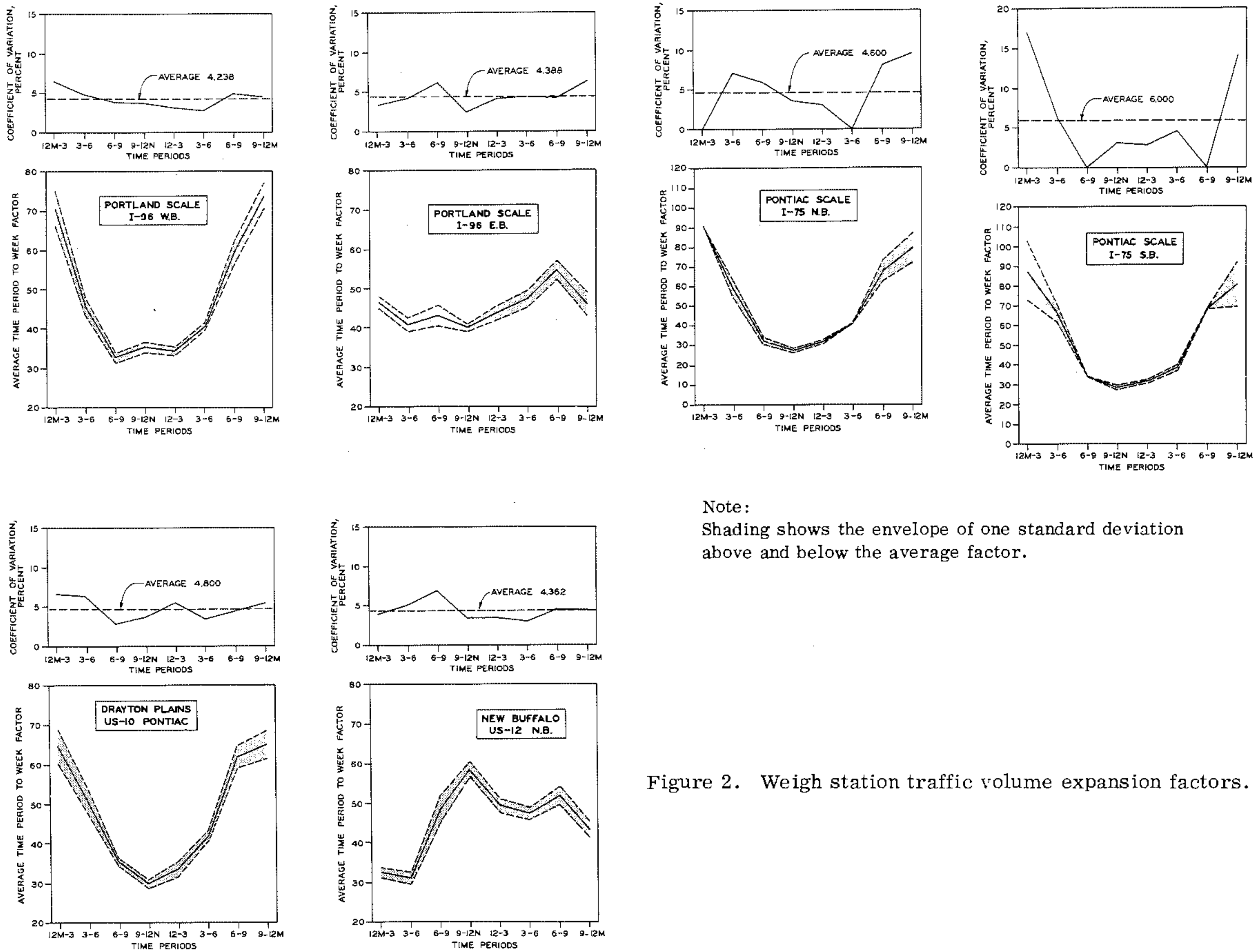
TABLE 2
WEIGH STATION AND YEAR IDENTIFICATION CODES

WEIGH STATION AND YEAR IDENTIFICATION CODES

	Code	Station	Highway
1960	01	Powers	US 2, US 41, NB, SB
	02	New Buffalo	US 12, NB
	03	Erie	I 75, NB
	04	Jackson	US 12, EB, WB
	05	Erie	I 75, SB
	06	Erie	US 24, NB, SB
	07	Cambridge Jct.	US 12, M 50, NB, SB
	08	New Buffalo	US 12, SB
	09	Pontiac (Drayton)	US 10, NB, SB
	10	Fowlerville	US 16, EB, WB
	45	Ionia	US 16, EB, WB
1961	11	Cambridge Jct.	US 12, M 50, NB, SB
	12	New Buffalo	US 12, NB
	13	Erie	US 24, NB, SB
	14	Powers	US 2, NB, SB
	15	Fowlerville	US 16, EB, WB
	16	Jackson	US 12, EB, WB
	17	Erie	I 75, SB
	18	Clio	US 10, NB, SB
	19	Pontiac (Drayton)	US 10, NB, SB
	20	Erie	I 75, NB
	21	New Buffalo	US 12, SB
1962	22	Portland	I 96, EB
	23	Grass Lake	I 94, WB
	24	Grass Lake	I 94, EB
	25	Erie	US 24, NB, SB
	26	Cambridge Jct.	US 12, M 50, NB, SB
	27	Erie	I 75, NB
	28	New Buffalo	US 12, SB
	29	New Buffalo	US 12, NB,
	30	Pontiac (Drayton)	US 10, NB, SB
	31	Erie	I 75, SB
	32	Portland	I 96, WB
1963	33	Cambridge Jct.	US 12, M 50, NB, SB
	34	Erie	US 24, NB, SB
	35	Fowlerville	I 96, WB
	36	Fowlerville	I 96, EB
	37	Grass Lake	I 94, WB
	38	Erie	I 75, NB
	39	Portland	I 96, EB
	40	Portland	I 96, WB
	41	Lansing	M 78, US 27, NB, SB

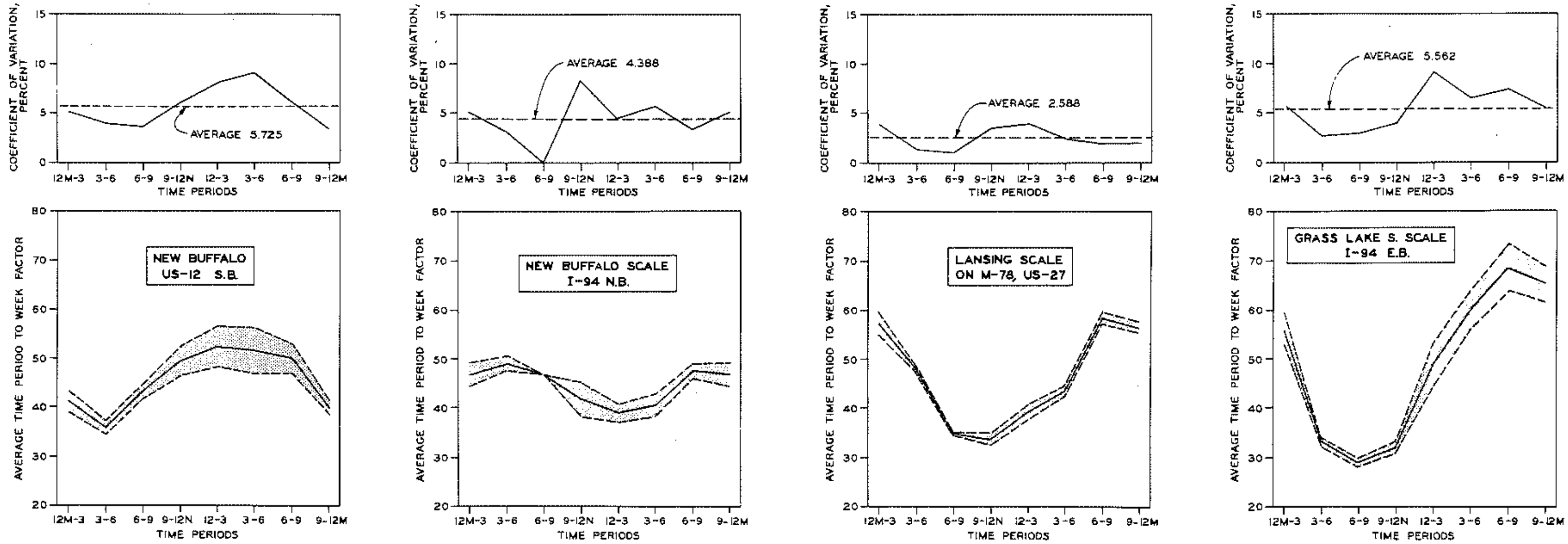
WEIGH STATION AND YEAR IDENTIFICATION CODES (Cont.)

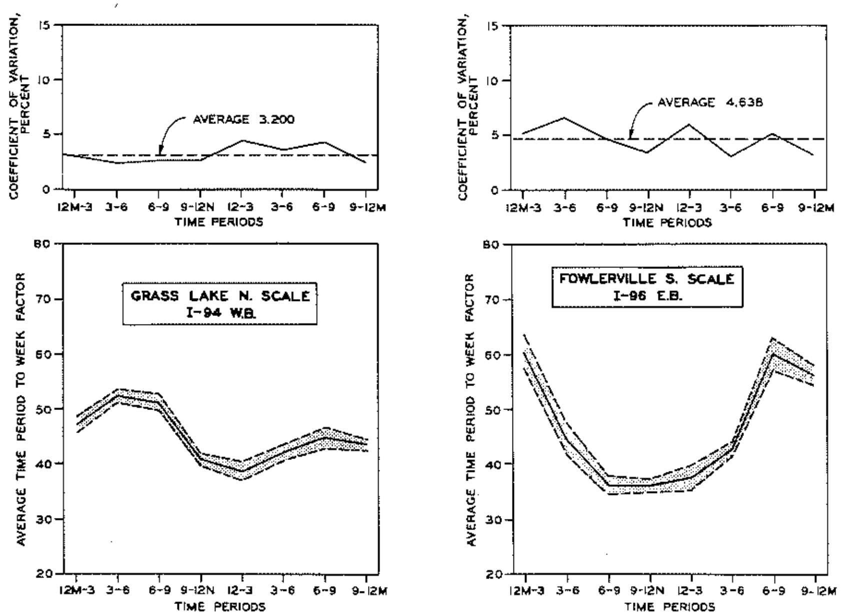
	Code	Station	Highway
1963 Cont.	42	New Buffalo	US 12, NB
	43	New Buffalo	US 12, SB
	44	Powers	US 2, US 41, NB, SB
	46	Grass Lake	I 94, EB
1964	47	Erie	US 24, NB, SB
	48	Fowlerville	I 96, EB
	49	Fowlerville	I 96, WB
	50	Erie	I 75, NB
	51	Erie	I 75, SB
	52	Grass Lake	I 94, EB
	53	Grass Lake	I 94, WB
	54	New Buffalo	I 94, NB
	55	Cambridge Jct.	US 12, M 50, NB, SB
	56	New Buffalo	US 12, NB
	57	New Buffalo	US 12, SB
	58	Pontiac (Drayton)	US 10, NB, SB
	59	Portland	I 96, EB
	60	Portland	I 96, WB
	61	Powers	US 2, US 41, NB, SB
	62	Pontiac	I 75, NB
	63	Pontiac	I 75, SB
	64	Birch Run	I 75, NB
	65	Birch Run	I 75, SB
1965	66	Birch Run	I 75, NB
	67	Birch Run	I 75, SB
	68	Cambridge Jct.	US 12, M 50, NB, SB
	69	Pontiac (Drayton)	US 10, NB, SB
	70	Erie	I 75, NB
	71	Erie	I 75, SB
	72	Erie	US 24, NB, SB
	73	Fowlerville	I 96, EB
	74	Fowlerville	I 96, WB
	75	Grass Lake	I 94, EB
	76	Grass Lake	I 94, WB
	77	Lansing	US 27, M 78, NB, SB
	78	New Baltimore	I 94, NB
	79	New Baltimore	I 94, SB
	80	New Buffalo	I 94, NB
	81	New Buffalo	US 12, NB
	82	New Buffalo	US 12, SB
	83	Pontiac	I 75, SB
	84	Pontiac	I 75, NB
	85	Portland	I 96, EB
	86	Portland	I 96, WB



Note:
Shading shows the envelope of one standard deviation above and below the average factor.

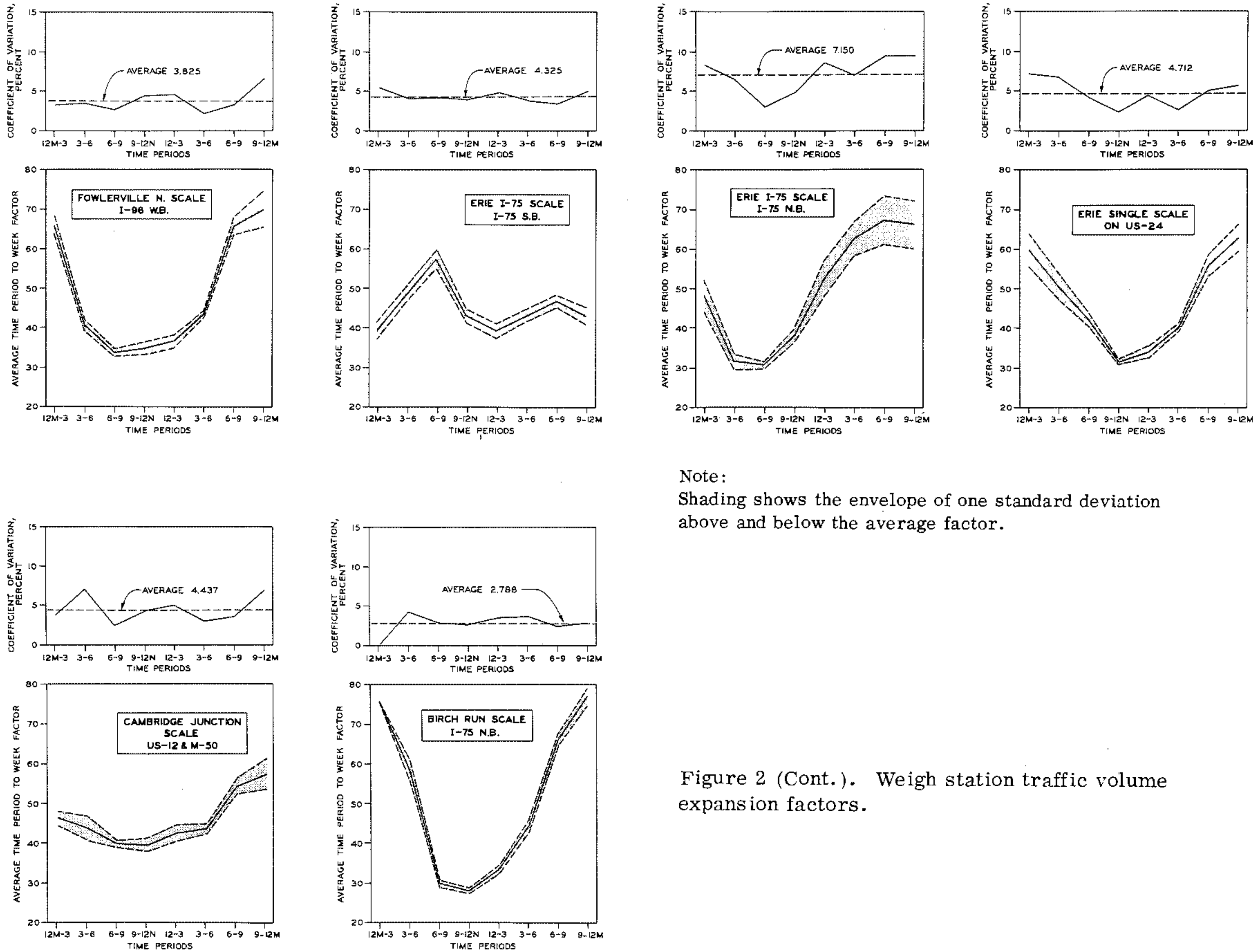
Figure 2. Weigh station traffic volume expansion factors.





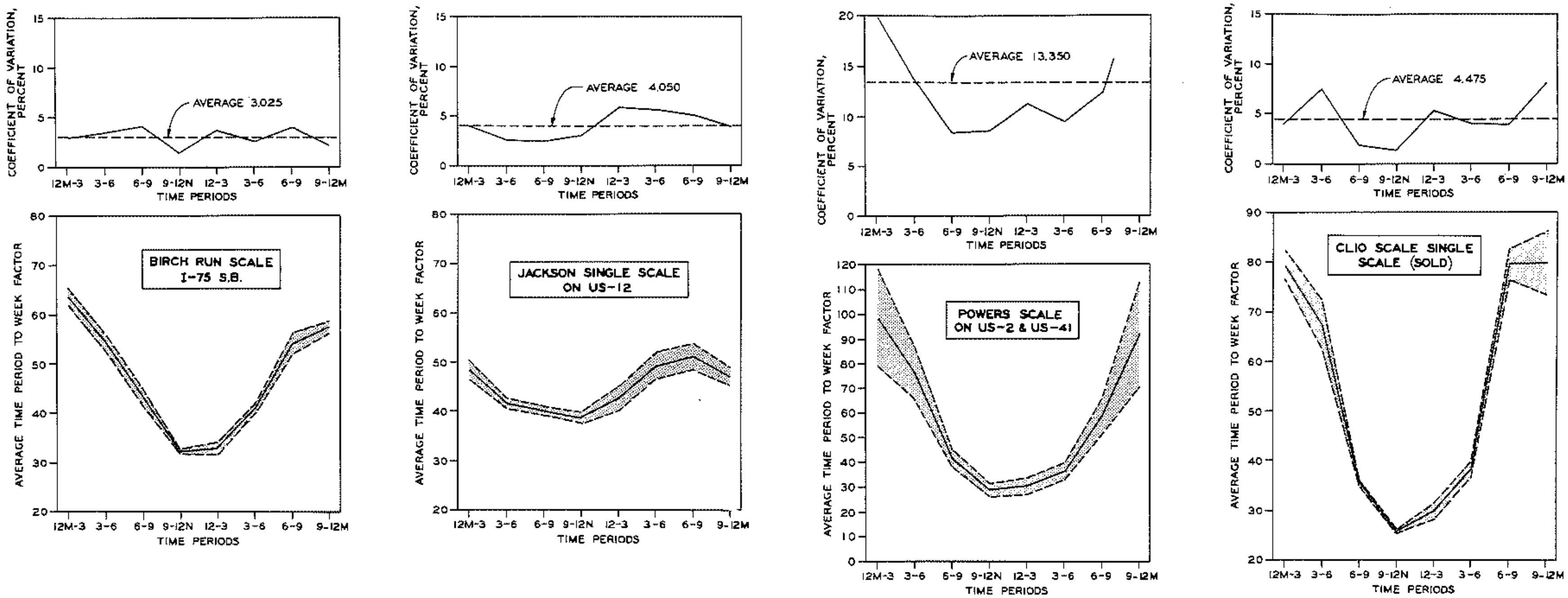
Note:
Shading shows the envelope of one standard deviation above and below the average factor.

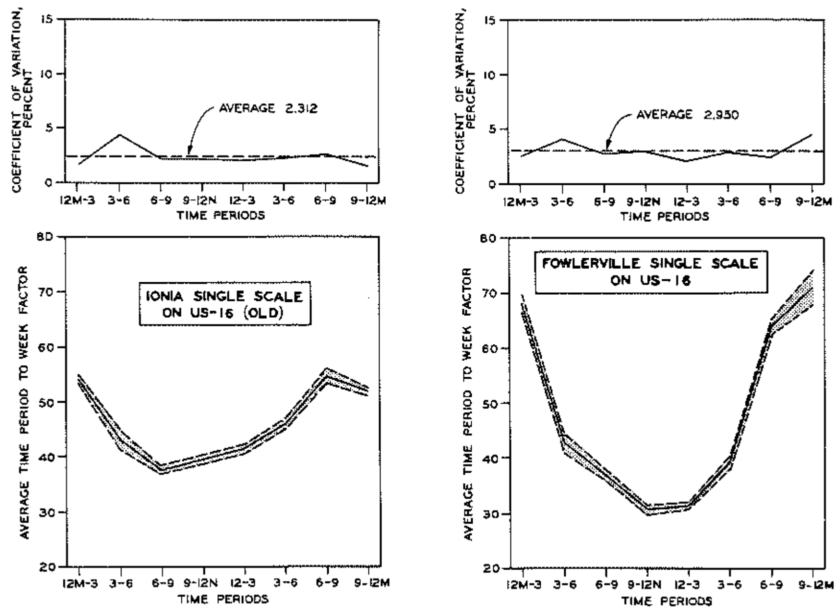
Figure 2 (Cont.). Weigh station traffic volume expansion factors.



Note:
Shading shows the envelope of one standard deviation above and below the average factor.

Figure 2 (Cont.). Weigh station traffic volume expansion factors.





Note:
Shading shows the envelope of one standard deviation above and below the average factor.

