USE OF TRAFFIC DATA FOR CALCULATING EQUIVALENT 18,000-LB SINGLE-AXLE LOADS

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A method for flexible pavement thickness design has been proposed for use in Minnesota. It requires the calculation of summation of equivalent 18,000-lb axle loads during a design period. To calculate equivalent loads requires a knowledge of equivalency factors for various axle loads and configurations, total traffic, vehicle-type distribution, and axle-load distribution within each vehicle type. The load distribution for each type of vehicle is laid out in the format of a standard W-4 table, and the average effect is determined and called an N-18 factor for each type of vehicle. Axle-load equivalencies, taken from the AASHO Road Test, are dependent on thickness index and terminal serviceability index. Based on a traffic-load and vehicle-type distribution study on 40 Minnesota test sections, it was found that design thicknesses can vary by 2 to 3 in. of granular equivalent for variations in vehicle-type distribution and up to 10 in. for typical variations in vehicle-weight distribution. A computer program, which can be used on either the IBM 360 or the CDC 6600, has been developed to calculate equivalent 18,000-lb axle loads by using total volume, vehicle-type distribution, and axle-load distribution data. Generally, volume and vehicle-type distribution data are available from highway department traffic sections. However, load distribution data are not usually available except on a statewide basis. Histograms are presented showing variations in the average effect of various types of vehicles in terms of average number of equivalent 18,000-lb axle loads per passage of that type of vehicle. The computer program is now usable for flexible pavement design.

•A REVISED method for designing flexible pavements in Minnesota has been proposed for use. It is based on the performance of 49 in-service test sections throughout the state. This method has been reported on elsewhere (1).

One of the parameters required to use this procedure is the traffic factor in terms of the total number of equivalent 18,000-lb single-axle loads over a proposed pavement section during a given design period. This factor and the embankment strength in terms of a stabilimeter R-value are used to establish a pavement section thickness factor called the granular equivalent. The equivalent load concept makes it possible to calculate the destructive effect of various axle loads relative to a base or standard axle load (18,000 lb). The relation between the base axle load and the respective axle loads are called "equivalency factors." It is possible to calculate the average effect of each type of vehicle in terms of equivalent 18,000-lb axle loads by multiplying the axle loads by their respective equivalency factors. The summation of effects divided by the number of vehicles used for determining the effect is called the N-18 factor. This factor can vary with location and time. For design purposes, the total number of equivalent loads for a given year is calculated by multiplying the N-18 factors for each type of vehicle by the number of vehicles in that category and then summing these

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values for all vehicle types. The same procedure is followed for each year of the design period, and the total summation of equivalent loads is derived.

In this paper, a method is proposed for determining the summation of equivalent 18,000-lb single-axle loads. The method requires information about the number, distribution, and weight of the vehicles using the highway at the point of interest and the variation of these values with time. The current and future number and distribution of vehicles can be determined by the traffic section of the highway department. A method of estimating the N-18 factors for each type of vehicle is also presented. Appropriate annual increases in the N-18 factors based on statewide data during the last 15 years are also presented.

A computer program was developed to calculate the summation of equivalent 18,000-lb single-axle loads for each year of the design period and is used to check the sensitivity of the pavement thickness to changes in the input parameters.

CONVERSION OF MIXED TRAFFIC DATA

The three factors that are used to calculate the summation of equivalent 18,000-lb single-axle loads from mixed traffic data are as follows: total volume, vehicle-type distribution, and vehicle-weight distribution. The variation of these with time and location is studied to determine the change in the summation of equivalent loads when the effect of these variations is taken into account. The CDC 6600 and IBM 360 computers have been used to study these changes.

DETERMINATION OF TOTAL NUMBER OF VEHICLES

A great deal of work has been done to determine the number of vehicles using a section of highway. These data are used for both geometric and thickness design of highways. The volume data are generally defined as the annual average daily traffic (AADT). The AADT, which represents the number of vehicles in both directions, is determined for highways by the projection of traffic counts made at selective locations at certain times of the year. For use in the structural design of pavements, the number of vehicles in the design lane of interest is determined. A value of AADT is needed for each year of the design period.

Currently, AADT data for a specific design section are obtained from a traffic flow map, a vehicle count at the proposed location, or an estimate made from a general knowledge of the area.

Predictions of future AADT data can be obtained from the traffic section of a highway department. These data are predicted from past trends and furture expectations of traffic in the given area. The AADT data are predicted for all the highways in the state every 5 or 6 years and cover at least 20 years in the future.