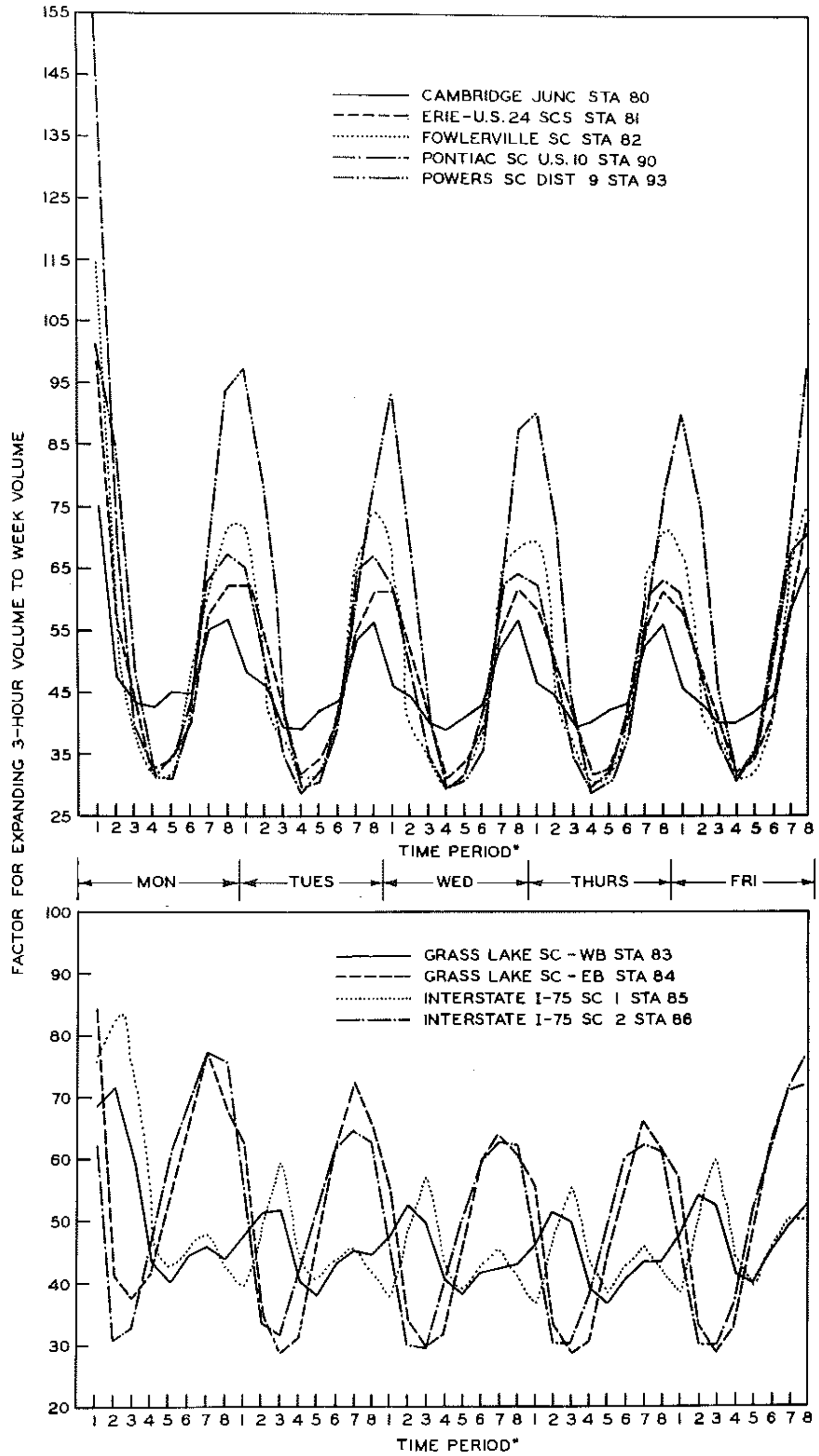
Figure 2 (Cont.). Weigh station traffic volume expansion factors.

Figure 3 shows average 3-hr time period expansion factors (for expanding to weekly volumes) across the five weekly work days for some of the weigh stations used. Shapes of daily curves (within stations) were somewhat similar, suggesting that averaging the expansion factors for all these days should not be unreasonable. Although the average 3-hr expansion factors for any station were similar from day to day, the variances about these averages were much smaller on some days than others. Figure 4 shows that the coefficients of variation were much smaller for Tuesday, Wednesday, and Thursday than for Monday and Friday. Figure 5 shows the coefficient of variation (C. V.) for each time period, and Figure 6 shows the C. V. by months. Although randomness is a key in the mathematically sound approach to sampling; if a survey had to be severly limited, consideration might be given to sampling during periods shown to have the smallest coefficient of variation.

Twelve-Hour Samples

The coefficient of variation for each station was small enough to permit use of 3-hr samples for estimating traffic volume at any station studied. However, since the purpose of this study is to develop a means for estimating traffic volume at any State trunkline location, and not just at those where weigh station data are available, expansion factors must be combined or pooled in such a way as to provide a representative or average value that is applicable Statewide. Figure 3 is a graph of 3-hr expansion factors for four Interstate highway locations, showing that the factors differ greatly between locations. Thus, an average value for 3-hr factors would represent a widely scattered distribution of individual factors and a large error could result from using this average to estimate traffic volume at some locations. It was decided that the wide range of factors between locations could be reduced by dealing with basic sample units larger than the original 3-hr units. After some trial, it was decided to try 12-hr samples and appropriate expansion factors were developed using the method previously described.

As a test of the mathematical procedures involved, 45 12-hr samples were selected randomly (simple random sampling without replacement) from all available weigh station data and expanded to estimate annual volumes. Sampling without replacement means that once a sample is selected, it is removed from having any chance of being selected again. The differences between estimated and actual volumes for the 45 samples are plotted on a histogram shown in Figure 7. If all mathematical procedures were correct, the histogram would have a mean close to zero. This is because the factors used in estimating volumes, and the sample taken, all came from the volumes being estimated. In other words, we started with total volume



*TIME PERIODS ARE IN 3 HOUR GROUPS; TIME PERIOD 1 IS FROM MIDNIGHT TO 3A.M., TIME PERIOD 2 IS FROM 3A.M. TO 6A.M., ETC.

Figure 3. Relationship between 3-hr commercial traffic volumes and total week volumes.

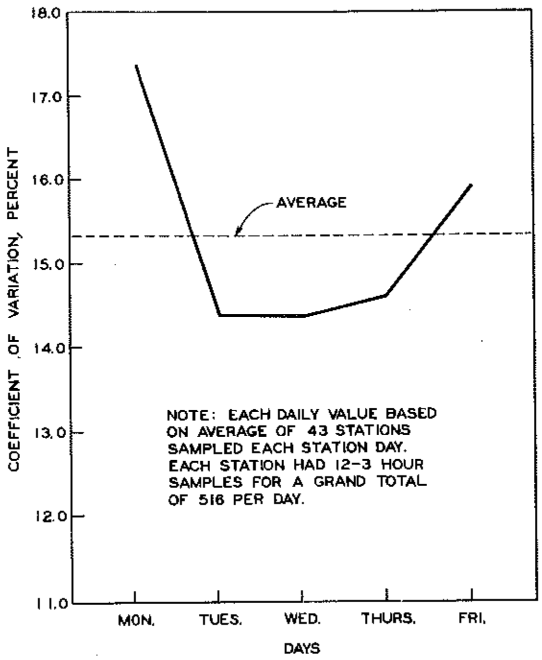


Figure 4. Coefficients of variation (C. V.) for factors used in expanding 24-hr commercial traffic volumes to total week volumes.

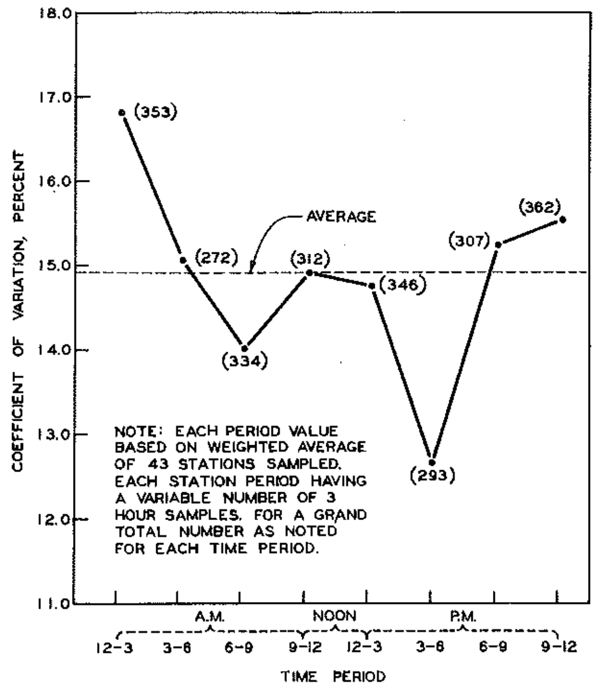


Figure 5. Coefficients of variation (C. V.) for factors used in expanding 3-hr commercial traffic volumes to total week volumes.

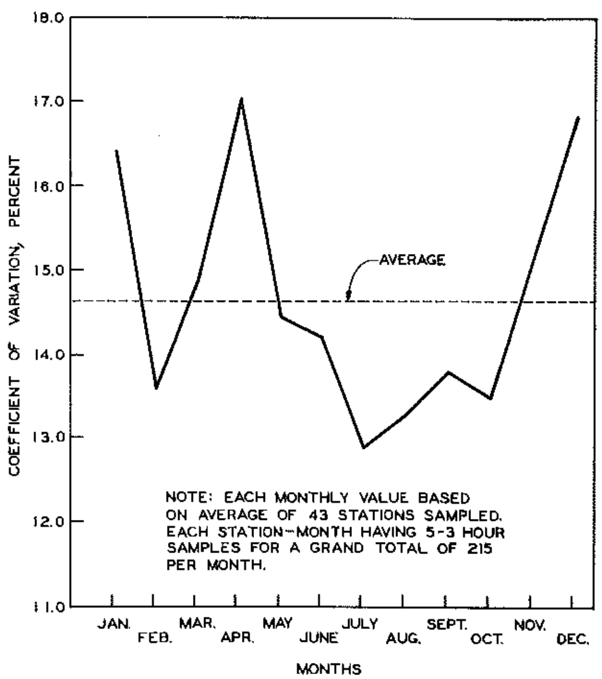


Figure 6. Coefficients of variation (C. V.) for factors used in expanding total month commercial traffic volumes to annual volumes.

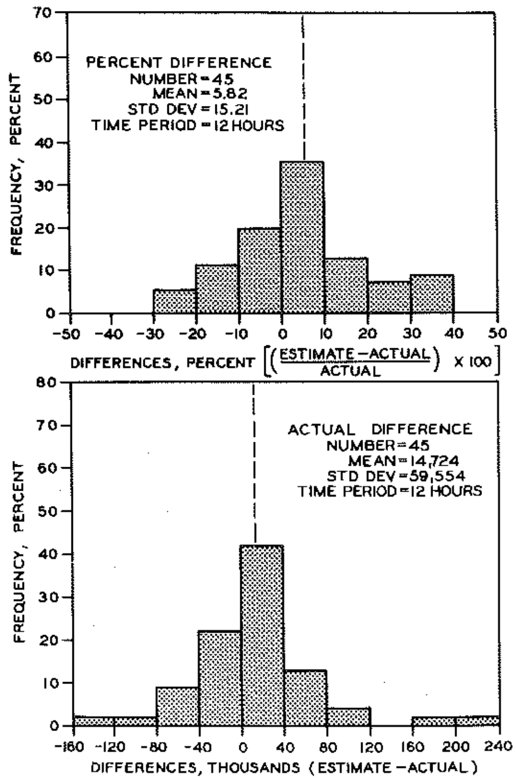


Figure 7. Distribution of total year volume estimates. Mixed Weigh Stations. (Each estimate based on a 12-hr sample).

and developed expansion factors. Now these factors are checked by selecting a number of samples from within these same volumes and expanding them back up to the annual volumes from which they came. Since the computed mean is 5.8 percent, a slight bias in the computations is suggested. Since this bias is small, if it actually does exist, it was decided to use the expansion factors as they were and to test them at individual stations.

A sample of 18 station-years was selected at random (first step) and for each of these station-years a sample of 25 12-hr time periods was randomly selected (second step). Traffic volumes for each period were expanded to estimate annual volumes. For the second step, systematic random sampling was used to select sample months from which to randomly select a time period. That is, a month from the first quarter was selected at random and every third month thereafter for a year was taken. In both steps, sampling without replacement was used. The difference between estimated and annual traffic volumes for each station are shown graphically in Figure 8. Figure 9, a summary of the data presented in Figure 8, shows distributions of sample means and sample standard deviations. Most sample means are clustered around zero, suggesting that the 12-hr expansion factors can be successfully used in most cases for estimating traffic volumes, provided that a sufficiently large sample is taken. The distribution of standard deviations shows the hazard of taking a sample that is too small; the average standard deviation being about 19. Therefore, for 95-percent assurance that, on the average, estimated annual traffic volume will be within ± 10 percent of the best estimate, a sample of 14 12-hr counts should be taken. For average accuracy of ± 15 percent, about six 12-hr counts would suffice. These estimates are based on random sampling without replacement. That is, time periods throughout a given year would be selected at random (systematic random sampling of months within quarters) and,

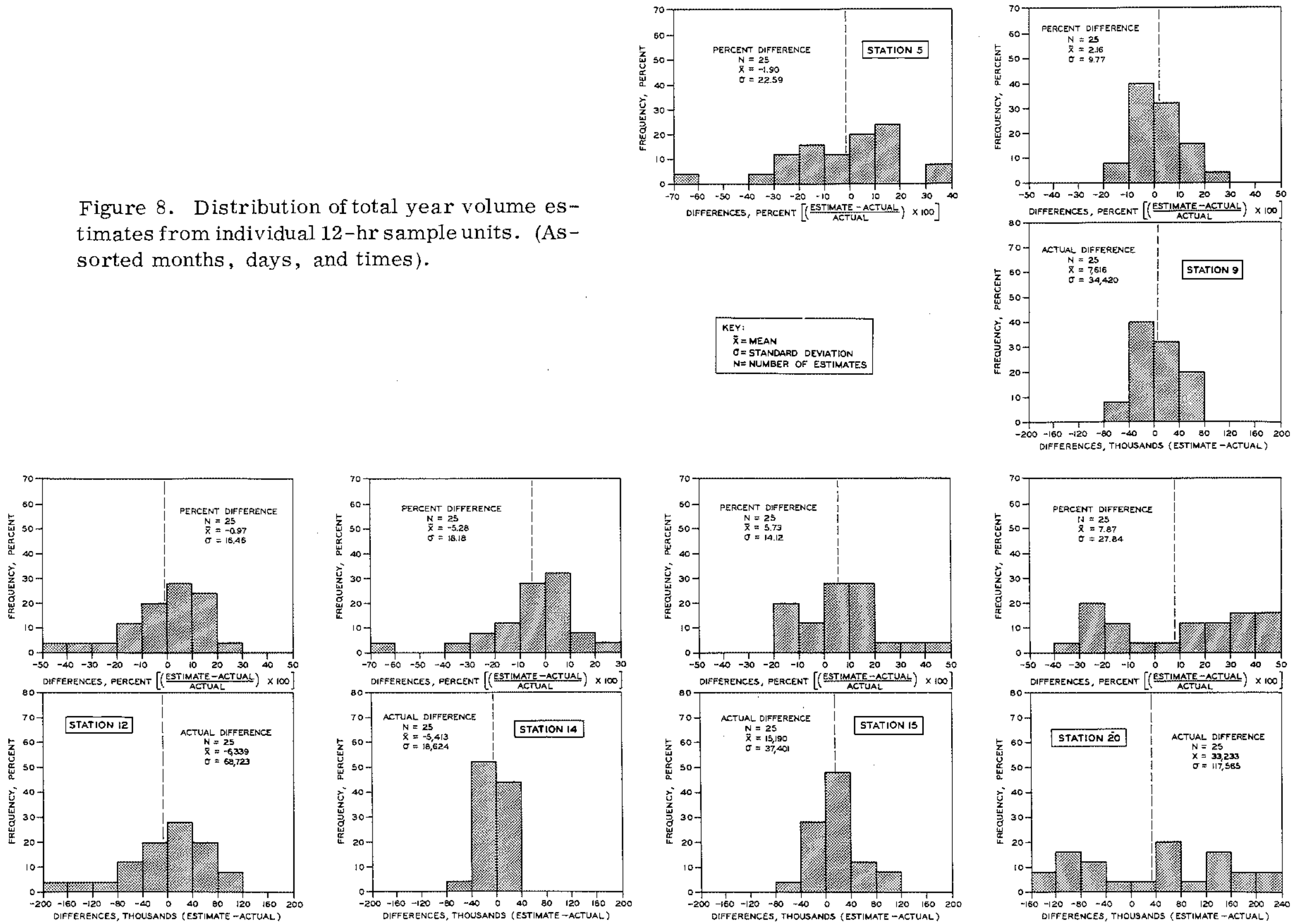


Figure 8. Distribution of total year volume estimates from individual 12-hr sample units. (Assorted months, days, and times).

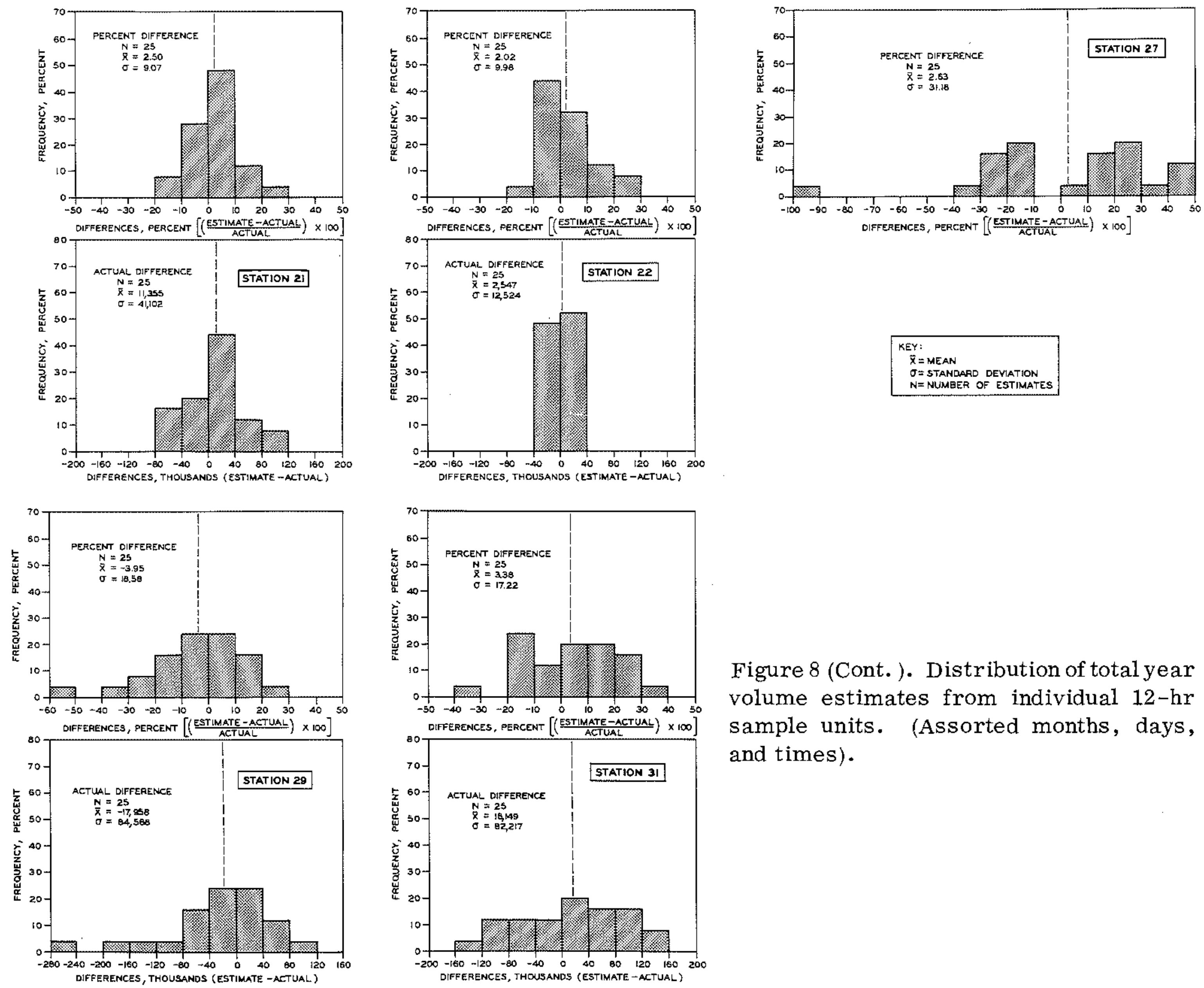


Figure 8 (Cont.). Distribution of total year volume estimates from individual 12-hr sample units. (Assorted months, days, and times).