For the method of calculating equivalent loads presented in this paper, current and future AADT values are used along with the years for which these values are predicted. A linear relation between the two predicted values is used to calculate the values for the intervening years. More than one future AADT value may be used to improve the prediction.

EFFECT OF VEHICLE-TYPE DISTRIBUTION VARIATION ON SUMMATION OF EQUIVALENT LOADS

The second factor used for calculating equivalent loads is the vehicle-type distribution. This factor is used to divide the AADT data into vehicle types for use with the weight distribution data. These data are commonly called the distribution data and consist of the percentages of the total number of vehicles represented in each vehicle category. The volume data in Minnesota are divided into ten vehicle types (Table 1).

The vehicle-type distribution is considered variable with location by most procedures used for calculating the summation of equivalent loads. None of the current methods of calculating equivalent loads considers the distribution data to vary with time (2, 3, 4, 5).

The data from a traffic study conducted by the Minnesota Highway Department and the Civil Engineering Department at the University of Minnesota in 1964 have been analyzed to determine if the distribution data vary significantly with time and location and how this variation affects a prediction of the summation of equivalent loads (6). The data include the percentage of vehicles in each of the ten vehicle types and the statewide average distribution data for 1964.

The effect of vehicle-type distribution variations can be shown by considering the percentage of equivalent loads of vehicle type 8. The range of distribution values for this type of vehicle is from 0 to 11.7 percent for the sections studied compared to 3.3 percent for the statewide data. The summation of equivalent 18,000-lb single-axle loads has been calculated for the statewide data and for the data from sections 1, 6, 26, 38, 43, and 47 of the Minnesota Satellite Study (6). These sections were chosen based on the percentage of type 8 vehicles: Sections 1 and 6 represent a high percentage of type 8 vehicles, sections 38 and 47 are similar to the statewide data, and sections 26 and 43 represent a low percentage. Calculations of equivalent loads were made in which only the percentage of vehicles was varied. The results of these calculations are given in Table 2. The results for the two sections, which have approximately the same percentage of type 8 vehicles as the statewide data, agree quite well with the number of loads predicted for the statewide data. The values for two high-percentage sections are 217 and 229 percent of the statewide value. The values for the two sections with a low percentage of type 8 vehicles are 18 and 37 percent of the statewide value.

If the variation in design summation of equivalent loads is assumed to be the same as the variation found for the summation of equivalent loads for 1964, it is possible to compare the pavement thicknesses required for each section. The comparison was made by using the calculated granular equivalent for each set of data (Table 3). The granular equivalent for a pavement section in Minnesota is calculated by using Eq. 1 (1):

$$GE = a_1D_1 + a_2D_2 + a_3D_3 \ldots \qquad (1)$$

where

GE = granular equivalent thickness, in.;
$a_1, a_2, a_3, \ldots$ = constants that define the relative effect of the given layer; and
$D_1, D_2, D_3, \ldots$ = thickness of individual layers, in.

The design summation of equivalent loads given in Table 3 was converted to granular equivalents by using a design chart given elsewhere (1). The variations in granular equivalent thicknesses for these various traffic values and an R-value of 20 for the embankment are given in Table 3. A difference in granular equivalent of 5 in. between the statewide data and the two sections with the high percentage of type 8 vehicles and a difference of 10 in. in granular equivalent between the statewide data and the low percentage sections are indicated. It is felt that this variation is of sufficient magnitude to require that the distribution data be varied with location.

The statewide distribution histories for vehicle types 6, 7, and 8 are shown in Figure 1 for 1952 through 1968. Vehicle type 8 has shown a steady increase of 0.25 percent per year, whereas the percentages of types 6 and 7 vehicles have decreased. This shows that the vehicle-type distribution is not necessarily constant over the design life of a road. An analysis was made to determine whether the summation of equivalent loads predicted by using variable distribution data was significantly different from the summation of equivalent loads predicted by using constant distribution data for the design period of a given section. The 1952 statewide distribution data were used for constant data for a design life of 17 years, and the 1952 through 1968 statewide distribution data were used as an example for variable distribution data.

For this example, the summation of equivalent loads using a constant distribution is 462,000; the summation of equivalent loads for the section with the variable distribution is 608,000. This latter value is 32 percent higher in equivalent loads. When using the same procedure to calculate the difference in granular equivalent as previously summarized, the difference is approximately 2 in. This is the same as saying that constant distribution data would yield a design that would require maintenance at 462,000 equivalent loads that hypothetically would take place in mid-1964 instead of the end of 1968 according to the variable data.