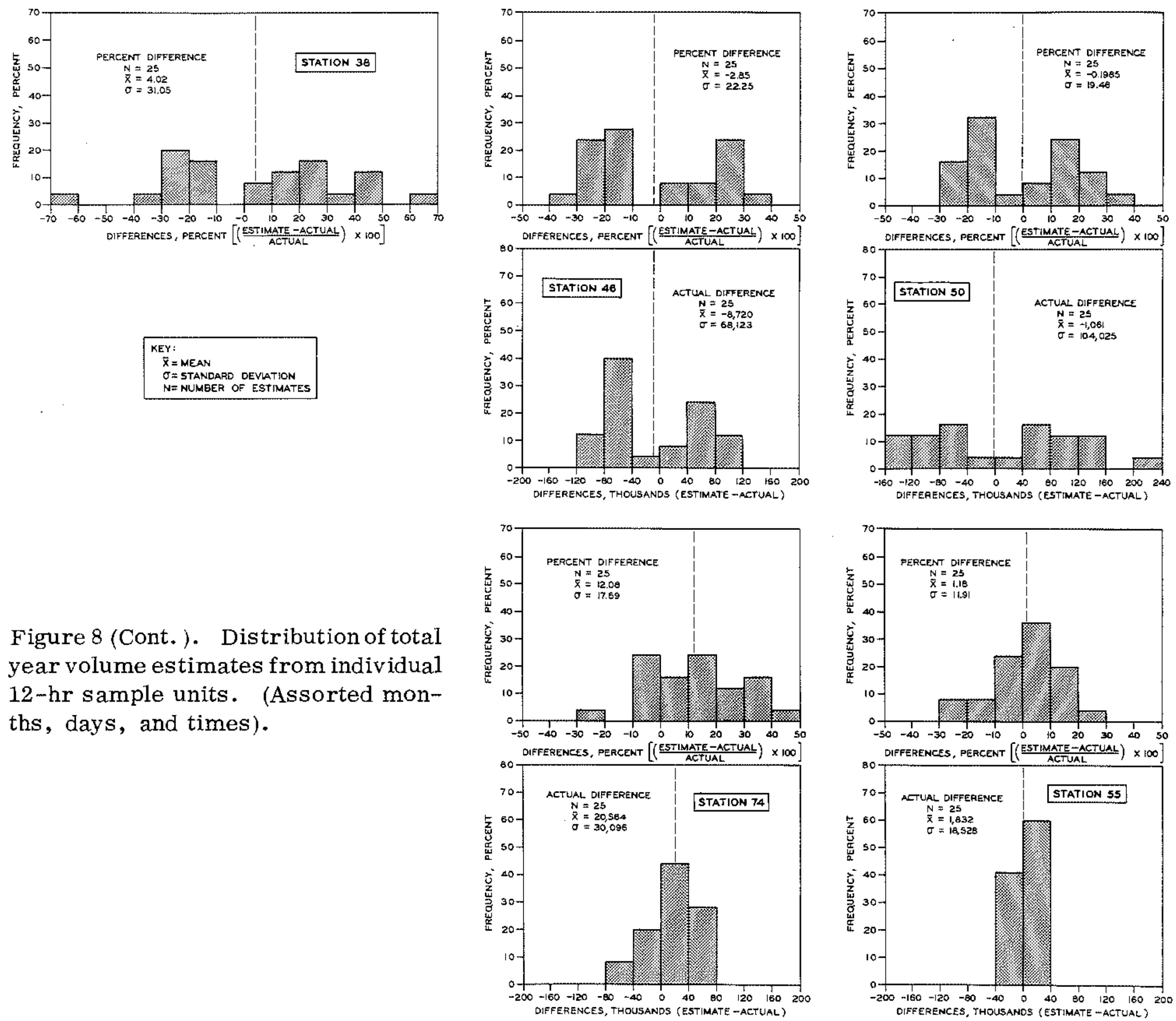


Figure 8 (Cont.). Distribution of total year volume estimates from individual 12-hr sample units. (Assorted months, days, and times).

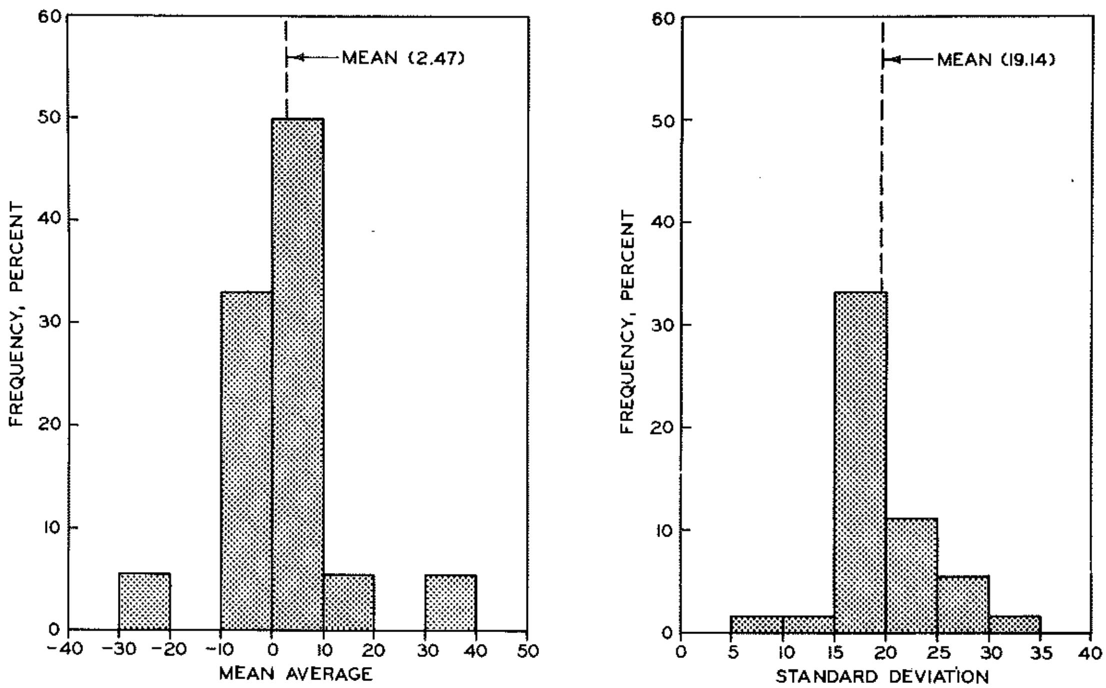


Figure 9. Distribution of sample mean averages and standard deviations summarized from 18 station years; 12-hr sample counts.

once a time period was selected, it would be given no chance of being selected a second time.

Nine-Hour Samples

Since annual truck weight and characteristics studies conducted in the past have based many conclusions on single 8-hr samples taken during a normal working day, it was decided to investigate the precision of such data. As discussed earlier, basic sample units in this study are 3-hr counts and, therefore, a 9-hr rather than an 8-hr sample was used for the investigation. The 9-hr time period used was between the hours of 9:00 a.m. and 6:00 p.m.

Similarly, as with the 12-hr samples, mathematical procedures were checked by selecting 45 9-hr samples at random from all the station-years available (simple random sampling without replacement with months selected using stratified random sampling). Each 9-hr sample count was expanded to an estimated annual volume which was then compared with its respective known annual volume. This comparison is shown in Figure 10, where the average difference between estimated and annual traffic volumes is about 2.3 percent; close enough to accept the hypothesis that the mathematics are correct.

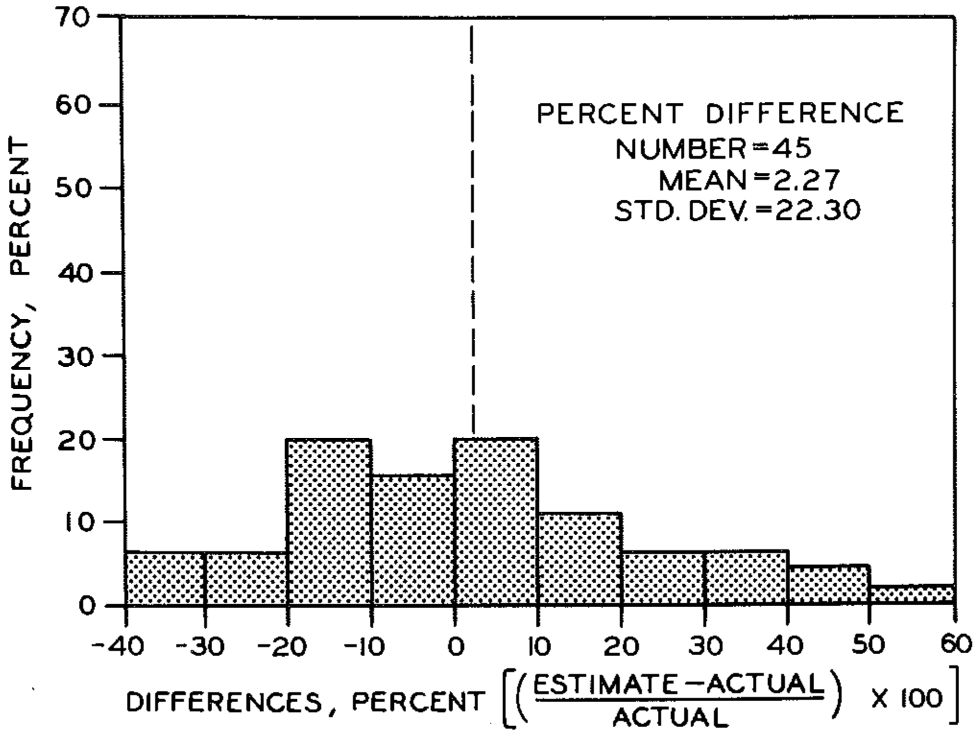


Figure 10. Distribution of differences between estimated and actual total year commercial vehicle volumes. Each estimate based on a single 9-hr count (9:00 a.m. to 6:00 p.m.), 45 assorted station, months, and days sampling units.

To evaluate the precision of estimation, 10 station-years were selected at random. Several 9-hr sample counts were randomly selected within the month of July for each station-year, expanded to estimated annual volumes, and compared with the known annual volume. Samples were restricted to the month of July to be consistent with the time of year when surveys for the annual truck weight and characteristics study are made. Differences between estimated and known annual volumes are shown in Figure 11.

The danger of using only one 9-hr count for estimating annual commercial traffic volume is clearly shown in Figure 11, where in some instances the error as determined by the difference between a known annual volume and an estimate based on one 9-hr count is over 40 percent.

Figure 12 summarizes the differences between estimated and actual traffic volumes for the 10 station-years. Although the mean value for all 10 surveys is fairly close to zero, the best estimate of annual traffic volume was over 15 percent in error for about 33 percent of the stations. This

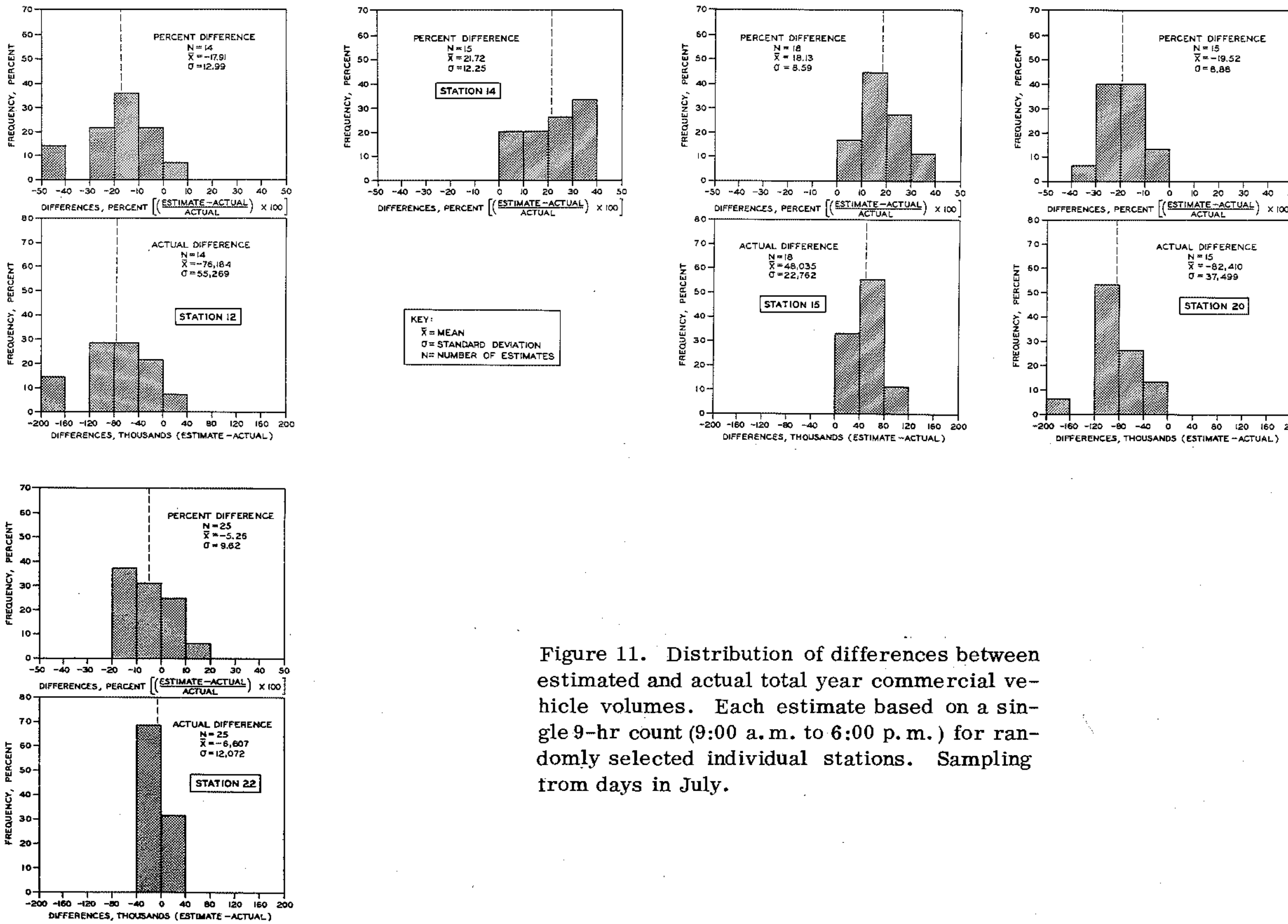


Figure 11. Distribution of differences between estimated and actual total year commercial vehicle volumes. Each estimate based on a single 9-hr count (9:00 a.m. to 6:00 p.m.) for randomly selected individual stations. Sampling from days in July.

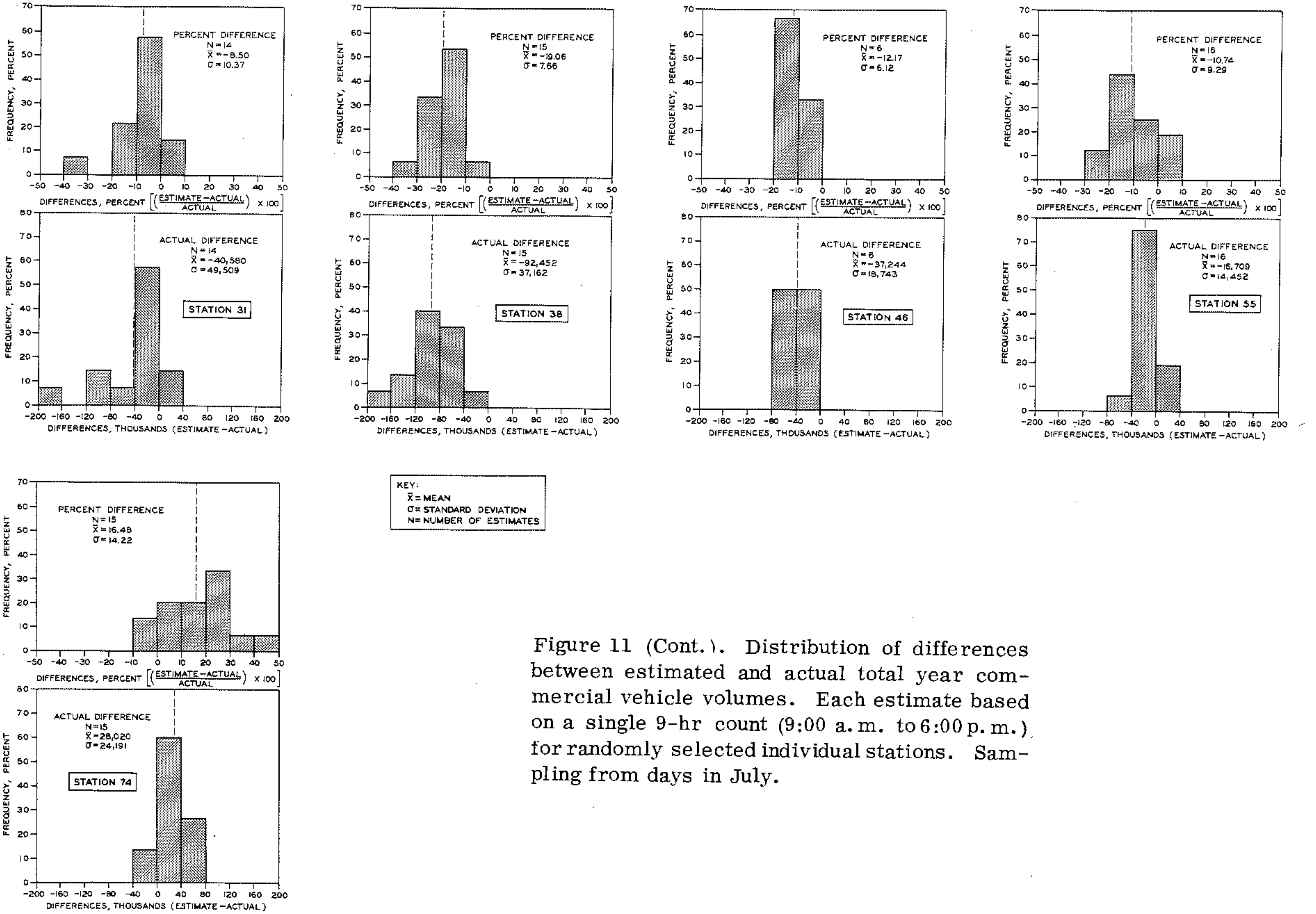


Figure 11 (Cont.). Distribution of differences between estimated and actual total year commercial vehicle volumes. Each estimate based on a single 9-hr count (9:00 a.m. to 6:00 p.m.) for randomly selected individual stations. Sampling from days in July.

best estimate was based on a minimum of 14 9-hr counts at each station. Since the mean standard deviation for all 10 station-years was about 10 percent (Fig. 12), a sample of about four 9-hr counts should be taken in July to insure that, on the average, an estimated annual commercial traffic volume would be within 10 percent of the best estimate 95 percent of the time. To be within 15 percent of the best estimate 95 percent of the time, a sample of two 9-hr counts should be taken. However, it should be remembered that the best estimate based on 9-hr sample counts can be over 20 percent in error at some locations.

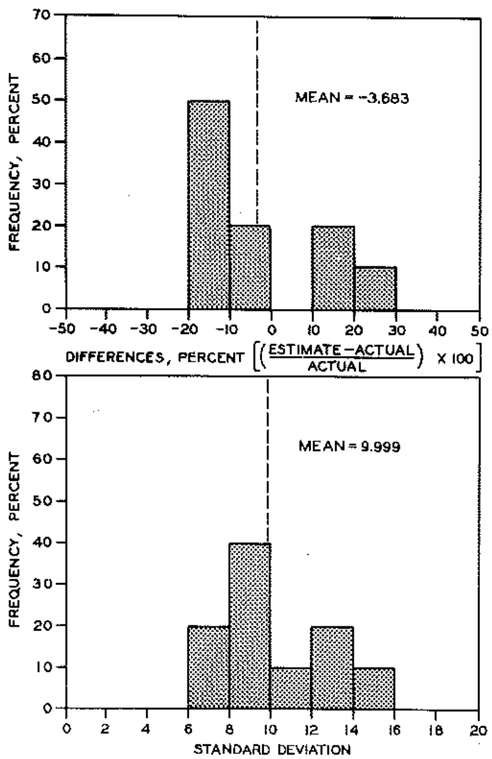


Figure 12. Distribution of sample means and standard deviations from 10 station-years, estimates are from 9-hr sample units (Summary of Fig. 11).

Twenty-Four-Hour Samples

Since 24-hr sample units were deemed necessary for determining the distribution of commercial vehicle types (as discussed later in this report) it was decided to investigate that size unit for estimating commercial vehicle volumes. As a check on the mathematics used in developing the expansion factors, 14 station-years were selected at random (simple random sampling without replacement). For each station-year, one 24-hr count was randomly selected each quarter of the year (the sample month from each quarter was again selected using systematic random sampling). This simulated survey process was carried out three times for each station-year and the values, expanded to estimate annual volumes, were compared with actual volumes (Fig. 13). The mean for the distribution of the 42 values was 0.23, sufficiently close to zero to indicate that the expansion factors had been computed correctly.