Current and future vehicle-type distribution data can be obtained from the traffic section of a highway department along with the volume data. The distribution data are generally predicted for the same years as the volume data. For the method proposed, the distribution values for the years between those given specific values are calculated by using a linear relation between the two data points entered. By using this method it is possible to account for possible changes in types of vehicles using a highway during the design period.

EFFECT OF VEHICLE-WEIGHT DISTRIBUTION VARIATION ON SUMMATION OF EQUIVALENT LOADS

The third factor used to calculate the summation of equivalent 18,000-lb axle loads is the distribution of axle loads within each type of vehicle. California, Idaho, and The Asphalt Institute use statewide loadometer data obtained from yearly W-tables to determine the average effect of traffic weights on a road (2, 3, 4). Recent studies in Minnesota and Kentucky have shown that weight distributions at various locations throughout the states differ to a great extent from the statewide averages (5, 6). It has also been found in Minnesota and Idaho that the weight data for individual vehicle types are not constant for the design period as assumed by some procedures (4, 6). Therefore, the proposed procedure allows for the variation of weight data with location and time. The weight distribution for each of the 10 types of vehicles listed previously has been studied invididually to determine the average load effect of each vehicle type. This term is called the N-18 factor.

To calculate the N-18 factor, we divide the weight data for each vehicle type into 32 weight categories, which coincide with the weight categories in standard W-4 tables. Each weight category has an equivalency factor calculated from the AASHO equations for the average weight of that category (7). The weight categories along with a set of equivalency factors are given in Table 4. The number of axles within each weight category is multiplied by the appropriate equivalency factor and summed for the 32 weight catagories. This value gives a total summation of equivalent 18,000-lb single-axle loads for the vehicles of that type. This value is then divided by the number of vehicles weighed to give the average load effect of the vehicle type in terms of equivalent 18,000-lb single-axle loads.

This method was used to calculate N-18 factors for each type of vehicle on the 49 Minnesota test sections. The data were gathered by setting up portable weighing stations at each of 40 locations for the 49 test sections during the summer and fall of 1964 and the spring of 1965. N-18 factors were calculated for each of the three seasons. The summer values represent both summer and winter and thus 7 months of the year, the fall values represent 3 months of the year, and the spring values represent 2 months of the year. The N-18 factors for each season are weighted according to the time periods. The 10 combined weighted N-18 factors are used to represent the average load effect of each of the 10 vehicle types on that location for 1964.

The 1964 N-18 factors for the 49 test sections and the 1964 statewide N-18 factors are presented elsewhere (8). These values show the wide range of average vehicle effect on the Minnesota highway system. Two sections have been chosen to study the effect of this variation. Section 47 with high N-18 factors and section 19 with low N-18 factors are used to compare the difference in the design summation of equivalent loads. The calculations have been made with the assumption that the volume and distribution data are constant for the design period of the section. The 1964 statewide vehicle-type distribution along with an AADT value of 1,000 was used for the calculation. The results of these computations are given in Table 5. A range of granular equivalent of more than 7 in. between the sections of high and low N-18 factors results. The statewide data indicate a granular equivalent thickness of 3 in. greater than the section with low N-18 factors and 4½ in. less than the section with the high N-18 factors. These variations are of sufficient magnitude to justify varying the weight data with location.

The N-18 factors calculated for the statewide data from 1952 through 1968 are plotted semilogarithmically to show the trends in N-18 factor for the various vehicle types. As shown in Figure 2, the N-18 factors for vehicle types 3 through 8 have increased generally at a uniform rate except for the 1968 values. Vehicle type 1 is considered constant

Table 1. Types of vehicles.

Vehicle Type	Vehicle Description
1	Passenger car
2	Panel and pickup (under 1 ton)
3	Single unit, 2-axle, 4-tired
4	Single unit, 2-axle, 6-tired
5	Single unit, 3-axle, 6-tired
6	Tractor semitrailer combination, 3-axle
7	Tractor semitrailer combination, 4-axle
8	Tractor semitrailer combination, 5-axle
9	Tractor semitrailer combination, 6-axle
10	Truck and trailer combination and bus

Table 2. Summation of equivalent 18,000-lb single-axle loads for 1964.