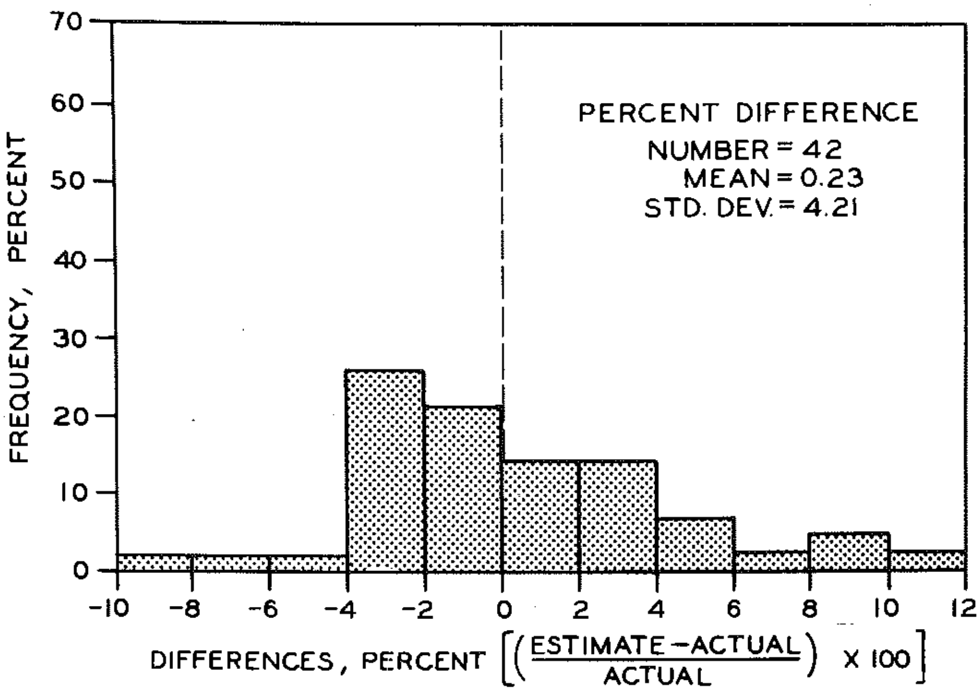


Figure 13. Distribution of differences between estimated and actual total year commercial traffic volumes. Each estimate based on average of 4 (1 each quarter) 24-hr sampling periods; samples taken from assorted stations, months, and days.

Surveys of each one of the 14 station-years were simulated using three 24-hr samples for each quarter of the year; a total of 12 sample units of 24 hr for each station-year. Systematic sampling was used with a month selected at random from the first quarter-year and every third month of the year was used thereafter. Thus, three systematic samples of four months each were selected.

Figure 14 shows graphical comparisons of estimated and actual annual traffic volumes for the 12 24-hr counts at each station. Figure 14 also shows that an error exceeding 40 percent is possible if only one 24-hr count is used for estimating annual commercial traffic volume. The mean of each

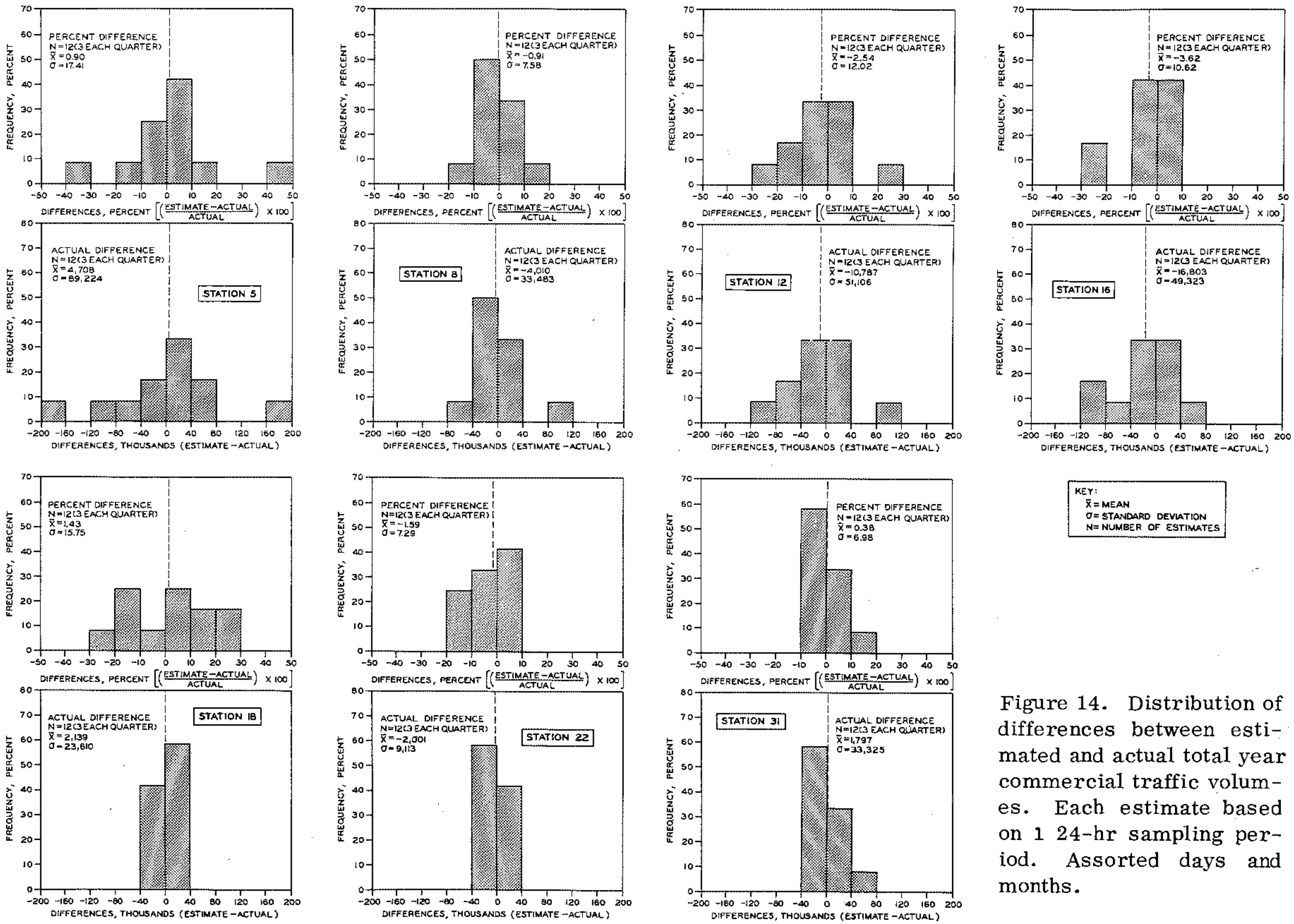


Figure 14. Distribution of differences between estimated and actual total year commercial traffic volumes. Each estimate based on 1 24-hr sampling period. Assorted days and months.

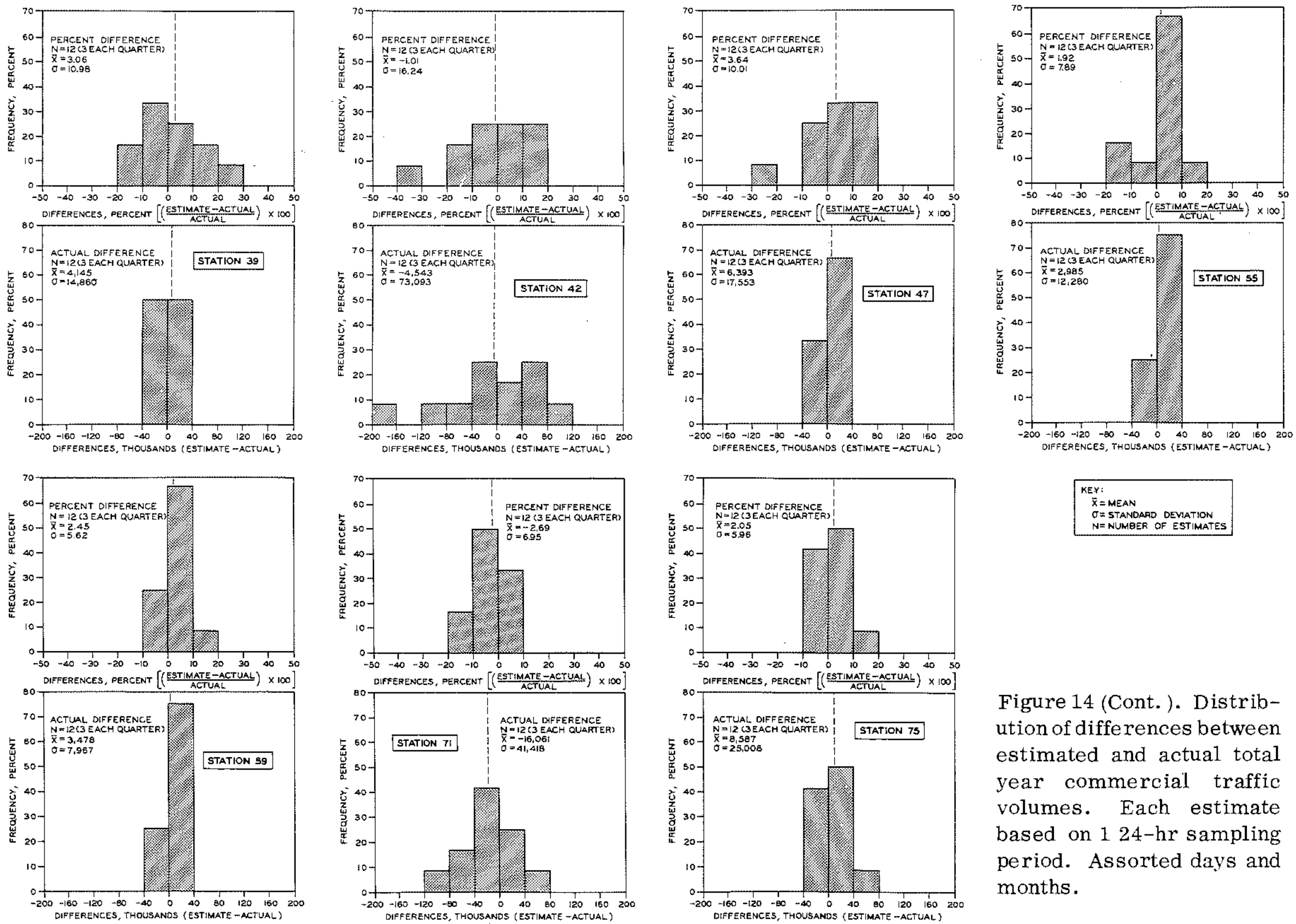


Figure 14 (Cont.). Distribution of differences between estimated and actual total year commercial traffic volumes. Each estimate based on 1 24-hr sampling period. Assorted days and months.

distribution, shown in Figure 14, represents the error resulting at the particular station when a sample of several 24-hr counts is used to obtain a best estimate of annual commercial traffic volumes. Figure 15 shows the distribution of best estimates for the 14 station-years. It is encouraging to note that the error from a best estimate of annual volume never exceeds 4 percent. This indicates that the expansion factors developed in this report can be used with confidence at any location.

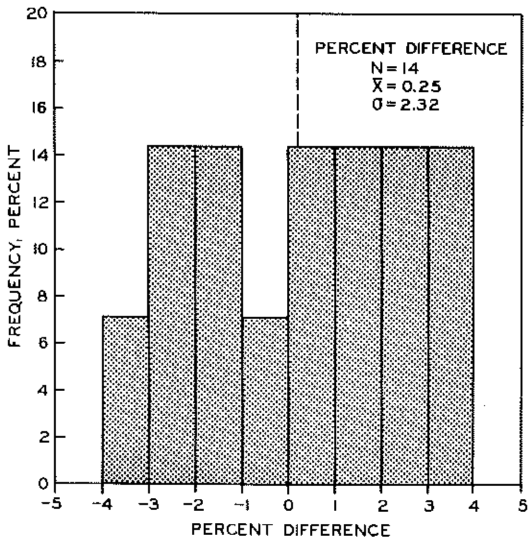


Figure 15. Distribution of weigh station averages summarized from Figure 14. Based on 14 weigh stations each having 12 24-hr time periods (3 each quarter).

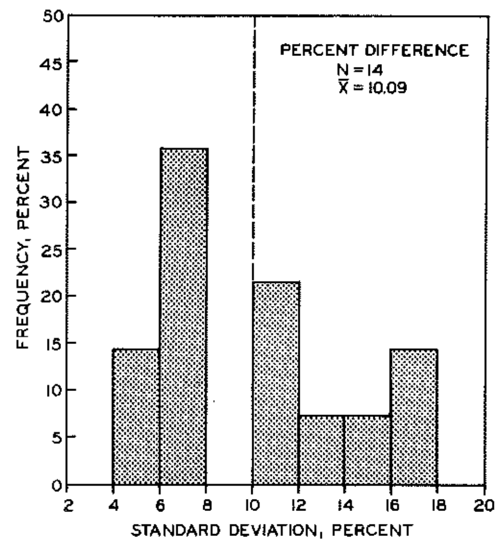


Figure 16. Distribution of standard deviations of 12 24-hr samples for each of 14 stations, summarized from Figure 14.

Figure 16 shows a distribution of standard deviations for the 14 station-years shown in Figure 14. The average standard deviation for the 14 station-years is about 10. Therefore, to have an average estimate of annual commercial traffic volume which was within 10 percent of the best estimate 95 percent of the time, a sample of four 24-hr counts should be taken, one each quarter. The greatest standard deviation for any of the stations was 17.4. Thus, to insure that an estimate of annual volume is within 10 percent of the best estimate in 95 percent of all cases, a sample of 12 24-hr counts must be taken. To insure that results will be within 15 percent of the best estimate in 95 percent of all cases, a sample of five 24-hr counts should be taken.

Expansion Factors

Table 3 lists expansion factors developed for basic sample units of 9, 12, and 24 hours. When each factor is multiplied by a commercial vehicle count for the appropriate time period, an estimate of average weekly volume is given. Multiplying the weekly volume by 52.2 gives an estimated annual volume. For example, if a 24-hr commercial vehicle count were taken on a Tuesday the expansion factor would be 5.582. If the count were 100, the estimated weekly commercial traffic volume would be 5.582 x 100 = 558.2; the estimated annual volume would be 558.2 x 52.2 = 29,138.

TABLE 3
FACTORS FOR EXPANDING COMMERCIAL VEHICLE SAMPLE COUNTS TO WEEKLY VOLUMES[1]

Sample Time Period	Day of Survey						
	Sun.	Mon.	Tues.	Wed.	Thus.	Fri.	Sat.
Midnight to noon	67.402	12.845	10.600	10.401	10.406	10.646	18.678
Noon to midnight	39.440	12.487	11.965	11.769	11.788	13.044	31.283
Midnight to midnight	26.543	6.229	5.582	5.483	5.490	5.815	11.648
9 a.m. to 6 p.m.	71.599	14.256	13.346	13.136	13.191	13.835	33.240

[1] A sample commercial vehicle count for any of the listed time periods may be used to estimate weekly volume by multiplying by the appropriate factor in the table. Multiply weekly volume by 52.2 to estimate annual volume.

Discussion

Figure 17 shows how commercial volume fluctuated over the months at six locations in Michigan. Because of the monthly fluctuations, it is likely that a sizeable error would result from a random sample of one 24-hr count that would be expanded with the factors given in Table 3. A probable reason for this month-to-month fluctuation is that activity in many industries is seasonal. Therefore, rather than simple random sampling, a stratified or systematic sampling plan should be used for estimating commercial traffic volume. As used in this report, stratification of 24-hr samples was by quarters of the year. A month was selected at random from the first quarter of a year and used in the sample together with every third month thereafter throughout the year. Therefore, stratification was assured through use of a systematic sampling plan. Stratified random sampling might instead be used where a month within each quarter was selected at random and then a day selected at random from the month.

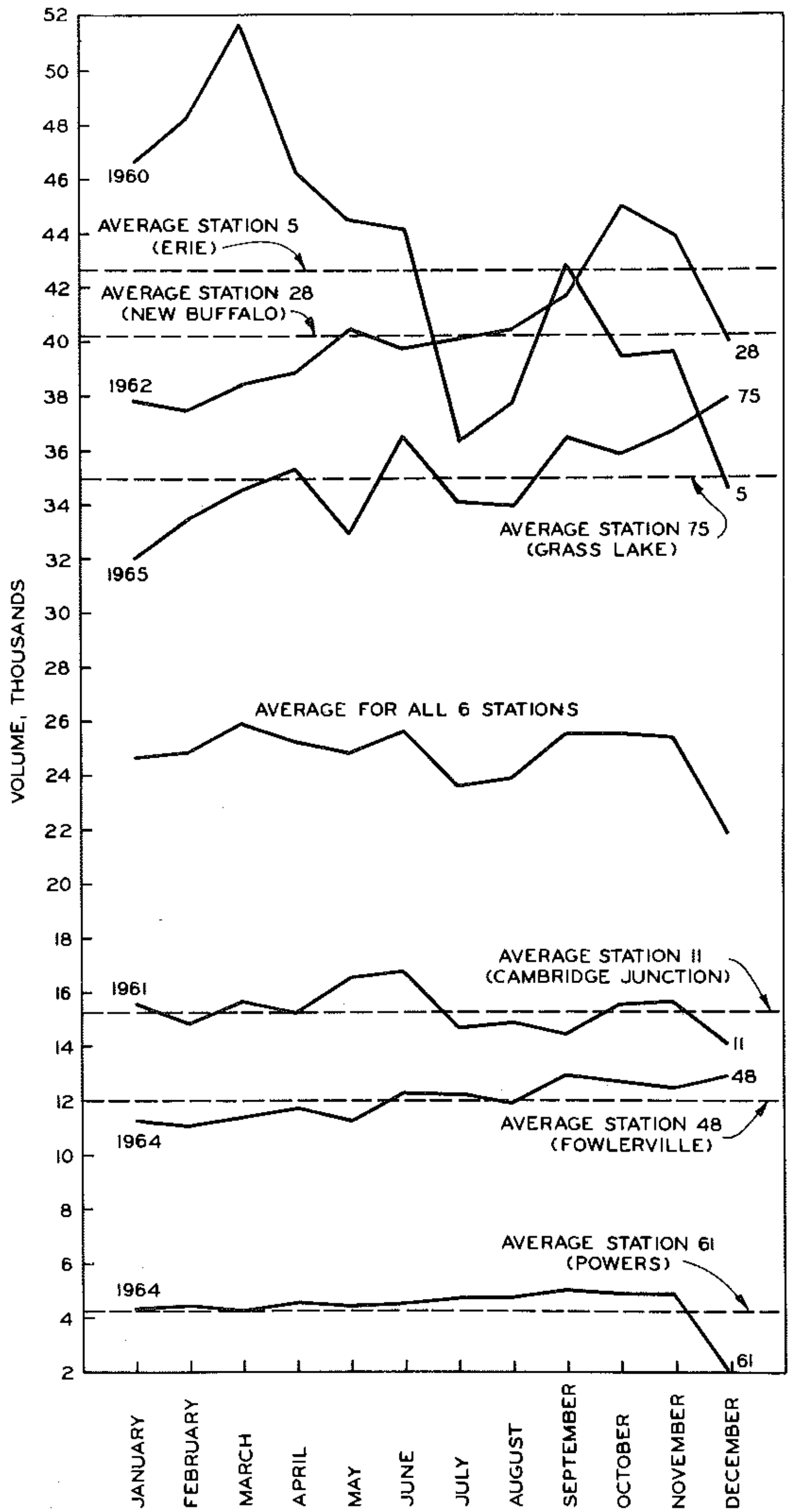


Figure 17. Distribution of commercial traffic volumes by months.

Differences between estimated and actual annual commercial traffic volumes for the 42 station-years used in the 24-hr sample study are plotted in Figure 18 for each quarter. There is no obvious bias when all 42 stations are considered together. However, Table 4, a listing of errors in estimates for each station, shows some stations to be very biased during certain quarters. This is a strong indication that seasonally stratified sampling should be used.

In summary, it appears that for most precision, 24-hr sample units should be used and sampling should be stratified by quarters to allow for seasonal variation. Average standard deviation values for the distribution of individual 24-hr sampling units is about 10 percent and the greatest standard deviation for any other distribution of sampling units at any one station is 17.4 percent. Figure 19 was developed from the preceding parameters and may be used for determining the number of 24-hr sampling units required for any given precision of estimate.