Location	Percentage of Type 8 Vehicles	Equivalent Loads for 1964	Percentage of Statewide Data
Statewide	3.3	14,263	100
Section 1	8.8	31,010	217
Section 6	11.7	32,673	229
Section 26	0.0	5,238	37
Section 38	3.4	15,453	108
Section 43	0.0	2,633	18
Section 47	3.0	14,348	101

Note: Volume data = 500 AADT; weight data derived from 1964 Minnesota statewide average (W-4 table).

Table 3. Comparison of granular equivalents for variations in vehicle-type distribution.

Location	Design Summation of Equivalent Loads	Granular Equivalents
Statewide	1,000,000	25.8
Section 1	2,170,000	30.5
Section 6	2,290,000	30.8
Section 26	370,000	20.0
Section 38	1,080,000	26.3
Section 43	180,000	15.7
Section 47	1,010,000	26.0

Note: The designs are based on an assumption of 1,000,000 equivalent loads for statewide data.

Figure 1. Variation of statewide vehicle-type distribution data with time.

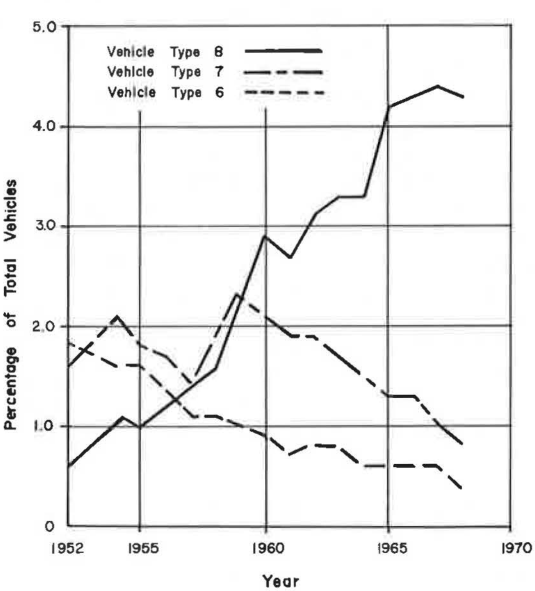


Table 4. Weight category used for determination of average load effect.

Category Number	Weight Category	Equivalency Factor[a]
1	1-2,999[b]	0.0002
2	3,000-6,999	0.005
3	7,000-7,999	0.03
4	8,000-11,999	0.09
5	12,000-15,999	0.36
6	16,000-17,999	0.80
7	18,000-19,999	1.24
8	20,000-21,999	1.83
9	22,000-23,999	2.58
10	24,000-25,999	3.53
11	26,000-29,999	5.39
12	30,000-34,999	9.42
13	35,000-39,999	16.33
14	40,000-44,999	26.90
15	1-5,999	0.01
16	6,000-11,999	0.01
17	12,000-17,999	0.04
18	18,000-23,999	0.15
19	24,000-29,999	0.43
20	30,000-31,999	0.75
21	32,000-33,999	0.97
22	34,000-35,999	1.23
23	36,000-37,999	1.53
24	38,000-39,999	1.89
25	40,000-41,999	2.29
26	42,000-43,999	2.75
27	44,000-45,999	3.27
28	46,000-49,999	4.17
29	50,000-54,999	5.83
30	55,000-59,999	8.18
31	60,000-64,999	11.17
32	65,000-69,999	14.95

[a]SN = 5.0 and terminal serviceability = 2.50.
[b]Single axle.
[c]Tandem axle.

over the design life of the section because this category is composed of passenger cars. At this time there is insufficient data on vehicle types 9 and 10 to show any trends. Therefore, these vehicle types are assumed to be constant over a given design period.

A best-fit line has been calculated for the data shown in Figure 2 for each vehicle type. The antilogarithm of the slopes of the lines through the data represents the percentage of increase in the statewide N-18 factor for each year. The slopes and percentage of increase from these analyses of the statewide data from 1952 to 1967 and also from 1952 through 1968 are given in Table 6. These percentages can be used to project future values of the N-18 factors.

By using the percentages of increase from the 1952-to-1967 analysis, which are slightly higher than those from the 1952-to-1968 analysis, we can compare the summation of equivalent loads predicted from constant weight data and time-dependent weight data. The values of the volume data and distribution data were held constant for these comparisons. An AADT value of 1,000 was used, and the distribution data were the average 1964 statewide distribution. The predictions were made by using the statewide weight data for 1964 from the W-4 tables and the 1964 weight data from sections 19 and 47.

The values for the 1964-through-1979 summation of equivalent loads (Table 7) show that the data using variable N-18 factors are about 66 percent higher than the data using constant N-18 factors. This difference represents about 3.2 in. of granular equivalent. It is felt that this variation warrants the use of a procedure in which the variation of N-18 factor with time can be accounted for. The data used to predict the increase in N-18 factors with time currently come from statewide loadometer studies that have been shown to underestimate the actual loading highways (6). Therefore, it may be possible that an even greater increase in N-18 factors could be taking place on individual sections.

When working with trends and percentages of increase for the N-18 factors, it is possible to predict N-18 factor values that exceed the maximum possible load a vehicle can haul. In order to prevent this, maximum values of N-18 factors have been determined individually for types 2 through 8 vehicles. The highest values of the measured N-18 factors in the 1964 weight study for each vehicle type (except types 2 and 4) were increased by 25 percent and were used as the maximum value possible for N-18 factors. In the case of types 2 and 4, the highest value was disregarded because it is more than twice the next largest value and only a few vehicles were weighed. The maximum assumed values for N-18 factors are given in Table 8.

There are two types of weight data that can be used with the developed computer program for calculating equivalent loads. It is possible to obtain the necessary data from a weight study at the proposed location of the highway. These data are put into the form of a W-4 table. The other form of data that can be used consists of a set of N-18 factors that have already been calculated from loadometer data. These N-18 factors would represent factors calculated for a similar section of highway. They are used when it is not possible to conduct a weight study at the proposed location. If no sections in the area are similar to the proposed section, it is possible to predict assumed values of N-18 factors from histograms plotted from the 1964 traffic study (9). The histograms (Figs. 3 through 6) indicate the distribution of N-18 factors for vehicle types 2 through 8 and type 10. The histograms represent the number of observations within a given range of N-18 factors for the respective vehicle types. It can be seen that there is a wide variation in these factors and that some thought must be given to the choice of an appropriate N-18 factor.

COMPUTER PROGRAM FOR CALCULATING SUMMATION OF EQUIVALENT 18,000-LB SINGLE-AXLE LOADS

A method that makes it possible to calculate equivalent 18,000-lb single-axle loads has been presented. The method developed utilizes the AADT, vehicle-type distribution, and axle-weight distribution within the various vehicle types for the prediction of equivalent 18,000-lb single-axle loads over a given design period. It has been shown that it is appropriate, in terms of design thickness variations, to allow these factors to vary

Table 5. Difference in computed granular equivalent thickness.

Location	Summation of Equivalent Loads, 20-Year Design	Granular Equivalent Thickness[a]	Difference From Statewide Granular Equivalent Thickness
Statewide	584,892	22.7	—
Section 19	361,845	19.8	2.9
Section 47	1,239,533	27.2	4.5

[a]From design chart in Ref. 1; assumed R-value = 20.

Figure 2. Variation of statewide N-18 factors with time.