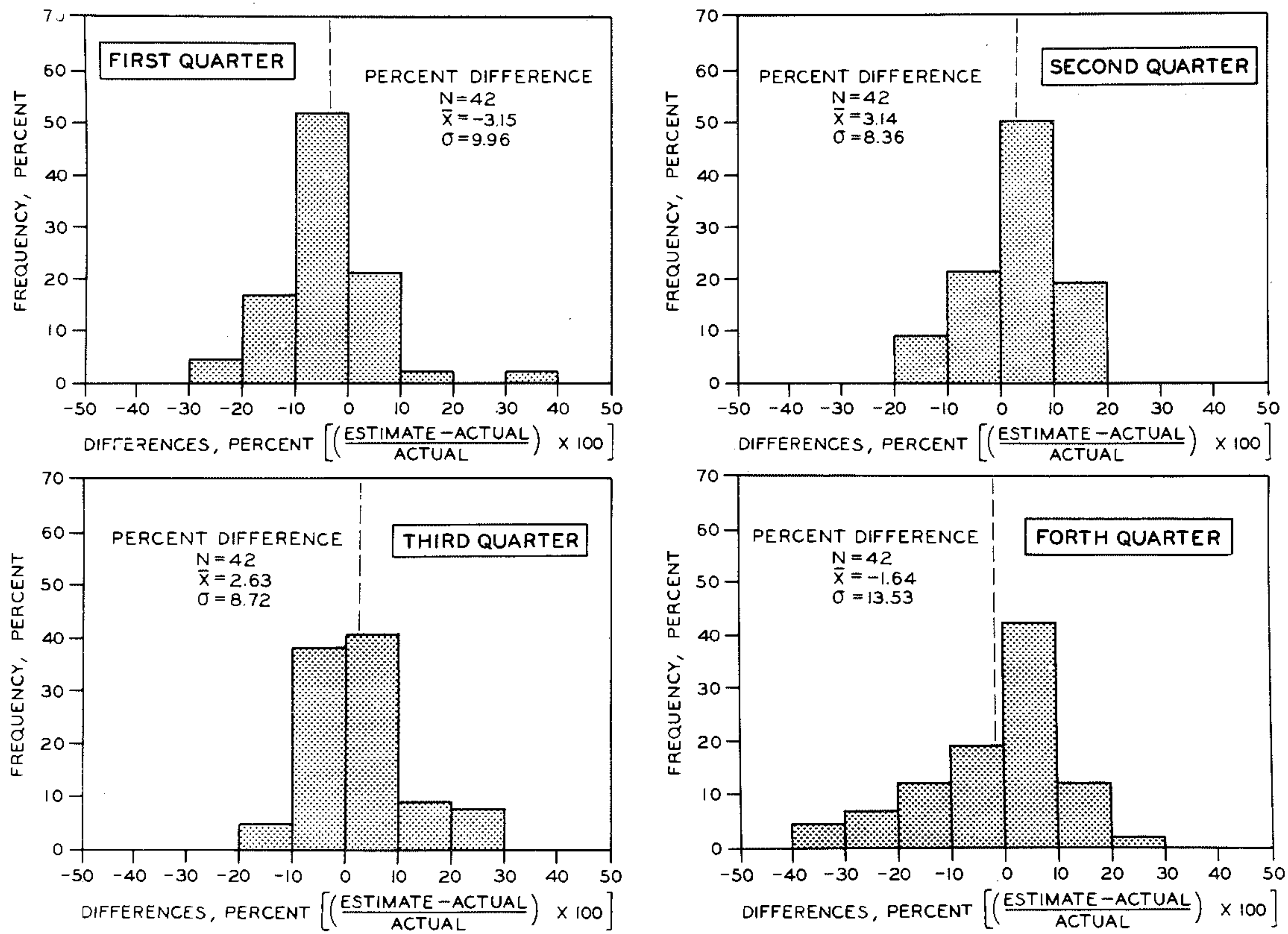


Figure 18. Distribution of differences between estimated and actual total year commercial vehicle volumes. Each estimate based on a single 24-hr sample.

TABLE 4
PERCENT DIFFERENCES BETWEEN ESTIMATED AND ACTUAL TOTAL YEAR COMMERCIAL VEHICLE VOLUMES

(24-hr Count; Assorted months, days)

Weigh Station	Quarter in Which Volume Estimate Sample was Taken				Station[2] Average
	1st Quarter[1] Average	2nd Quarter Average	3rd Quarter Average	4th Quarter Average	
5	20.33	0.00	1.84	-18.53	0.90
8	- 2.66	- 1.97	- 3.09	4.09	-0.91
12	-15.70	- 1.06	6.50	0.11	-2.54
16	- 1.01	- 4.51	5.99	-17.94	-3.62
18	- 9.80	4.98	17.40	- 6.87	1.43
22	- 5.81	- 4.09	- 2.11	5.62	-1.59
31	- 1.74	4.91	- 6.11	4.44	0.38
39	- 3.07	- 1.21	13.13	3.39	3.06
42	- 0.53	16.65	3.83	-24.00	-1.01
47	- 5.55	22.65	4.03	8.54	3.64
55	- 3.01	5.31	0.01	5.28	1.92
59	- 3.07	5.64	2.16	5.08	2.45
71	-10.40	3.91	- 6.16	1.87	-2.69
75	- 1.87	4.90	- 0.76	5.91	2.05
Averages $\bar{x}$	- 3.13	4.01	2.62	- 1.64	0.25
σ	8.01	7.63	6.71	10.72	2.32

[1] Each quarterly entry represents the mean of 3 24-hr samples taken during the quarter.

[2] Each "station average" based on average of 12 (3 each quarter) 24-hr time periods.

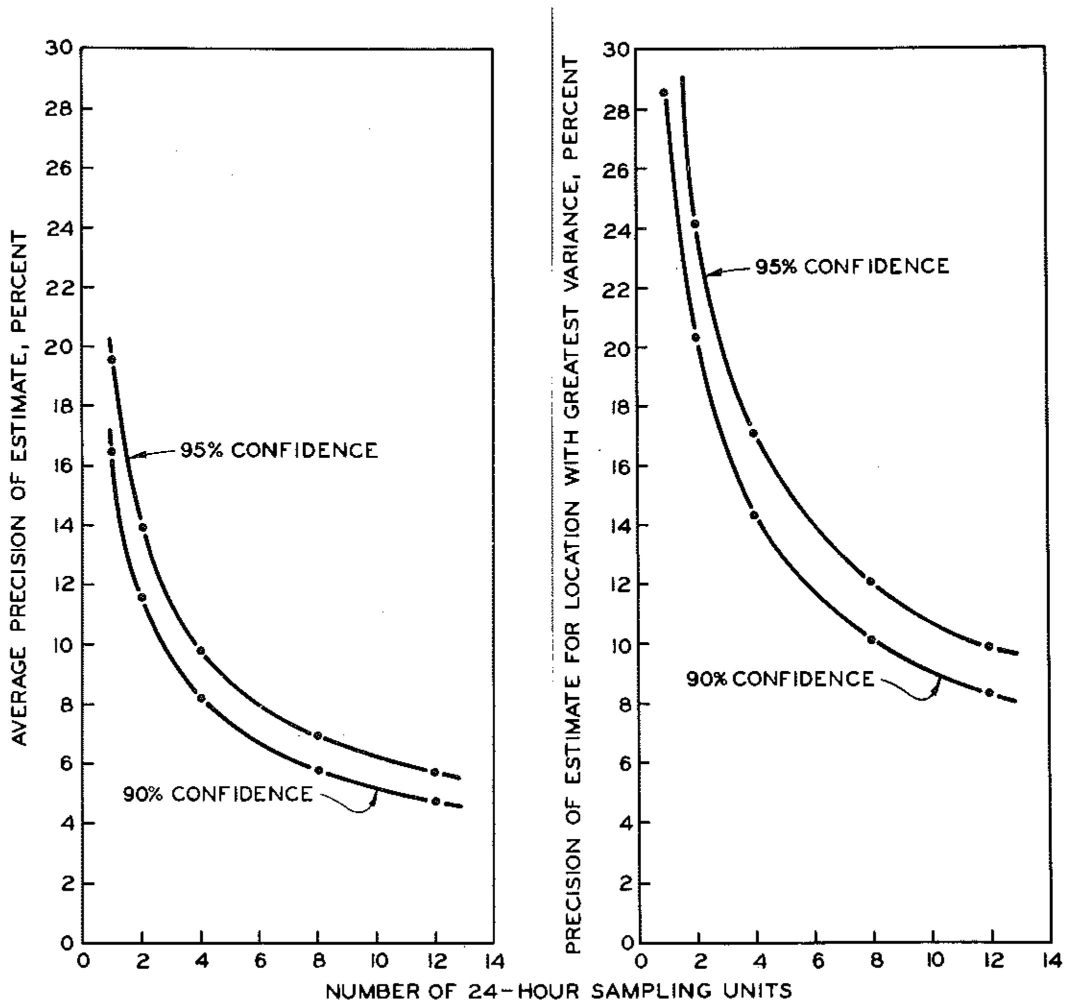


Figure 19. Relationship between precision of estimated annual commercial vehicle volumes and sample size.

PHASE II
VEHICLE AXLE WEIGHTS

Purpose

This phase of the project was concerned with investigating axle weights for the various types of commercial vehicles traveling over Michigan highways. Average axle load values and variations in these values were investigated to develop a sampling plan providing desired confidence limits and necessary sample sizes for estimating axle weight characteristics of vehicles traveling any given trunkline.

Research Procedure

Commercial vehicles were weighed, by individual axles or tandem axle groups, at eight different permanent weigh stations (Fig. 1). This axle weight survey, spanning several months in 1965, was carried out using a sampling plan designed to insure that meaningful quantities of each type commercial vehicle were weighed where 100 percent vehicle weighing was impractical. Several 6-hr sample surveys were taken at each location and were scheduled to provide coverage for the entire 24 hr of a day. The number of surveys varied, with a maximum of 13 6-hr surveys being taken at any one station.

Analysis of Data

Keeping vehicles separate by weigh station, each axle or tandem group was analyzed and mean average weights and variances were calculated. This provided an indication of the sample size required to obtain an acceptable estimate of average axle weights for each type of vehicle. However, these parameters apply only to the particular location from which they were developed. Next, data from all weigh stations were analyzed to determine between-station variations in axle weights. If the between-station variation in axle weights were small enough, it should not be unreasonable to assume that the mean axle weight for all stations could provide a good estimate of axle weights at any location throughout the State.

Results

Table 5 lists mean axle weights for each type of commercial vehicle. Since data from all weigh stations were pooled, two ways were considered for calculating all-station mean axle weights:

$$(1) \qquad \bar{\bar{X}} = \frac{\sum_{i=1} X_i}{N}$$

$$(2) \qquad \bar{\bar{X}} = \frac{\sum_{j=1} \bar{X}_j}{S}$$

where: $\bar{\bar{X}}$ = all-station mean axle weight
X_i = individual axle weight of i-th vehicle
N = total number of axles weighed of the vehicle type considered
$\bar{X}_j$ = mean axle weight, at j-th station of the vehicle type considered
S = number of stations being considered.

If the objective were to estimate a Statewide mean weight of a particular axle on a given type of truck, Eq. (1) would be applicable. However, since the objective of this study is to obtain a best estimate of the mean weight of a particular axle on a given type of truck at any location throughout the State, Eq. (2) is more applicable. Equation (1) would weight the values too heavily in favor of the high-volume situations which were surveyed in this study.

Table 5 also lists both within-station and between-station variances. The within-station variance, showing how axle weight values vary about each station mean, provides an indication of the number of 6-hr weight surveys required to reduce estimated error to a desired level at any location. Since the variance of sample means (standard error of estimate) is an inverse function of the square root of the sample size (i.e., $\sigma_{\bar{x}} = \frac{\sigma x}{\sqrt{n}}$), within-station accuracy may be increased by taking a larger number of surveys.

Between-station variances indicate the possible error resulting from pooling data from all the weigh stations to provide an estimate of the grand mean. There appears to be no reason for not assuming stochastic independence. Therefore, for estimating axle loads at any location, total variance can be calculated by adding within-station and between-station variances.

Summary

Table 5 provides average axle weights for various types of commercial vehicles traveling Michigan trunklines. Because of the small variances for most vehicles, values in Table 5 may be used for estimating axle weights of commercial vehicles. Further, since the variance of axle weights is small for each type of vehicle, annual truck weight study data may be used for estimating axle weights.

TABLE 5

COMMERCIAL VEHICLE AVERAGE AXLE WEIGHT DATA

Parenthisized Values are Standard Deviations

Vehicle Type		Steering Axle				Drive Axle(s)				Semi-Trailer Axle(s) 1				Semi-Trailer Axle(s) 2				Semi-Trailer Axle(s) 3				Trailer Axles 1				Trailer Axles 2				Total Equiv. 18-Kip Singles
				Mean Axle Weight				Mean Axle Weight				Mean Axle Weight				Mean Axle Weight				Mean Axle Weight				Mean Axle Weight				Mean Axle Weight		
Standard Code	Lab Code	Mean Weight, kips	Equiv. 18-Kip Singles*	Within-Station Variance, kips	Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Within-Station Variance, kips	Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Within-Station Variance, kips	Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Within-Station Variance, kips	Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Within-Station Variance, kips	Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Within-Station Variance, kips	Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Within-Station Variance, kips	Between-Station Variance, kips	
2-D	(2-2)	5.06	0.01	0.07 (0.26)	0.03 (0.18)	8.98	0.06	0.27 (0.52)	0.43 (0.66)																					0.06
3	(2-3)	7.64	0.03	0.28 (0.53)	1.46 (1.21)	18.82 (Tan.)	0.16	4.17 (2.04)	8.72 (2.95)																					0.19
2S1	(3-3)	6.61	0.02	0.05 (0.22)	0.62 (0.79)	11.84	0.17	0.29 (0.54)	2.58 (1.61)	11.06	0.14	0.38 (0.62)	4.13 (2.03)																	0.32
3S1	(3-4)	7.75	0.03	0.05 (0.22)	1.75 (1.32)	23.03 (Tan.)	0.38	2.19 (1.48)	71.31 (8.45)	14.09	0.35	0.86 (0.93)	13.54 (3.68)																	0.76
2S2	(3-4)	7.50	0.03	0.01 (0.10)	0.16 (0.40)	12.73	0.24	0.08 (0.28)	0.32 (0.57)	18.60 (Tan.)	0.15	0.33 (0.57)	1.36 (1.17)																	0.42
2S2L	(3-4)	7.55	0.03	0.09 (0.30)	0.35 (0.59)	13.09	0.27	0.47 (0.69)	1.66 (1.29)	11.21	0.14	0.69 (0.83)	2.18 (1.48)	11.38	0.15	0.73 (0.85)	2.16 (1.47)													0.58
3S2L	(3-5)	8.91	0.05	0.03 (0.18)	0.36 (0.60)	22.47 (Tan.)	0.34	0.59 (0.77)	6.20 (2.49)	11.81	0.17	0.50 (0.71)	3.36 (1.83)	12.03	0.18	0.23 (0.48)	2.56 (1.60)													0.74
3S2	(3-5)	8.71	0.05	0.02 (0.14)	0.08 (0.28)	19.89 (Tan.)	0.21	0.38 (0.62)	3.40 (1.85)	20.62 (Tan.)	0.24	0.68 (0.83)	5.62 (2.37)																	0.49
2S3L1	(3-5)	8.59	0.05	0.62 (0.79)	0.63 (0.79)	15.03	0.48	2.13 (1.46)	-0.58 (0.76)	13.02	0.26	8.22 (2.87)	1.28 (1.13)	22.88 (Tan.)	0.37	10.46 (3.23)	9.92 (3.15)													1.16
2S3	(3-5)	6.92	0.02	1.64 (1.28)	4.64 (2.15)	14.00	0.34	3.48 (1.87)	20.30 (4.51)	27.08 (Triple)	0.75	20.40 (4.51)	268.04 (16.37)																	1.11
2S3L	(3-5)	8.80	0.05	0.25 (0.50)	1.16 (1.08)	14.81	0.44	2.60 (1.61)	3.14 (1.77)	11.21	0.14	2.74 (1.66)	34.22 (5.85)	23.58 (Tan.)	0.41	9.44 (3.07)	22.52 (4.75)													1.05
2S3L2	(3-5)	8.95	0.06	0.98 (0.99)	0.81 (0.90)	15.98	0.60	1.62 (1.27)	0.32 (0.57)	26.95 (Tan.)	0.74	7.67 (2.77)	10.70 (3.27)	13.80	0.32	2.94 (1.72)	2.69 (1.64)													1.71
2S3LL	(3-5)	8.68	0.05	0.52 (0.72)	1.18 (1.09)	14.85	0.46	5.33 (2.31)	2.33 (1.53)	10.71	0.12	21.01 (4.58)	15.77 (3.97)	12.23	0.20	9.24 (3.04)	6.24 (2.50)	12.06	0.19	10.36 (3.22)	9.05 (3.01)									1.02
3S3LL	(3-6)	9.81	0.08	0.75 (0.87)	1.47 (1.21)	25.42 (Tan.)	0.57	8.85 (2.98)	24.07 (4.91)	11.38	0.15	1.68 (1.30)	31.34 (5.60)	11.75	0.17	4.88 (2.21)	6.47 (2.54)	11.80	0.17	3.97 (1.99)	5.84 (2.42)									1.13
3S3L	(3-6)	9.58	0.07	0.86 (0.93)	6.05 (2.46)	23.27 (Tan.)	0.39	15.76 (3.97)	24.36 (4.94)	14.19	0.37	11.81 (3.44)	34.37 (5.86)	25.11 (Tan.)	0.54	10.60 (3.26)	48.16 (6.94)													1.37
3S3L2	(3-6)	9.90	0.08	0.05 (0.22)	1.80 (1.34)	25.05 (Tan.)	0.53	0.45 (0.67)	18.01 (4.24)	23.60 (Tan.)	0.41	0.57 (0.76)	20.30 (4.51)	14.65	0.42	0.35 (0.59)	0.36 (0.60)													1.44
3S3	(3-6)	9.11	0.06	0.84 (0.92)	2.70 (1.64)	20.22 (Tan.)	0.22	14.25 (3.78)	59.60 (7.72)	21.69 (Triple)	0.30	31.62 (5.62)	90.26 (9.50)																	0.57
3S3L1	(3-6)	8.48	0.40	0.87 (0.93)	4.13 (2.03)	19.92 (Tan.)	0.21	3.78 (1.94)	45.23 (6.73)	9.59	0.07	1.72 (1.31)	32.02 (5.66)	15.13 (Tan.)	0.07	8.23 (2.87)	69.80 (8.35)													0.38
3S4	(3-7)	10.50	0.11	0.25 (0.50)	0.00 (0.00)	24.00 (Tan.)	0.44	0.00 (0.00)	0.00 (0.00)	40.50 (Quad.)	3.94	2.25 (1.50)	0.00 (0.00)																	4.49
3S5	(3-8)	12.00	0.18	0.67 (0.82)	0.00 (0.00)	31.50 (Tan.)	1.40	0.42 (0.65)	0.00 (0.00)	16.75	0.76	0.06 (0.25)	0.00 (0.00)	52.50 (Quad.)	11.00	2.42 (1.56)	0.00 (0.00)													13.34
2S1-2	(4-5)	7.40	0.02	0.39 (0.62)	0.15 (0.39)	12.61	0.23	3.86 (1.97)	7.04 (2.65)	11.59	0.16	4.63 (2.15)	11.36 (3.37)									11.64	0.16	5.48 (2.34)	11.47 (3.39)	11.20	0.14	5.54 (2.35)	13.17 (3.63)	0.71
2S2-2	(4-6)	8.30	0.04	0.20 (0.45)	0.40 (0.63)	14.66	0.43	1.40 (1.18)	0.86 (0.93)	24.21 (Tan.)	0.46	6.18 (2.49)	4.53 (2.13)									13.40	0.29	1.91 (1.38)	1.53 (1.24)	13.45	0.30	2.00 (1.41)	1.88 (1.38)	1.52

* Based on AASHO Road Test equivalence factors for 9-in. rigid pavement with terminal serviceability index of 2.5

TABLE 5 (cont.)
COMMERCIAL VEHICLE AVERAGE AXLE WEIGHT DATA
Parenthisized Values are Standard Deviations