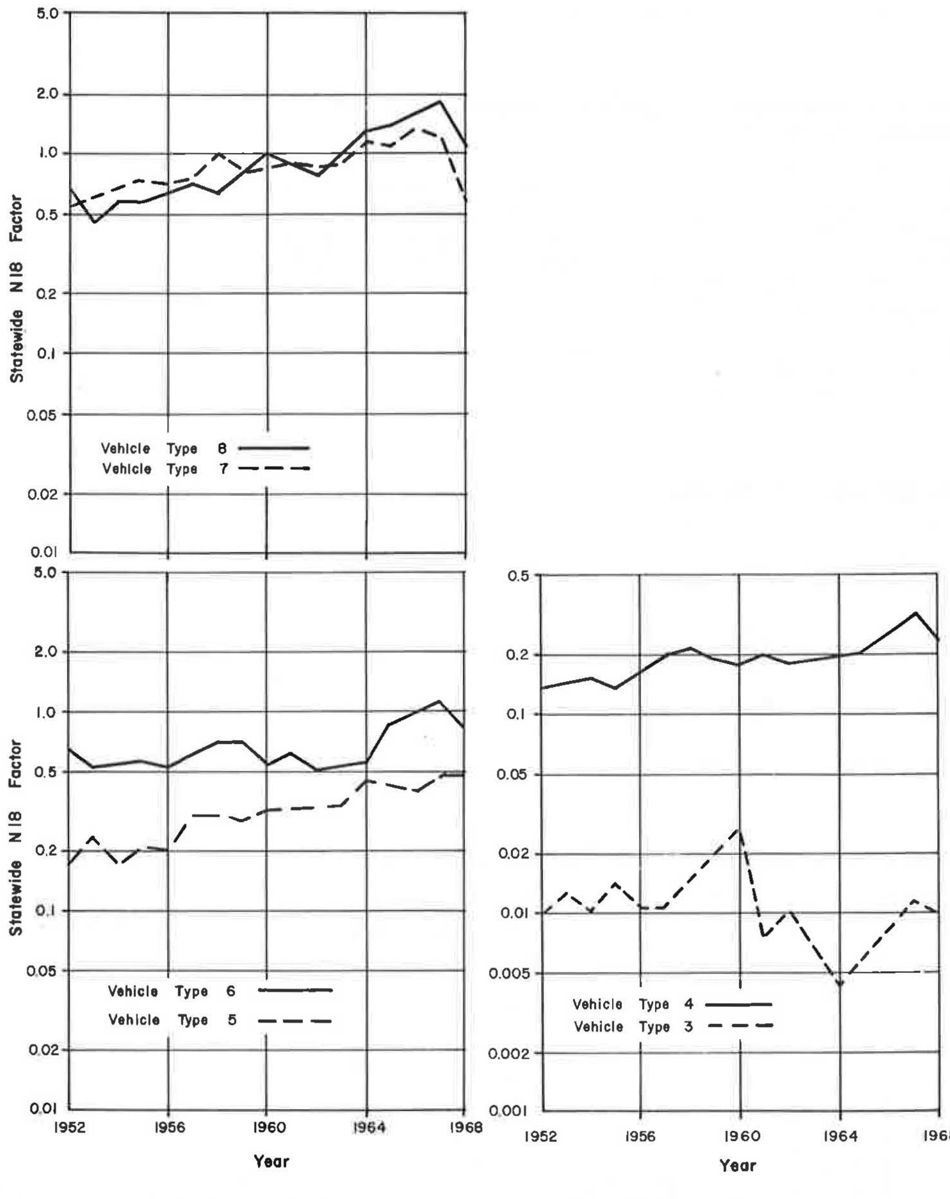


Table 6. Least squares regression analysis of Minnesota statewide N-18 factors with time.

	1952-1967			1952-1968		
Vehicle Type	Slope	Percentage of Increase Per Year	Standard Error	Slope	Percentage of Increase Per Year	Standard Error
2	0.00158	0.36	0.0858	0.00191	0.44	0.0830
3	0.01837	4.32	0.1999	-0.01509	-3.42	0.1969
4	0.1626	3.82	0.0537	0.01544	3.62	0.0528
5	0.02698	6.41	0.0517	0.02643	6.28	0.0503
6	0.01198	2.80	0.0782	0.01143	2.67	0.0759
7	0.02101	4.96	0.0415	0.01461	3.42	0.0847
8	0.03242	7.75	0.0597	0.02961	7.07	0.0663

Table 7. Variation in the summation of equivalent loads caused by varying the weight-distribution data with time.

Type of Data	Statewide	Section 19	Section 47
Summation of equivalent loads, 1964-1968			
Variable N-18F	147,382	90,868	311,890
Constant N-18F	128,391	79,429	272,093
Percentage of increase when using variable data	15	14	15
Summation of equivalent loads, 1964-1979			
Variable N-18F	737,926	453,161	–
Constant N-18F	442,236	273,590	–
Percentage of increase when using variable data	67	66	–

Table 8. Maximum assumed N-18 factors.

Vehicle Type	Maximum N-18 Factor, Table Measured	Maximum Assumed N-18 Factor
2	0.008	0.012
3	0.04	0.05
4	0.46	0.58
5	0.68	0.85
6	1.94	2.42
7	3.13	3.91
8	3.19	3.99

Figure 3. Histograms of number of N-18 factors for vehicle types 2 and 3.