Vehicle Type		Steering Axle				Drive Axle(s)				Semi-Trailer Axle(s) 1				Semi-Trailer Axle(s) 2				Semi-Trailer Axle(s) 3				Trailer Axles 1				Trailer Axles 2				Total Equiv. 18-Kip Singles
Standard Code	Lab Code	Mean Weight, kips	Equiv. 18-Kip Singles*	Mean Axle Weight: Within-Station Variance, kips	Mean Axle Weight: Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Mean Axle Weight: Within-Station Variance, kips	Mean Axle Weight: Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Mean Axle Weight: Within-Station Variance, kips	Mean Axle Weight: Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Mean Axle Weight: Within-Station Variance, kips	Mean Axle Weight: Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Mean Axle Weight: Within-Station Variance, kips	Mean Axle Weight: Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Mean Axle Weight: Within-Station Variance, kips	Mean Axle Weight: Between-Station Variance, kips	Mean Weight, kips	Equiv. 18-Kip Singles*	Mean Axle Weight: Within-Station Variance, kips	Mean Axle Weight: Between-Station Variance, kips	
2S2L-2	(4-6)	9.16	0.06	0.65 (0.81)	0.45 (0.67)	14.22	0.37	2.43 (1.56)	4.95 (2.23)	13.09	0.27	4.91 (2.22)	4.98 (2.23)	13.36	0.29	3.90 (1.98)	5.33 (2.31)					13.17	0.28	3.97 (1.99)	8.59 (2.93)	12.90	0.25	3.86 (1.97)	9.19 (3.03)	1.51
3S1-2	(4-6)	8.00	0.03	0.00 (0.00)	2.00 (1.41)	21.50 (Tan.)	0.29	0.00 (0.00)	0.50 (0.22)	17.00	0.80	0.00 (0.00)	0.00 (0.00)									16.00	0.60	0.00 (0.00)	2.00 (1.41)	16.50	0.70	0.00 (0.00)	0.50 (0.71)	2.42
3S2-2	(4-7)	9.38	0.07	0.26 (0.51)	2.34 (1.53)	17.88 (Tan.)	0.13	3.57 (1.89)	25.04 (5.00)	19.83 (Tan.)	0.20	5.07 (2.25)	64.67 (8.04)									11.67	0.17	1.42 (1.19)	19.37 (4.40)	11.00	0.13	1.51 (1.23)	24.50 (4.95)	0.69
2S2-3	(4-7)	9.27	0.06	0.73 (0.85)	0.75 (0.87)	13.66	0.32	2.24 (1.50)	7.05 (2.66)	22.63 (Tan.)	0.35	10.60 (3.26)	33.79 (5.81)									12.62	0.23	3.50 (1.87)	9.10 (3.02)	18.38 (Tan.)	0.15	6.12 (2.47)	28.28 (5.32)	1.10
2S3L-3	(4-7)	10.38	0.10	0.65 (0.81)	0.83 (0.91)	14.28	0.38	5.02 (2.24)	2.38 (1.54)	13.65	0.32	6.42 (2.53)	12.82 (3.58)	13.53	0.30	6.50 (2.55)	6.41 (2.53)					13.24	0.28	5.24 (2.29)	4.65 (2.16)	23.28 (Tan.)	0.39	17.76 (4.21)	27.11 (5.21)	1.77
32L3-2	(4-7)	9.44	0.07	0.59 (0.77)	2.26 (1.50)	19.18 (Tan.)	0.18	13.62 (3.69)	85.36 (9.24)	10.47	0.11	4.23 (2.06)	32.65 (5.71)	10.73	0.12	4.16 (2.04)	37.61 (6.13)					10.44	0.10	6.26 (2.50)	36.93 (6.08)	10.40	0.10	5.35 (2.31)	38.68 (6.22)	0.66
3S2-3	(4-8)	10.11	0.09	0.31 (0.56)	2.79 (1.67)	18.58 (Tan.)	0.15	2.40 (1.55)	52.15 (7.22)	22.64 (Tan.)	0.35	3.75 (1.94)	156.64 (12.52)									12.94	0.25	1.49 (1.22)	43.34 (6.58)	18.03 (Tan.)	0.13	2.43 (1.56)	97.17 (9.86)	0.97
2S3-3	(4-8)	10.50	0.11	0.50 (0.71)	0.50 (0.71)	16.50	0.70	0.50 (0.71)	4.50 (2.12)	40.00 (Triple)	3.74	0.50 (0.71)	2.00 (1.41)									17.25	0.84	0.12 (0.35)	15.12 (3.89)	27.75 (Tan.)	0.83	1.13 (1.06)	1.12 (1.06)	6.21
3S3-2	(4-8)	12.50	0.22	0.00 (0.00)	0.50 (0.71)	27.50 (Tan.)	0.79	0.00 (0.00)	12.50 (3.54)	35.00 (Triple)	2.18	0.00 (0.00)	32.00 (5.66)									16.50	0.70	0.00 (0.00)	4.50 (2.12)	16.00	0.60	0.00 (0.00)	8.00 (2.83)	4.49
2S2-4	(4-8)	8.00	0.03	0.33 (0.57)	0.00 (0.00)	16.67	0.74	0.11 (0.33)	0.00 (0.00)	31.33 (Tan.)	1.37	0.44 (0.66)	0.00 (0.00)									24.00 (Tan.)	0.44	0.33 (0.57)	0.00 (0.00)	26.00 (Tan.)	0.62	0.00 (0.00)	0.00 (0.00)	3.23
3S2-4	(4-9)	7.75	0.03	0.12 (3.46)	6.13 (2.48)	17.25 (Tan.)	0.11	0.12 (3.46)	48.12 (6.72)	13.75 (Tan.)	0.05	0.12 (3.46)	55.12 (7.42)									11.75 (Tan.)	0.03	0.12 (3.46)	21.12 (4.60)	11.25 (Tan.)	0.02	0.12 (3.46)	28.12 (5.30)	0.24
2S3-4	(4-9)	10.00	0.08	1.00 (1.00)	0.00 (0.00)	18.00	1.00	0.00 (0.00)	0.00 (0.00)	38.67 (Triple)	3.29	0.11 (3.32)	0.00 (0.00)									25.67 (Tan.)	0.59	0.11 (3.32)	0.00 (0.00)	25.67 (Tan.)	0.59	0.11 (3.32)	0.00 (0.00)	5.55
3S3-4	(4-10)	10.96	0.13	0.51 (7.14)	2.57 (1.60)	18.90 (Tan.)	0.17	4.18 (2.04)	73.71 (8.59)	21.45 (Triple)	0.28	10.09 (3.18)	168.85 (2.99)									14.51 (Tan.)	0.06	4.39 (2.10)	61.89 (7.87)	13.86 (Tan.)	0.05	4.79 (2.19)	76.76 (8.76)	0.69
3S3-4	(4-10)	13.00	0.26	0.00 (0.00)	0.20 (0.45)	27.50 (Tan.)	0.79	0.00 (0.00)	0.50 (0.71)	36.00 (Triple)	2.43	0.00 (0.00)	72.00 (8.49)									11.50	0.16	0.00 (0.00)	4.50 (2.12)	41.50 (Triple)	4.35	0.00 (0.00)	12.50 (3.54)	7.99
3S3-5	(4-11)	11.82	0.17	1.04 (1.02)	1.98 (1.41)	20.91 (Tan.)	0.26	8.81 (2.97)	54.05 (7.35)	25.44 (Triple)	0.57	15.03 (3.88)	123.62 (11.19)									16.20 (Tan.)	0.09	7.42 (2.73)	36.96 (6.08)	22.64 (Triple)	0.35	18.24 (4.27)	89.90 (9.48)	1.43
3S4-4	(4-11)	13.12	0.27	0.56 (0.75)	1.40 (1.18)	23.75 (Tan.)	0.43	16.50 (4.06)	16.25 (4.03)	45.88 (Quad.)	6.48	100.81 (10.04)	77.73 (8.82)									23.00 (Tan.)	0.38	22.62 (4.76)	19.17 (4.38)	23.25 (Tan.)	0.39	25.62 (5.06)	17.42 (4.17)	7.94
3S4-5	(4-12)	13.38	0.00	2.45 (1.57)	0.78 (0.88)	22.00 (Tan.)	0.31	4.34 (2.08)	12.50 (3.54)	40.75 (Quad.)	4.06	31.21 (5.59)	78.12 (8.04)									20.88 (Tan.)	0.26	6.45 (2.54)	34.03 (5.83)	32.75 (Triple)	1.66	15.71 (3.96)	91.12 (9.55)	6.58
12-2	(5-4)	3.50	0.00	0.91 (0.95)	0.47 (0.69)	5.80	0.01	0.62 (0.79)	0.59 (0.77)													6.67 (Tan.)	0.01	2.43 (1.56)	4.06 (2.02)					0.02
2-2	(5-4)	9.50	0.07	0.00 (0.00)	0.50 (0.71)	17.00	0.80	0.00 (0.00)	2.00 (1.41)													12.50	0.22	0.00 (0.00)	6.50 (7.78)	12.50	0.22	0.00 (0.00)	6.50 (7.78)	1.31
3-2	(5-5)	11.04	0.13	0.67 (0.82)	6.04 (2.46)	20.57 (Tan.)	0.24	0.27 (0.52)	110.23 (10.50)													11.35	0.15	0.38 (0.62)	34.56 (5.88)	10.95	0.13	0.15 (0.39)	35.57 (5.96)	0.65
3-3	(5-6)	10.00	0.08	0.00 (0.00)	8.00 (2.83)	20.00 (Tan.)	0.21	0.00 (0.00)	2.00 (1.41)													11.00	0.13	0.00 (0.00)	72.00 (8.49)	15.00 (Tan.)	0.07	0.00 (0.00)	200.00 (14.14)	0.49
3-5	(5-8)	12.80	0.24	0.00 (0.00)	8.70 (2.95)	23.60 (Tan.)	0.41	0.80 (0.89)	113.30 (10.64)													17.50 (Tan.)	0.12	0.05 (0.22)	71.00 (8.42)	26.30 (Triple)	0.65	0.45 (0.67)	236.20 (15.37)	1.43

PHASE III
DISTRIBUTION OF COMMERCIAL VEHICLE TYPES

Purpose

This phase of the project involved developing a plan for estimating the distribution of types of commercial vehicles traveling over Michigan roadways. Sampling plans were to be developed which would be effective on any highway and would provide an estimate of the average proportion of the total commercial traffic stream for each type of commercial vehicle.

Method of Investigation

It was decided to investigate the possibility that vehicle type distributions might be similar for different roads located in areas having the same types of industry, such as urban industrial or rural agricultural. If this were the case, surveys taken at one location might be used as an indicator of vehicle types at other locations in similar areas.

In surveying for this investigation, cluster sampling was used with clusters consisting of all commercial vehicles passing a given point during a specific time period, usually eight continuous hours. Repeated samples were taken at 22 locations throughout the State over a period of two years (Table 6 and Fig. 20); 11 of these sites were permanent weigh stations. In selecting survey locations, attention was given to selecting roads with different traffic characteristics, e. g., Interstate in heavily industrial locations, two-lane roadway in agricultural areas, etc.

Results

Figure 21 shows how the proportion of the more common vehicle types varies throughout a 24-hr day. As expected, variations during a day are sizeable. Note also how, for identical time periods, proportions of vehicle types vary between stations.

Attempts were made to group similar traffic distribution patterns and then to investigate causes of similarity. Figure 22 shows distributions grouped into three general patterns based on proportions for averages of an entire 24-hr day. Type 2-1 vehicles (two-axle with single rear wheels) were deleted from the distributions since their structural effect on a pavement does not differ a great deal from that of automobiles. Class I consists

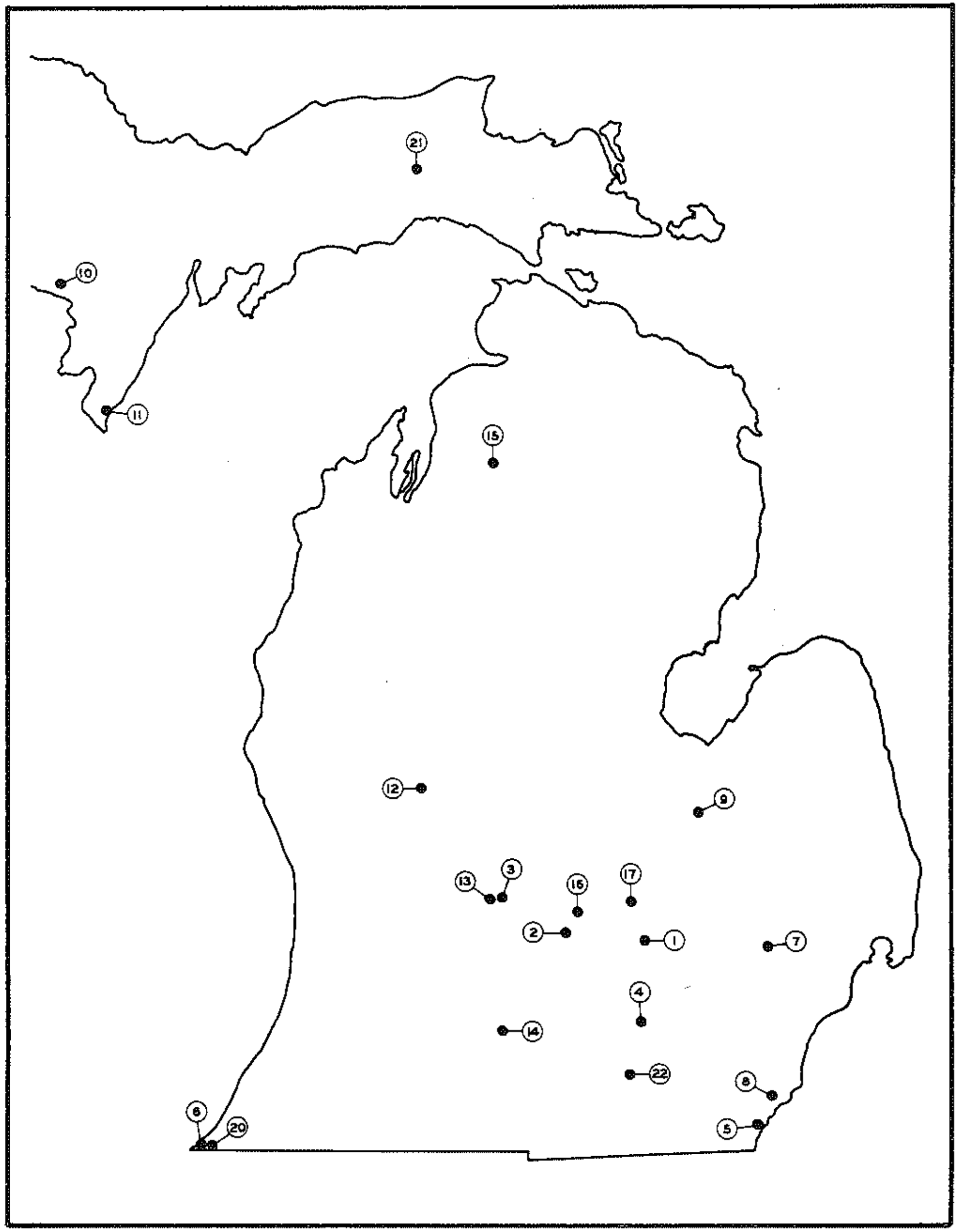
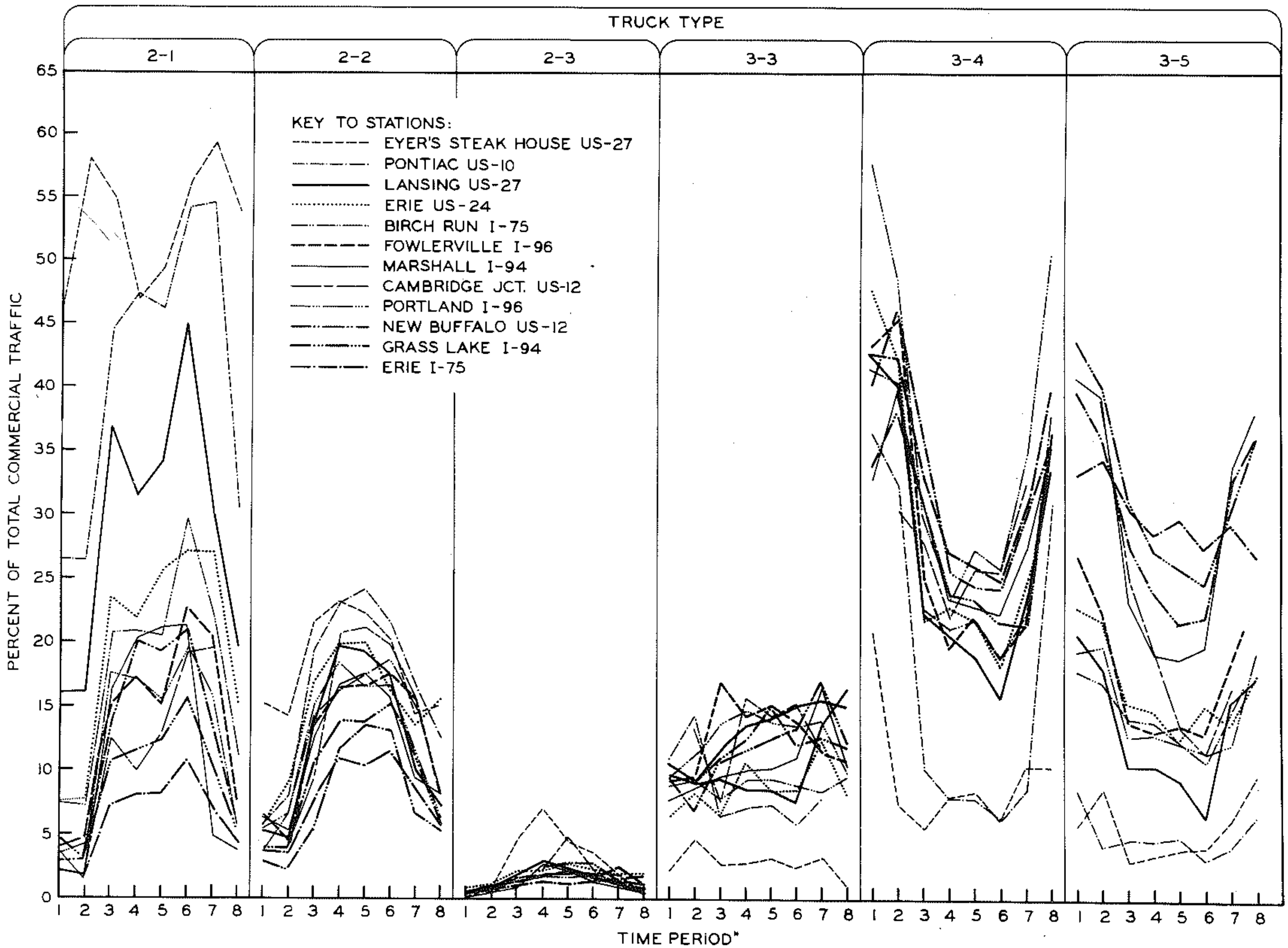


Figure 20. Location of survey points for classification of commercial vehicles.

TABLE 6
VEHICLE CLASSIFICATION SURVEY SITES

Station	Location	Route
1	Fowlerville scale	I 96
2	Lansing scale	US 27
3	Portland scale	I 96
4	Grass Lake scale	I 94
5	Erie scale	I 75
6	New Buffalo scale	US 12
7	Pontiac scale	US 10
8	Erie scale	US 24
9	Saginaw scale	I 75
10	Vulcan corners	US 2 E of Norway
11	Menominee	M 35, US 41
12	Howard City	US 131, M 46
13	Ionia	M 66
14	Marshall	US 27, I 94
15	Mancelona	US 31, M 88
16	Eyers Steak House	US 27
17	Perry	M 78, M 47
20	New Buffalo scale	I 94
21	Roberts Corners	M 28, M 123
22	Cambridge scale	M 50, US 12



*TIME PERIODS ARE IN 3 HOUR GROUPS; TIME PERIOD 1 IS FROM MIDNIGHT TO 3A.M., TIME PERIOD 2 IS FROM 3A.M. TO 6A.M., ETC.

Figure 21. Vehicle classification counts (type as percent of total volume per 3-hr period).

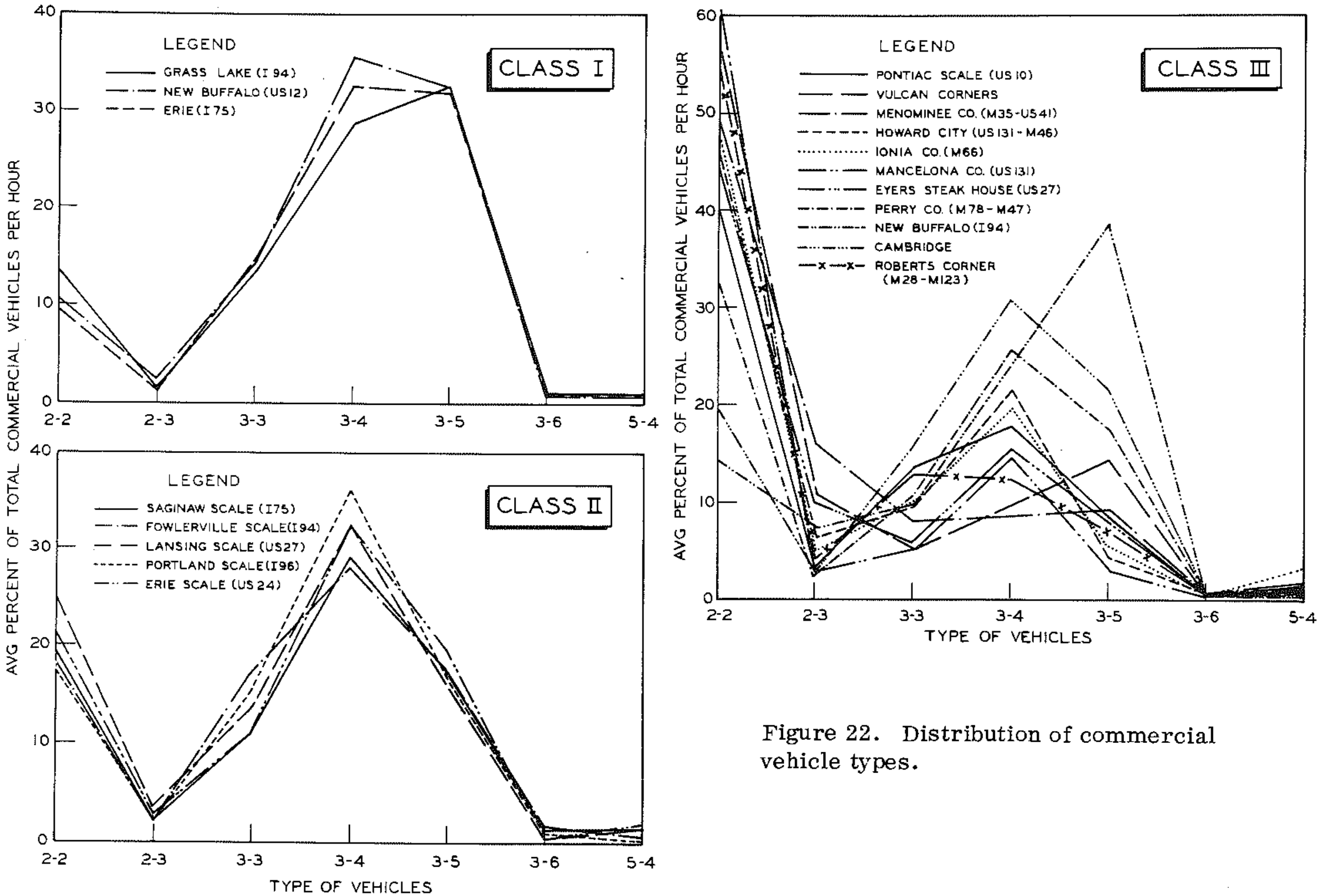


Figure 22. Distribution of commercial vehicle types.

of main trunklines connecting Detroit with the outstate industrial cities of Chicago and Toledo. Class II consists of trunklines connecting industrial cities within Michigan. Finally, Class III consists of trunklines not clearly falling into the preceding two classes. It appears that the majority of the pavements in Michigan fall into Class III which has the greatest between-station variation for similar vehicle types. Therefore, it does not appear feasible to use data from one location to estimate vehicle type distributions for another location. Thus, for the majority of Michigan highways, samples should be taken at any location where it is desired to determine proportions of commercial vehicle types in the traffic stream. Further, because of the drastic change in the make-up of the traffic throughout a day (Fig. 21), sampling units which include all 24 hr of a day should be taken.

Development of Sampling Plan

Data from all the surveys were grouped into 6-hr clusters and were analyzed to determine, among other things, the between-day consistency of vehicle types on each road. Figure 23 is a small segment of the computer printout of the analysis of vehicle types for survey station No. 1, the Fowlerville scales, for the hours of midnight to 6 a.m. and 6 a.m. to noon. The between-survey days' standard deviations and coefficients of variation proved to be different for each vehicle type for each time period, and for similar vehicle types and time periods but at different stations. Therefore, it would be impossible to design a sampling plan which would provide a uniform degree of accuracy of estimate for each vehicle type. Further, it would be impractical to base a sampling plan on obtaining a desired degree of accuracy for the vehicle-hour-station combination with the highest coefficient of variation because highest coefficients of variation occur where vehicle counts are lowest. For example, a sampling plan based upon data in Figure 23 for station No. 1, for hours midnight to 6 a.m. and vehicle type 3-8, would be based upon a coefficient of variation of 346.4. However, because of the small number of type 3-8 vehicles on the highways, an error in estimating this type unit wouldn't greatly affect overall accuracy of the total vehicle number.

The most pragmatic approach was considered to be one in which the vehicles having the greatest effect on the structural integrity of a pavement were considered of critical importance. Relative effect on a pavement was estimated using the AASHO Road Test method of converting axle loads to equivalent 18-kip single axles. Three types of vehicles were determined to be critical, i.e., having the greatest number of equivalent 18-kip single axles per 100 commercial vehicles.

Table 7 is a tabulation of data for the three critical vehicle types. There is no clean, textbook method for developing a broadly applicable

TRUCK TYPE	STATION NUMBER	HOURS	MEAN PERCENT OF TOTAL VEHICLES	STANDARD DEVIATION	COEFFICIENT OF VARIATION
2-1	1	1218	18.88	3.6489	19.3293
2-2	1	1218	17.73	3.1441	17.7365
2-3	1	1218	1.88	0.7643	40.6197
2-4	1	1218	0.00	0.0000	0.0000
3-3	1	1218	14.85	4.6535	31.3284
3-4	1	1218	19.91	1.7894	8.9898
3-5	1	1218	13.43	1.7003	12.6638
3-6	1	1218	0.68	0.3844	56.4338
3-7	1	1218	0.00	0.0000	0.0000
3-8	1	1218	0.01	0.0431	346.4102
4-5	1	1218	0.66	0.4207	63.3587
4-6	1	1218	2.68	1.2958	48.3534
4-7	1	1218	2.31	0.8409	36.3546
4-8	1	1218	0.99	0.4003	40.3487
4-9	1	1218	0.71	0.5274	74.7724
4-10	1	1218	0.75	0.6420	85.6938
4-11	1	1218	1.04	0.4878	46.8511
4-12	1	1218	0.17	0.2503	151.2895
4-13	1	1218	0.00	0.0000	0.0000
5-4	1	1218	0.85	0.5914	69.2504
5-5	1	1218	0.65	0.7314	113.1264
5-6	1	1218	0.15	0.2853	193.9287
5-7	1	1218	0.18	0.2954	160.9037
5-8	1	1218	0.18	0.2712	153.8479
5-9	1	1218	0.00	0.0000	0.0000
6-2	1	1218	0.87	0.3474	39.7058
6-3	1	1218	0.19	0.1780	93.3610
6-4	1	1218	0.25	0.3644	144.5103
2-5	1	1218	0.00	0.0000	0.0000
2-1	1	1824	14.11	2.2977	16.2864
2-2	1	1824	11.48	3.2641	28.4273
2-3	1	1824	2.06	0.6381	30.9384
2-4	1	1824	0.00	0.0000	0.0000
3-3	1	1824	11.43	3.8928	34.0708
3-4	1	1824	31.94	3.5541	11.1274
3-5	1	1824	19.74	3.6305	18.3888
3-6	1	1824	0.98	0.6226	63.4299
3-7	1	1824	0.00	0.0000	0.0000
3-8	1	1824	0.00	0.0000	0.0000
4-5	1	1824	0.99	0.8952	90.5665
4-6	1	1824	0.95	0.7931	83.5649
4-7	1	1824	1.91	0.7605	39.7216
4-8	1	1824	0.63	0.9180	144.9170
4-9	1	1824	0.21	0.3597	168.0180
4-10	1	1824	0.55	0.6191	111.7749
4-11	1	1824	0.95	0.8006	83.8406
4-12	1	1824	0.19	0.2628	139.9229
4-13	1	1824	0.00	0.0000	0.0000
5-4	1	1824	0.50	0.6046	120.1412
5-5	1	1824	0.06	0.1231	200.1041
5-6	1	1824	0.04	0.1199	300.0000
5-7	1	1824	0.07	0.2058	300.0000
5-8	1	1824	0.15	0.3554	233.7344
5-9	1	1824	0.00	0.0000	0.0000
6-2	1	1824	0.95	0.4657	48.8719
6-3	1	1824	0.03	0.0821	300.0000
6-4	1	1824	0.06	0.1092	198.4345
2-5	1	1824	0.00	0.0000	0.0000

Figure 23. Segment of computer printout of vehicle type analysis for the Fowlerville scales (midnight to 6:00 a.m. and 6:00 a.m. to noon).

TABLE 7

DISTRIBUTION OF TRUCK TYPES FOR SEVEN SURVEY LOCATIONS

	Survey Station	3-3 Truck Type: Commercial Volume ($\overline{V}$) Represented, percent	3-3 Truck Type: Standard Deviation σ	3-3 Truck Type: Coefficient of Variation C. V. = $\frac{\sigma \times 100}{\overline{V}}$	3-4 Truck Type: Commercial Volume ($\overline{V}$) Represented, percent	3-4 Truck Type: Standard Deviation σ	3-4 Truck Type: Coefficient of Variation C. V. = $\frac{\sigma \times 100}{\overline{V}}$	3-5 Truck Type: Commercial Volume ($\overline{V}$) Represented, percent	3-5 Truck Type: Standard Deviation σ	3-5 Truck Type: Coefficient of Variation C. V. = $\frac{\sigma \times 100}{\overline{V}}$
Midnt to 6 a.m.	1	8.44	2.40	28.50	41.18	7.21	17.50	25.31	7.78	30.74
	2	---	---	---	---	---	---	---	---	---
	3	9.22	2.47	26.75	51.53	7.95	15.43	20.70	5.63	27.19
	4	7.88	1.25	15.87	35.43	3.99	11.25	43.05	5.39	12.52
	6	---	---	---	---	---	---	---	---	---
	7	---	---	---	---	---	---	---	---	---
	9	8.56	2.84	33.15	35.74	4.48	12.52	21.10	5.56	26.36
			avg. 2.24	avg. 26.06		avg. 5.90	avg. 14.17		avg. 6.09	avg. 24.20
6 a.m. to Noon	1	17.35	2.40	13.85	22.64	1.88	8.29	12.25	1.69	13.84
	2	9.62	1.95	20.25	22.52	2.49	11.05	10.87	1.84	16.94
	3	14.83	3.19	21.48	26.95	2.93	10.89	11.65	4.06	34.84
	4	11.56	1.84	15.88	26.80	3.10	11.58	29.38	6.99	23.78
	6	12.56	2.77	22.03	30.88	3.48	11.28	25.27	2.67	10.56
	7	7.16	1.51	21.05	10.56	0.95	9.03	5.03	0.71	14.15
	9	8.83	1.85	20.97	21.79	3.53	16.21	13.42	2.14	15.84
			avg. 2.21	avg. 19.35		avg. 2.62	avg. 11.19		avg. 2.87	avg. 18.56
9 a.m. to 3 p.m.	1	11.92	2.57	21.53	20.67	2.06	9.98	14.05	1.27	9.02
	2	5.11	1.77	34.56	18.97	3.55	18.69	9.19	0.90	9.81
	3	14.26	3.75	26.26	25.94	2.58	9.96	11.63	2.09	17.93
	4	11.26	2.81	24.96	23.14	2.25	9.74	26.14	3.25	12.41
	6	11.47	2.17	18.90	26.34	0.89	3.38	27.01	1.83	6.76
	7	5.91	0.09	1.54	6.06	0.26	4.26	5.19	0.36	7.02
	9	---	---	---	---	---	---	---	---	---
			avg. 2.19	avg. 21.29		avg. 1.93	avg. 9.33		avg. 1.61	avg. 10.49
Noon to 6 p.m.	1	14.85	4.65	31.33	19.91	1.79	8.99	13.43	1.70	12.66
	2	9.31	1.92	20.65	18.09	2.92	16.16	7.97	2.61	32.73
	3	13.49	2.50	18.49	26.89	2.88	10.69	12.18	3.73	30.63
	4	12.46	2.36	18.94	22.35	2.23	9.96	25.22	3.11	12.31
	6	14.17	3.75	26.44	24.65	2.24	9.09	20.43	3.09	15.12
	7	6.68	2.29	34.32	7.33	2.19	29.85	4.17	1.12	26.94
	9	9.34	2.03	21.72	19.78	1.51	7.62	11.58	2.01	17.37
			avg. 2.78	avg. 24.55		avg. 2.25	avg. 13.19		avg. 2.48	avg. 21.10
6 p.m. to midnt	1	11.43	3.89	34.07	31.94	3.55	11.13	19.74	3.63	18.39
	2	---	---	---	---	---	---	---	---	---
	3	12.06	2.12	17.55	41.42	8.73	21.07	16.40	7.07	43.09
	4	13.30	3.45	25.97	29.17	4.35	14.91	34.02	6.30	18.53
	6	12.34	3.98	32.24	33.24	2.62	7.89	34.20	3.73	10.92
	7	---	---	---	---	---	---	---	---	---
	9	8.47	2.30	27.11	28.48	4.76	16.73	16.96	3.02	17.83
			avg. 3.14	avg. 27.38		avg. 4.80	avg. 14.34		avg. 4.75	avg. 21.75

sampling plan. One reasonable method might entail using the average standard deviation as a criterion for a sampling plan. Table 8, a compilation of across-station average of standard deviations of C.V.s, shows that the use of a grand average standard deviation might be considered reasonable since the individual values are grouped rather closely.

TABLE 8

COMPILATION OF BETWEEN-STATION STANDARD DEVIATION AND COEFFICIENTS OF VARIATION FOR CRITICAL VEHICLES

Time Period	Vehicle Type					
	3-3		3-4		3-5	
	σ[1]	C.V.[2]	σ	C.V.	σ	C.V.
Midnight to 6 a.m.	2.24	26.06	5.90	14.17	6.09	24.20
6 a.m. to noon	2.21	19.35	2.62	11.19	2.87	18.56
9 a.m. to 3 p.m.	2.19	21.29	1.93	9.33	1.61	10.49
Noon to 6 p.m.	2.78	24.55	2.25	13.19	2.48	21.10
6 p.m. to midnight	3.14	27.38	4.80	14.34	4.75	21.75
$\bar{X}_j = \frac{\Sigma X_i}{3}$	2.51	23.72	3.50	12.44	3.56	19.22

Grand Mean $= \frac{\Sigma X_j}{3}$

$\bar{\bar{\sigma}}$ = 3.19 (mean standard deviation for 3 critical vehicle types, all time periods, and all stations)

$\overline{\overline{C.V.}}$ = 18.46 (mean C.V. for 3 critical vehicle types, all time periods, and all stations)

[1] σ = standard deviation

[2] C.V. or Coefficient of Variation equals (σ x 100) ÷ mean average.

For example, if it is desired that the proportion of critical vehicles be estimated within 2 percent, the required minimum sample size, n, based upon average standard deviation, could be determine as follows:

$$n = \left(\frac{\bar{\bar{\sigma}}}{\sigma_{\bar{X}}} \right)$$

If we want 95 percent confidence that our estimate will be within 2 percent of the best estimate of the true proportion, then $2\sigma_{\bar{X}} = 2$, and $\sigma_{\bar{X}} = 1$.

$$n = \left(\frac{3.19}{1} \right)^2 \cong 10$$

where n = number of 24-hr sampling clusters. As stated earlier, each sampling cluster should consist of all vehicles surveyed during a 24-hr period.

$\bar{\bar{\sigma}}$ = overall mean standard deviation = 3.19 (See Table 8)
$\sigma_{\bar{x}}$ = desired standard error.

Figure 24 graphically shows the preceding mathematical relationship between average precision of estimate for distribution of vehicle types and the number of 24-hr sampling units. Therefore, Figure 24 can be used to estimate the number of 24-hr sampling units to attain a desired precision.

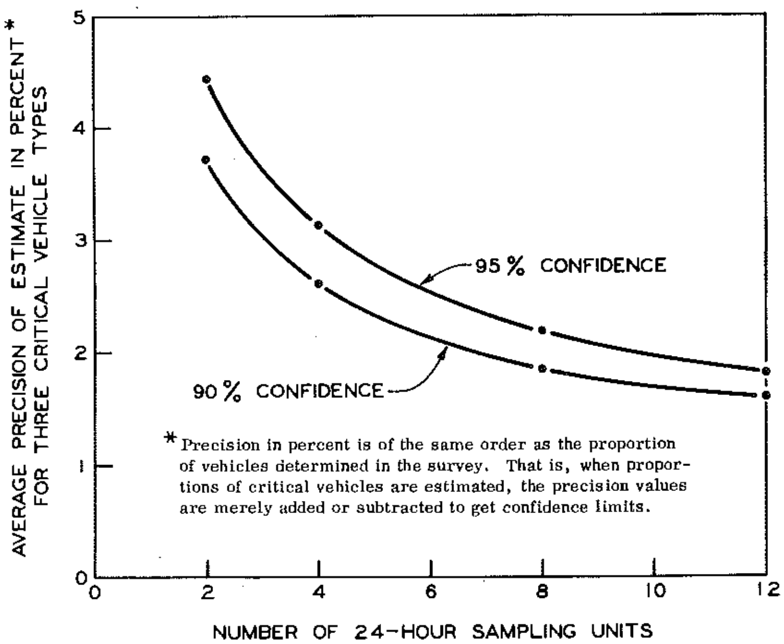


Figure 24. Relationship between average precision of estimate of distribution of vehicle types and number of 24-hr sampling units.

The preceding sampling plan would provide assurance that, for several locations, the average error for any of the three critical vehicle types and for any location would be at a desired level. However, some vehicle types at certain locations would have larger errors and others would be smaller.

Sample size could also be determined with the preceding mathematical model by using the largest standard deviation, for any critical vehicle type. This would insure that no critical vehicle type at any location would have an error larger than desired. If the accuracy of estimate were of extreme importance, at some particular location, this latter approach might be used, but it would involve considerably larger sample sizes.

Abbreviated Samples

Since vehicle classification sample surveys are more easily taken during the conventional work day, the feasibility of using estimators derived from clusters, each of which was taken continuously during the hours of 9 a. m. to 3 p. m. was investigated. Table 9 gives a comparison of average daily (24 hr) vehicle proportions and surveys observed from 9 a. m. to 3 p. m.

Averages observed from 9 a. m. to 3 p. m. (6 hr) compared quite closely with 24-hr averages. For all 22 sample stations, the average difference (avg 24-hr minus 9 a. m. to 3 p. m. avg) for the critical vehicles (3-3, 3-4, and 3-5) was 0.8 with a standard deviation of 1.5. Therefore, 24-hr average classifications might be estimated using data available only from 9 a. m. to 3 p. m. surveys. This would be recommended only in cases where 24-hr data were not available since there is no way to determine if the close relationship between 24-hr and 9 a. m. to 3 p. m. vehicle classification averages might change.

TABLE 9
VEHICLE TYPE DISTRIBUTION AS PROPORTION OF AVERAGE DAILY VOLUME
(percent)

Fowlerville Scale

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	16.5	16.2	0.3
2- 2	15.2	16.5	-1.3
2- 3	1.8	2.1	-0.3
3- 3	14.2	14.7	-0.5
3- 4	23.3	20.9	2.4
3- 5	14.7	13.4	1.3
3- 6	1.1	1.1	0.0
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.7	0.7	0.0
4- 6	2.9	3.3	-0.4
4- 7	2.6	2.8	-0.2
4- 8	1.0	1.0	0.0
4- 9	0.8	1.0	-0.2
4-10	0.9	0.7	0.2
4-11	1.3	1.5	-0.2
4-12	0.2	0.2	0.0
4-13	0.0	0.0	0.0
5- 4	0.7	0.8	-0.1
5- 5	0.5	0.7	-0.2
5- 6	0.1	0.1	0.0
5- 7	0.1	0.1	0.0
5- 8	0.2	0.2	0.0
6- 2	0.7	0.6	0.1
6- 3	0.1	0.1	0.0
6- 4	0.1	0.1	0.0

Lansing Scale

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	34.0	32.8	1.2
2- 2	16.8	19.5	-2.7
2- 3	2.2	2.7	-0.5
3- 3	9.0	8.5	0.5
3- 4	21.3	19.9	1.4
3- 5	10.5	9.9	0.6
3- 6	0.3	0.2	0.1
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.5	0.5	0.0
4- 6	0.6	0.7	-0.1
4- 7	0.8	0.9	-0.1
4- 8	0.5	0.7	-0.2
4- 9	0.1	0.1	0.0
4-10	0.1	0.1	0.0
4-11	0.1	0.2	-0.1
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	1.0	1.1	-0.1
5- 5	0.4	0.5	-0.1
5- 6	0.1	0.0	0.1
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	0.8	0.9	-0.1
6- 3	0.0	0.0	0.0
6- 4	0.9	0.4	0.5

Portland Scale (I 96)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	15.2	16.2	-1.0
2- 2	14.7	17.4	-2.7
2- 3	1.8	1.9	-0.3
3- 3	13.1	14.3	-1.2
3- 4	30.6	25.4	5.2
3- 5	14.1	12.6	1.5
3- 6	0.7	0.7	0.0
3- 7	0.1	0.0	0.1
3- 8	0.1	0.0	0.1
4- 5	0.9	1.0	-0.1
4- 6	2.4	2.5	-0.1
4- 7	1.6	1.7	-0.1
4- 8	0.5	0.5	0.0
4- 9	0.3	0.4	-0.1
4-10	0.7	0.8	-0.1
4-11	0.8	1.1	-0.3
4-12	0.2	0.2	0.0
4-13	0.0	0.0	0.0
5- 4	0.5	0.6	-0.1
5- 5	0.3	0.3	0.0
5- 6	0.0	0.0	0.0
5- 7	0.1	0.1	0.0
5- 8	0.1	0.1	0.0
8- 2	1.2	1.3	-0.1
6- 3	0.2	0.2	0.0
6- 4	0.2	0.1	0.1

Grass Lake Twnshp.