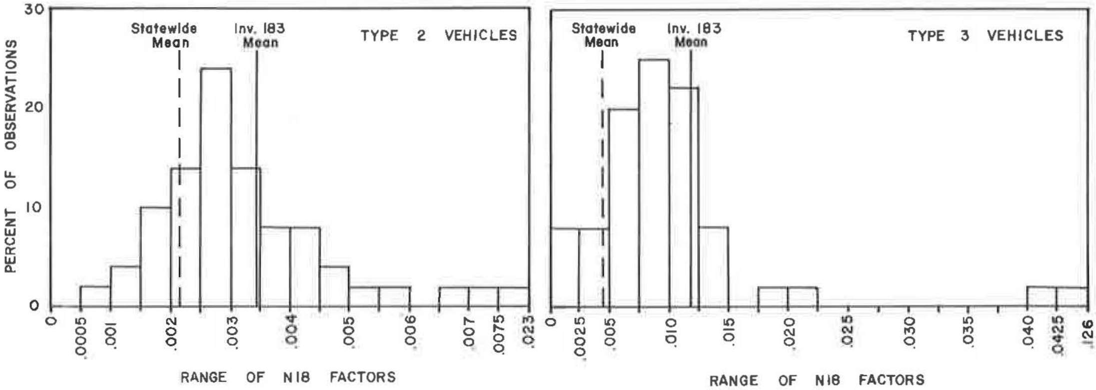


Figure 4. Histograms of number of N-18 factors for vehicle types 4 and 5.

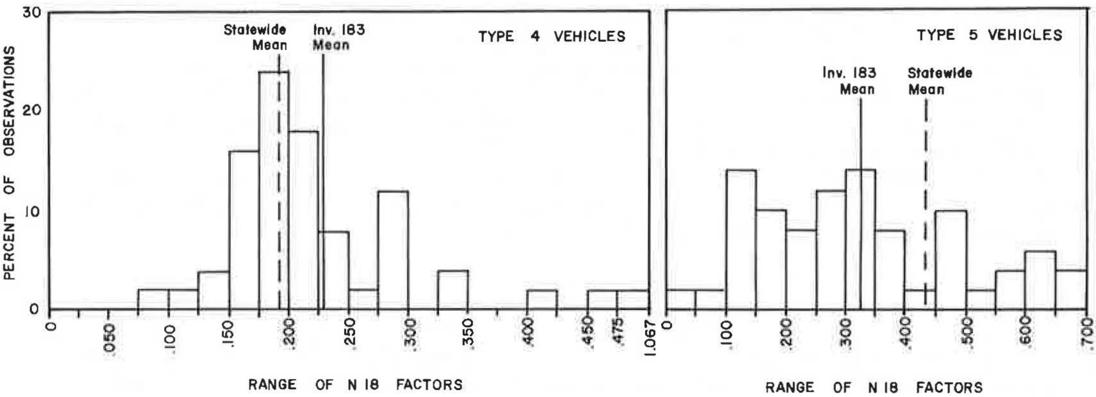


Figure 5. Histograms of number of N-18 factors for vehicle types 6 and 7.

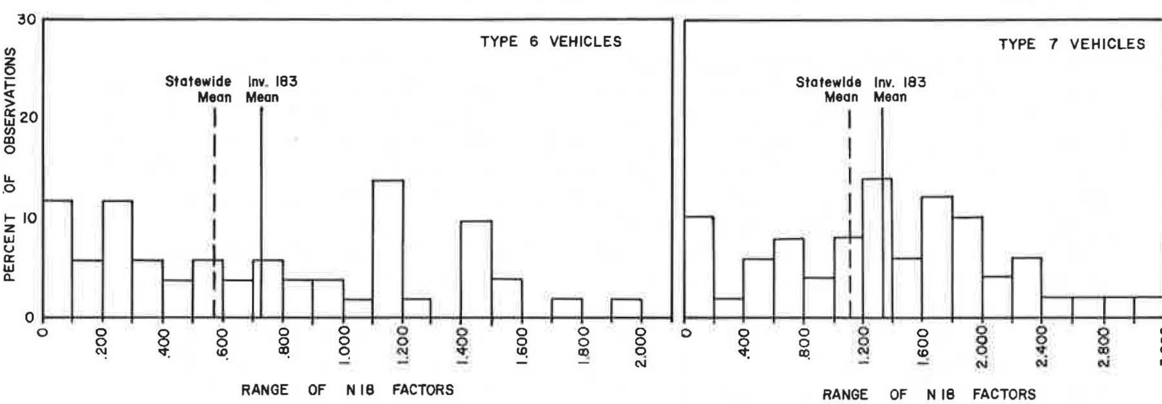
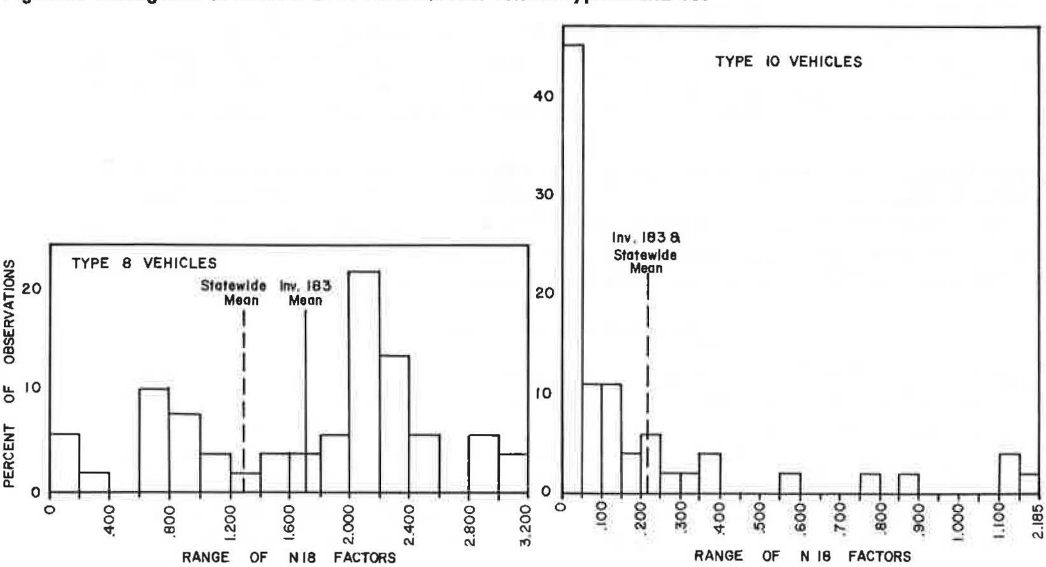


Figure 6. Histograms of number of N-18 factors for vehicle types 8 and 10.



with both time and location. It would not be practical to use this method and make the calculations without a computer. Therefore, all the calculations have been programmed in FORTRAN for the CDC 6600 and IBM 360 computers.

The program developed has the capabilities of calculating the number of equivalent loads for past and/or future traffic. The input data required include total vehicle volume, vehicle-type distribution, and weight-distribution data along with some general information about the proposed highway sections. The future summation of the equivalent 18,000-lb axle loads is calculated by using predicted values of volume and vehicle-type distribution for future years along with assumed percentages of increase in N-18 factors based on the statewide trends from past years.

CONCLUSIONS

The design of an asphalt pavement requires an estimate of the loading anticipated on the pavement during its design life. It has been shown by others that this loading can be expressed in terms of the summation of equivalent 18,000-lb axle loads. A computer program was developed and used to check the variation of the pavement thickness due to variations of the input values with time and location. The three main input variables were defined as the annual average daily traffic, vehicle-type distribution, and the axle-weight distribution. The thickness variations found as a result of this study are as follows:

1. Variation of distribution data with location. A comparison was made between the summation of equivalent loads for sections of high and low percentages of 5-axle vehicles and the statewide value. It was found that the required granular equivalent thickness by a particular design method indicated a difference of 15 in. in granular equivalent between the sections with high and low percentages of 5-axle vehicles. The granular equivalent for the statewide distribution data was 10 in. higher than the low percentage section and 5 in. lower than the high percentage section.
2. Variation of distribution data with time. The statewide vehicle-type distribution percentages were calculated from 1952 through 1968. These values were used to show that there is a significant variation of distribution data with time. An analysis was made to determine the difference in granular equivalent thicknesses for a section of constant distribution data and one with variable distribution data (assuming all other data are constant). The analysis shows that the variable data result in a granular equivalent of 2 in. thicker than the constant data.
3. Variation of axle-weight distribution data with location. The weight data from the 1964 traffic study on the Minnesota test sections were used to analyze the effect of varying this information with location. N-18 factors were calculated for each of the sections and also for the 1964 statewide data. High, low, and statewide N-18 factors were used to calculate the granular equivalent thickness, again holding all other data constant. The range of granular equivalent was 7.5 in. from low to high N-18 factors. The statewide values for the N-18 factor resulted in a design in the middle of this range.
4. Variation of axle-weight distribution data with time. Statewide loadometer data were analyzed from 1952 through 1968. The results of the analysis showed that all vehicle types except single unit trucks (2-axle, 4-tired) have increasing N-18 factors with time. The difference in granular equivalent thickness was 3.2 in. between the section with constant N-18 factors and one with variable N-18 factors.

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