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	11.3	11.8	-0.5
2- 2	12.3	13.8	-1.5
2- 3	1.4	1.6	-0.2
3- 3	12.1	12.0	0.1
3- 4	25.4	23.7	1.7
3- 5	28.8	26.6	2.2
3- 6	0.8	0.8	0.0
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.8	0.9	-0.1
4- 6	1.9	2.3	-0.4
4- 7	1.1	1.2	-0.1
4- 8	0.3	0.3	0.0
4- 9	0.2	0.3	-0.1
4-10	0.3	0.4	-0.1
4-11	0.4	0.5	-0.1
4-12	0.1	0.0	0.1
4-13	0.0	0.0	0.0
5- 4	0.7	0.9	-0.2
5- 5	0.3	0.4	-0.1
5- 6	0.1	0.1	0.0
5- 7	0.1	0.1	0.0
5- 8	0.1	0.1	0.0
6- 2	1.2	1.2	0.0
6- 3	0.1	0.1	0.0
6- 4	0.2	0.2	0.0

Erie Twnshp. (I 75)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	7.4	8.1	-0.7
2- 2	9.1	10.5	-1.4
2- 3	1.1	1.2	-0.1
3- 3	13.3	13.8	-0.5
3- 4	30.2	26.8	3.4
3- 5	29.7	29.2	0.5
3- 6	0.6	0.7	-0.1
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	2.9	3.3	-0.4
4- 6	2.1	2.1	0.0
4- 7	0.3	0.3	0.0
4- 8	0.0	0.0	0.0
4- 9	0.0	0.0	0.0
4-10	0.0	0.0	0.0
4-11	0.0	0.0	0.0
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	0.8	1.0	-0.2
5- 5	0.6	0.8	-0.2
5- 6	0.1	0.1	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	1.2	1.1	0.1
6- 3	0.4	0.4	0.0
6- 4	0.2	0.2	0.0

TABLE 9 (Cont.)
VEHICLE TYPE DISTRIBUTION AS PROPORTION OF AVERAGE DAILY VOLUME (percent)

New Buffalo (US 12)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	15.1	19.6	-4.6
2- 2	9.2	12.5	-3.3
2- 3	1.9	2.5	-0.6
3- 3	12.3	13.7	-1.4
3- 4	30.3	25.1	5.2
3- 5	27.7	22.9	4.8
3- 6	0.4	0.3	0.1
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.7	0.7	0.0
4- 6	0.2	0.1	0.1
4- 7	0.1	0.0	0.1
4- 8	0.1	0.0	0.1
4- 9	0.0	0.0	0.0
4-10	0.1	0.0	0.1
4-11	0.0	0.0	0.0
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	0.4	0.5	-0.1
5- 5	0.1	0.1	0.0
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	0.7	0.9	-0.2
6- 3	0.0	0.0	0.0
6- 4	0.8	0.5	0.3

Pontiac Scale (US 10)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	47.2	46.7	1.4
2- 2	21.5	23.6	-2.1
2- 3	1.7	1.8	-0.1
3- 3	7.2	7.2	0.0
3- 4	9.4	8.2	1.2
3- 5	4.5	4.8	-0.3
3- 6	0.2	0.2	0.0
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.6	0.6	0.0
4- 6	1.4	1.3	0.1
4- 7	1.2	1.2	0.0
4- 8	0.5	0.4	0.1
4- 9	0.3	0.3	0.0
4-10	0.5	0.5	0.0
4-11	0.6	0.7	-0.1
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	0.6	0.6	0.0
5- 5	0.2	0.2	0.0
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	0.8	0.7	0.1
6- 3	0.1	0.1	0.0
6- 4	1.3	0.4	0.9

Erie Twnshp. Scale (US 24)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	22.0	23.7	-1.7
2- 2	16.6	19.9	-3.3
2- 3	2.1	2.4	-0.3
3- 3	8.7	9.4	-0.7
3- 4	25.1	22.4	2.7
3- 5	15.5	13.6	1.9
3- 6	0.4	0.5	-0.1
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	1.5	1.2	0.3
4- 6	1.9	1.5	0.4
4- 7	1.1	0.8	0.3
4- 8	0.0	0.0	0.0
4- 9	0.0	0.0	0.0
4-10	0.0	0.0	0.0
4-11	0.1	0.1	0.0
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	1.5	2.1	-0.6
5- 5	0.1	0.1	0.0
5- 6	0.1	0.0	0.1
5- 7	0.1	0.1	0.0
5- 8	0.0	0.0	0.0
6- 2	0.1	0.0	0.1
6- 3	0.0	0.0	0.0
6- 4	3.0	1.9	1.1

Saginaw Scale (I 75)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	21.4	21.0	0.4
2- 2	15.3	16.7	-1.4
2- 3	1.7	1.7	0.0
3- 3	8.8	9.2	-0.4
3- 4	22.9	21.3	1.6
3- 5	13.8	13.4	0.4
3- 6	0.8	0.8	0.0
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	1.3	1.5	-0.2
4- 6	3.1	3.4	-0.3
4- 7	7.3	7.2	0.1
4- 8	0.4	0.3	0.1
4- 9	0.2	0.2	0.0
4-10	0.5	0.6	-0.1
4-11	0.3	0.3	0.0
4-12	0.1	0.0	0.1
4-13	0.0	0.0	0.0
5- 4	1.0	1.0	0.0
5- 5	0.2	0.4	-0.2
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.1	0.1	0.0
6- 2	0.4	0.3	0.1
6- 3	0.1	0.0	0.1
6- 4	0.2	0.2	0.0

Vulcan Corners Count

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	40.3	39.0	1.6
2- 2	34.1	35.7	-1.6
2- 3	6.4	7.5	-1.1
3- 3	3.0	3.4	-0.4
3- 4	5.7	6.0	-0.3
3- 5	6.5	7.2	1.3
3- 6	0.1	0.0	0.1
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.1	0.1	0.0
4- 6	0.0	0.0	0.0
4- 7	0.0	0.0	0.0
4- 8	0.0	0.0	0.0
4- 9	0.1	0.1	0.0
4-10	0.0	0.0	0.0
4-11	0.0	0.0	0.0
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	0.3	0.1	0.2
5- 5	0.1	0.0	0.1
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	0.3	0.2	0.1
6- 3	0.2	0.1	0.1
6- 4	1.0	0.4	0.6

TABLE 9 (Cont.)
VEHICLE TYPE DISTRIBUTION AS PROPORTION OF AVERAGE DAILY VOLUME
(percent)

Eyer's Steak House on US 27

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	51.1	48.2	2.9
2- 2	21.6	22.8	-1.2
2- 3	4.8	5.6	-0.8
3- 3	2.8	3.0	-0.2
3- 4	7.5	8.0	-0.5
3- 5	4.0	3.8	0.2
3- 6	0.3	0.4	-0.1
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.9	1.0	-0.1
4- 6	2.0	2.2	-0.2
4- 7	1.5	1.6	-0.1
4- 8	0.1	0.1	0.0
4- 9	0.0	0.0	0.0
4-10	0.1	0.0	0.1
4-11	0.1	0.2	-0.1
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	0.9	1.0	-0.1
5- 5	1.1	1.4	-0.3
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	0.4	0.4	0.0
6- 3	0.0	0.0	0.0
6- 4	0.5	0.3	0.2

Perry County (Int. of M 78 and M 47)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	33.4	32.3	1.1
2- 2	21.6	22.5	-0.9
2- 3	1.9	1.6	0.3
3- 3	7.0	7.0	0.0
3- 4	16.8	16.6	0.2
3- 5	11.8	12.4	-0.6
3- 6	0.5	0.5	0.0
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.8	0.8	0.0
4- 6	1.2	1.3	-0.1
4- 7	1.5	1.6	-0.1
4- 8	0.0	0.0	0.0
4- 9	0.0	0.0	0.0
4-10	0.1	0.1	0.0
4-11	0.1	0.1	0.0
4-12	0.1	0.0	0.1
4-13	0.0	0.0	0.0
5- 4	0.9	0.9	0.0
5- 5	0.4	0.4	0.0
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.4	0.4	0.0
6- 2	0.7	0.6	0.1
6- 3	0.0	0.0	0.0
6- 4	0.8	0.2	0.6

New Buffalo Scale (I-94)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	12.7	13.8	-1.1
2- 2	12.5	13.5	-1.0
2- 3	6.2	7.1	-0.9
3- 3	8.3	8.0	0.3
3- 4	20.9	19.7	1.2
3- 5	33.8	32.0	1.8
3- 6	0.3	0.2	0.1
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.6	0.5	0.1
4- 6	0.4	0.5	-0.1
4- 7	0.2	0.3	-0.1
4- 8	0.0	0.0	0.0
4- 9	0.0	0.0	0.0
4-10	0.0	0.0	0.0
4-11	0.0	0.0	0.0
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	0.5	0.4	0.1
5- 5	0.1	0.0	0.1
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	2.6	3.0	-0.4
6- 3	0.5	0.2	0.3
6- 4	0.3	0.5	-0.2

Roberts Corner Scale (M 28 and M 123)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	53.5	52.8	0.7
2- 2	25.2	26.6	-1.4
2- 3	1.9	2.3	-0.4
3- 3	5.9	5.7	0.2
3- 4	5.6	5.9	-0.3
3- 5	3.4	4.2	-0.8
3- 6	0.2	0.2	0.0
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.0	0.0	0.0
4- 6	0.0	0.0	0.0
4- 7	0.5	0.8	-0.3
4- 8	0.0	0.0	0.0
4- 9	0.0	0.0	0.0
4-10	0.0	0.0	0.0
4-11	0.0	0.0	0.0
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	0.4	0.5	-0.1
5- 5	0.1	0.0	0.1
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	0.2	0.3	-0.1
6- 3	0.0	0.0	0.0
6- 4	3.1	0.3	2.8

Cambridge Scales

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	13.7	11.5	2.2
2- 2	17.2	21.0	-3.8
2- 3	2.5	3.5	-1.0
3- 3	13.4	15.1	-1.7
3- 4	26.5	24.2	2.3
3- 5	18.4	16.5	1.9
3- 6	0.7	0.8	-0.1
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	1.0	1.3	-0.3
4- 6	1.7	1.6	0.1
4- 7	2.0	1.4	0.6
4- 8	0.1	0.1	0.0
4- 9	0.1	0.0	0.1
4-10	0.1	0.0	0.1
4-11	0.2	0.4	-0.2
4-12	0.1	0.0	0.1
4-13	0.0	0.0	0.0
5- 4	0.5	0.2	0.3
5- 5	0.0	0.0	0.0
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.1	0.1	0.0
6- 2	1.1	1.6	-0.5
6- 3	0.1	0.1	0.0
6- 4	0.5	0.1	0.4

TABLE 9 (Cont.)
VEHICLE TYPE DISTRIBUTION AS PROPORTION OF AVERAGE DAILY VOLUME (percent)

Menominee County (Int. of M 35 and US 41)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	42.1	43.0	-0.9
2- 2	28.5	28.0	0.5
2- 3	9.3	8.8	0.5
3- 3	4.6	4.9	-0.3
3- 4	5.1	4.9	0.2
3- 5	5.3	4.7	0.6
3- 6	0.4	0.2	0.2
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.1	0.1	0.0
4- 6	0.0	0.0	0.0
4- 7	0.1	0.0	0.1
4- 8	0.0	0.0	0.0
4- 9	0.0	0.0	0.0
4-10	0.0	0.0	0.0
4-11	0.0	0.0	0.0
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	1.1	1.2	-0.1
5- 5	0.0	0.0	0.0
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.2	0.0	0.2
6- 2	1.9	2.0	-0.1
6- 3	0.1	0.2	-0.1
6- 4	1.3	1.5	-0.2

Howard City (Int. of US 131 and M 46)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	40.9	40.9	0.0
2- 2	27.2	28.1	-0.9
2- 3	3.7	3.5	0.2
3- 3	5.6	5.1	0.5
3- 4	12.8	12.5	0.3
3- 5	2.6	2.6	0.0
3- 6	0.5	0.5	0.0
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.4	0.5	-0.1
4- 6	1.4	1.6	-0.2
4- 7	1.7	1.7	0.0
4- 8	0.1	0.1	0.0
4- 9	0.0	0.0	0.0
4-10	0.3	0.3	0.0
4-11	0.2	0.2	0.0
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	0.8	0.8	0.0
5- 5	0.2	0.1	0.1
5- 6	0.1	0.1	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	0.6	0.6	0.0
6- 3	0.0	0.0	0.0
6- 4	0.9	0.4	0.5

Ionia County (M 66)

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	41.1	40.8	0.3
2- 2	28.8	29.8	-1.0
2- 3	2.9	2.8	0.1
3- 3	5.8	5.9	-0.1
3- 4	11.5	11.3	0.2
3- 5	3.2	3.1	0.1
3- 6	0.3	0.3	0.0
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.6	0.5	0.1
4- 6	0.8	0.7	0.1
4- 7	0.8	0.6	0.2
4- 8	0.1	0.2	-0.1
4- 9	0.1	0.1	0.0
4-10	0.1	0.1	0.0
4-11	0.2	0.3	-0.1
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	2.1	2.1	0.0
5- 5	0.1	0.2	-0.1
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	1.1	1.0	-0.1
6- 3	0.0	0.0	0.0
6- 4	0.3	0.0	0.3

Marshall (near) Intersection US 27 and I 94

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	17.4	20.6	-3.2
2- 2	14.7	17.0	-2.3
2- 3	1.7	2.4	-0.7
3- 3	10.2	10.0	0.2
3- 4	26.0	23.3	2.7
3- 5	22.7	19.1	3.6
3- 6	0.6	0.4	0.2
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.8	0.9	-0.1
4- 6	1.4	1.6	-0.2
4- 7	1.4	1.4	0.0
4- 8	0.1	0.0	0.1
4- 9	0.1	0.1	0.0
4-10	0.1	0.1	0.0
4-11	0.1	0.0	0.1
4-12	0.0	0.1	-0.1
4-13	0.0	0.0	0.0
5- 4	1.6	1.9	-0.3
5- 5	0.3	0.2	0.1
5- 6	0.1	0.0	0.1
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	0.5	0.4	0.1
6- 3	0.0	0.0	0.0
6- 4	0.2	0.2	0.0

Mancelona on US 131

Truck Type	Average Vehicles, percent		Difference (Avg. daily less the 6-hr avg.)
	Per Day	9 a.m. to 3 p.m.	
2- 1	56.3	56.2	0.1
2- 2	26.7	27.5	-0.8
2- 3	1.0	1.2	-0.2
3- 3	2.2	1.8	0.4
3- 4	6.4	6.1	0.3
3- 5	1.3	1.5	-0.2
3- 6	0.1	0.0	0.1
3- 7	0.0	0.0	0.0
3- 8	0.0	0.0	0.0
4- 5	0.3	0.3	0.0
4- 6	1.2	1.2	0.0
4- 7	0.6	0.7	-0.1
4- 8	0.1	0.1	0.0
4- 9	0.1	0.1	0.0
4-10	0.1	0.2	-0.1
4-11	0.1	0.2	-0.1
4-12	0.0	0.0	0.0
4-13	0.0	0.0	0.0
5- 4	0.8	0.6	0.2
5- 5	0.1	0.1	0.0
5- 6	0.0	0.0	0.0
5- 7	0.0	0.0	0.0
5- 8	0.0	0.0	0.0
6- 2	0.8	1.0	-0.2
6- 3	0.0	0.0	0.0
6- 4	1.8	1.2	0.6

SUMMARY

Example

For any highway location, commercial traffic axle load frequencies can be estimated with known precision by using methods described in this report. For example, suppose it is desired to estimate the characteristics of commercial vehicle traffic on US 127 near the town of Leslie. We want 90 percent confidence that annual volumes are estimated with a precision of 10 percent. Using Figure 19, for average precision of 10 percent, three 24-hr sampling units are required.

Figure 24 shows that for estimating distribution of commercial vehicle types, three 24-hr sample units give about 3 percent precision with 90 percent confidence. We will use annual loadometer results for estimating axle loadings for each type of vehicle.

Since three samples will be taken, we will divide the year into thirds (four-month periods) and take one 24-hr sample survey randomly (excluding weekends and holidays) from each four-month period. Let us assume that our random sample gives the following days and the surveys on those days give the 24-hr commercial volumes: January 14 (500), July 6 (625), and October 20 (580). Suppose January 14 is on Thursday, July 6 is on Tuesday, and October 20 is on Wednesday: from Table 3, we compute weekly volumes by multiplying 500 by 5,490; 625 by 5,582; and 580 by 5,483. Each product is then multiplied by 52.2 to give estimates of annual volumes, and the mean average of the three final products gives a pooled estimate of total annual commercial volume; in this case it is 163,800.

During the survey, vehicle classification counts were also made. For conciseness in this example we will look only at vehicle type 3-4 and assume the proportions of that type vehicle were 25.2, 19.7, and 22.3. The mean average proportion of those three values is 22.4. Multiplying the estimated annual commercial volume, 163,800 by 0.224 gives us 36,690; the estimated number of type 3-4 vehicles traveling over the roadway in question.

Axle load configurations can then be taken from Annual Truck Weight and Characteristics Study reports. Axle load values can be converted to 18-kip single axle equivalents using the AASHO factors (2, 3).

Conclusions

1) The problem of determining commercial vehicle loadings on any given highway can logically be separated into three phases: I. Estimates of traffic volume. II. Estimates of the distribution of vehicle types. III. Relation of axle loads to vehicle types.

2) Because of the consistency of axle loads for each vehicle type, Phase III can be resolved by using annual loadometer data. Within-station and between-station variances are different for each truck type and are listed in Table 5.

3) Because of large seasonal variations, samples should be taken at intervals spaced throughout a year to estimate annual commercial volumes. Expansion factors for using 9, 12, and 24-hr sampling units are listed in Table 3.

4) Sampling for both commercial vehicle volumes and their types can be carried out simultaneously by a surveyor. Figures 19 and 24 can be used for estimating the number of 24-hr sampling units required to give a desired precision.

5) Samples for both commercial vehicle volumes and types requires sampling units covering all 24 hr of a day, although surveys of vehicle types taken between the hours of 9 a.m. to 3 p.m. might be used at greater and unpredictable risk.

REFERENCES

1. "The AASHO Road Test," Highway Research Board Special Reports 61A - 61G, Washington, D. C., 1961-62.

2 "The AASHO Interim Guide for the Design of Rigid Pavement Structures," Committee on Design, American Association of State Highway Officials, Washington, D. C., 1962.

3. "The AASHO Interim Guide for the Design of Flexible Pavement Structures," Committee on Design, American Association of State Highway Officials, Washington, D. C., 1961.

APPENDIX

Statistics

Details of statistical computations are not included since conventional techniques have been used. However, for those with no statistical background, common statistical terms used in this report are defined below.

Standard Deviation (σ_x or S_x) of a set of N numbers X_1, X_2, X_3. . . X_N

where
$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \bar{x})^2}{N-1}}$$

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N}$$

For normal distributions:

(a) 68.27 percent of the data are between $x - \sigma_x$ and $\bar{x} + \sigma_x$
(b) 95.45 percent of the data are between $\bar{x} - 2\sigma_x$ and $\bar{x} + 2\sigma_x$
(c) 99.73 percent of the data are between $\bar{x} - 3\sigma_x$ and $\bar{x} + 3\sigma_x$

Sampling Distribution of Mean

Let all possible samples of size n be drawn without replacement from a population of size N. Compute the mean of each sample and consider the distribution of such means. Then the mean ($\bar{x}$) of the sampling distribution will equal the population mean ($\bar{X}$) and the standard deviation (sometimes called standard error) $\sigma_{\bar{x}}$ will be

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{n}} \sqrt{1 - \frac{n}{N}}$$

where n is small compared to N, the standard error can be simplified to

$$\sigma_{\bar{x}} \cong \frac{\sigma_x}{\sqrt{n}}$$

Further, for almost any type of population distribution, when n is large ($n \geq 30$) the sampling distribution of means is approximately normal (provided that the population mean and variance are finite and the population size is at least twice that of the sample).

Methods of Sample Selection

Simple Random Sampling (srs) - The fundamental method of sampling whereby each unit in the population has an equal chance of being selected. A common method used for srs is to assign a number to each unit and then use a table of random numbers for making selections.

If selected units are not returned to the population and thus have no chance of again being selected, sampling is said to be without replacement. If selected units are returned to the population after selection and thus have a chance of being selected again, sampling is said to be with replacement.

Sampling of Clusters - With simple random sampling, each item in the population is selected at random. However, srs would be virtually impossible in certain cases such as the commercial vehicle surveys discussed in this report. Therefore, clusters of vehicles were selected with the cluster size being dependent upon the number of commercial vehicles passing a point during a given time. Cluster sampling is very efficient under certain conditions but data must be treated differently than for srs.

Stratified Random Sampling - If a population is very heterogeneous but can be divided into homogeneous parts (strata), it is more efficient to sample at random from within each stratum then to sample at random from the entire population. Such a basic method is known as stratified random sampling.

Systematic Random Sampling - If units in a population are numbered in some order, one unit can be selected from the first k units and then every k-th unit thereafter is selected. Thus, selection of the first unit atuomatically selects an entire cluster of units (every k-th one). Further, the sample is automatically stratified into k units per stratum. This is known as systematic random sampling.

Coefficient of Variation (C. V.)

Indicates the precision of an estimator of the mean and is

$$C.V. = \frac{\sigma_{\bar{x}}}{\bar{X}}$$

It is usually multiplied by 100 and expressed as a percentage.