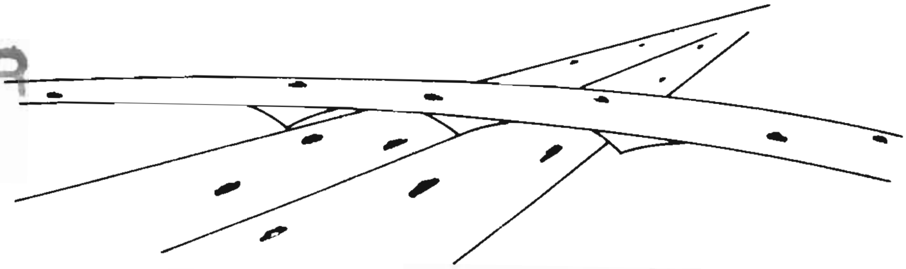

DEPARTMENTAL RESEARCH

Report Number 63 - 3A

A NEW METHOD OF TRAFFIC EVALUATION FOR USE IN PAVEMENT DESIGN

by

Conrad J. Derdeyn

For Presentation
at the
43rd Annual Meeting of the
Highway Research Board

TEXAS HIGHWAY DEPARTMENT

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Conrad J. Derdeyn
Engineering Assistant II

Research Section
Highway Design Division
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January 1964

A B S T R A C T

Most procedures currently used for the structural and geometric design of pavements fail to treat adequately the effects of mixed traffic on pavement life. The effects of the magnitude, the configuration, and the number of repetitions of various wheel loads should be included as variables in any good pavement design procedure.

An analysis of the axle loads observed on Texas highways is used with equivalence factors developed at the recently completed American Association of State Highway Officials' Road Test to develop a practical method for analyzing the damaging effects of mixed traffic. The method of traffic evaluation can be adapted for use with many different design procedures.

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DEFINITIONS AND ABBREVIATIONS

1. AASHO - American Association of State Highway Officials.
2. Tandem Axle Set - Two single axles whose centers are included between two parallel transverse vertical planes forty inches apart, extending across the full width of the vehicle.
3. Axle Load - The total load transmitted to the pavement structure by all wheels of either a single axle or a tandem axle set.
4. Design Interval - That period of time required for the design traffic to develop.
5. Equivalence Factor - The number of applications of an 18,000 pound single axle load required to produce the same effect on the serviceability of a pavement as one application of a particular axle load. All axle loads are expressed in terms of the equivalent number of repetitions of an 18,000 pound single axle by utilizing the equivalence factor developed at the AASHO Road Test.
6. Serviceability - The ability, at the time of observation of a pavement to serve high speed, high volume automobile and truck traffic.

I. INTRODUCTION

Background

Within the last twenty years, the methods used to determine the design thickness of each layer in flexible pavements have changed from procedures based almost solely on the experience and judgment of one individual to procedures which utilize many scientific techniques.

All of the design methods take into consideration in some form the relative strength properties of the roadway materials, the effect of traffic, and the effect of time. It is difficult, however, to clearly differentiate and explain how some procedures take the variables of material properties, traffic, and time into consideration.

Upon a review of many design procedures it is apparent that most methods of evaluating traffic are completely empirical. Most methods fail to account for three important elements: (1) the effect of the number of repetitions of wheel loads, (2) the effect of variations in the magnitude of wheel loads on in-service roads, and (3) the effect of volume, or the number of each specific wheel load by weight.

The apparent attitude of resignation among pavement designers concerning the evaluation of the effects of mixed traffic has not occurred without reason. There are three predominant extenuating circumstances which contributed to this.

(1) First, procedures developed prior to about 1940 were based on design considerations for roads carrying relatively small volumes of traffic with few heavily loaded vehicles. The use of a static loading test to evaluate the behavior of a soil which would be subjected to dynamic loads on the road proved to be satisfactory in the early years, and design procedures such as the CBR method resulted in pavements which stood up under traffic for a period of time. There appeared to be no reason to worry about precise analysis of the effects of traffic.

(2) Second, and probably the most fundamental factor, there was no scientific method of defining the serviceability of pavements. As a result of this deficiency, the damaging effect of a specific wheel load could not be evaluated accurately. An analysis of mixed traffic on in-service roads further complicated the problem.

(3) Third, there was no method for evaluating the effect of the variables other than those directly associated with traffic. The effect of construction control and variations of both temperature and moisture in the area were but a few of the unresolved conditions which further complicated the problem and contributed to an attitude of resignation.

These extenuating circumstances have for the most part been overcome. The AASHO Road Test has been completed and the results are being studied by highway engineers everywhere. The <u>AASHO Interim Guide for the Design of Flexible Pavement Structures</u> and the <u>AASHO Interim Guide for the Design of Rigid Pavement Structures</u> are summaries of the AASHO Road Test data prepared by the AASHO Committee on Design. These Guides provided a tool by which pavement designers may combine local experience with experience gained at the AASHO Road Test.

This paper discusses the development of a practical traffic analysis which may be used to analyze mixed traffic for pavement design.

AASHO Road Test

The most thorough evaluation of the effect of traffic on pavement performance to date is contained in the reports of the AASHO Road Test. The equivalence factors developed represent an extensive evaluation of the relative destructive effect of traffic. The definition of an equivalence factor is "the number of applications of an 18,000 pound single axle load required to produce the same effect on the serviceability of a pavement as one application of a particular axle load".

Mr. W. N. Carey, Jr., Chief Engineer of Research on the AASHO Road Test, made the following comment in respect to the equivalence factors:

> The most important result of the physical tests at Ottawa was the one by which the relative effects of different axle loadings on pavement performance can be determined. This could not have been found by study of ordinary highways in operation. Controlled traffic, as at the Road Test, where only one axle load operated over any given test pavement, was essential. This controlled traffic made it possible to assign responsibility for damage to a specific load. The effect of specific loads on performance was so clearly shown that it is possible to evolve very rational theories as to the probable effects of mixed traffic on pavement performance. . . The Road Test could not show whether or not the load effect would be the same in other environments as it was at Ottawa. On the other hand, without another controlled traffic test it cannot be shown that they would not be. I suggest that pavement designers might accept the load effect relationships resulting from the Road Test as good approximations of the load relationships everywhere until such time as

another controlled traffic research is undertaken. If this advice is accepted, highway engineers can immediately look to the entire highway system as testing ground for study of the many design relationships that are still unknown. Mixed traffic, if the Road Test equivalencies are used, will be a perfectly satisfactory treatment for numerous experiments involving pavement design parameters. It is only required that the axle loads and frequencies of the mixed traffic be determined with fair precision.

In the succeeding chapters a method of determining the axle loads and their frequencies in mixed traffic is presented.

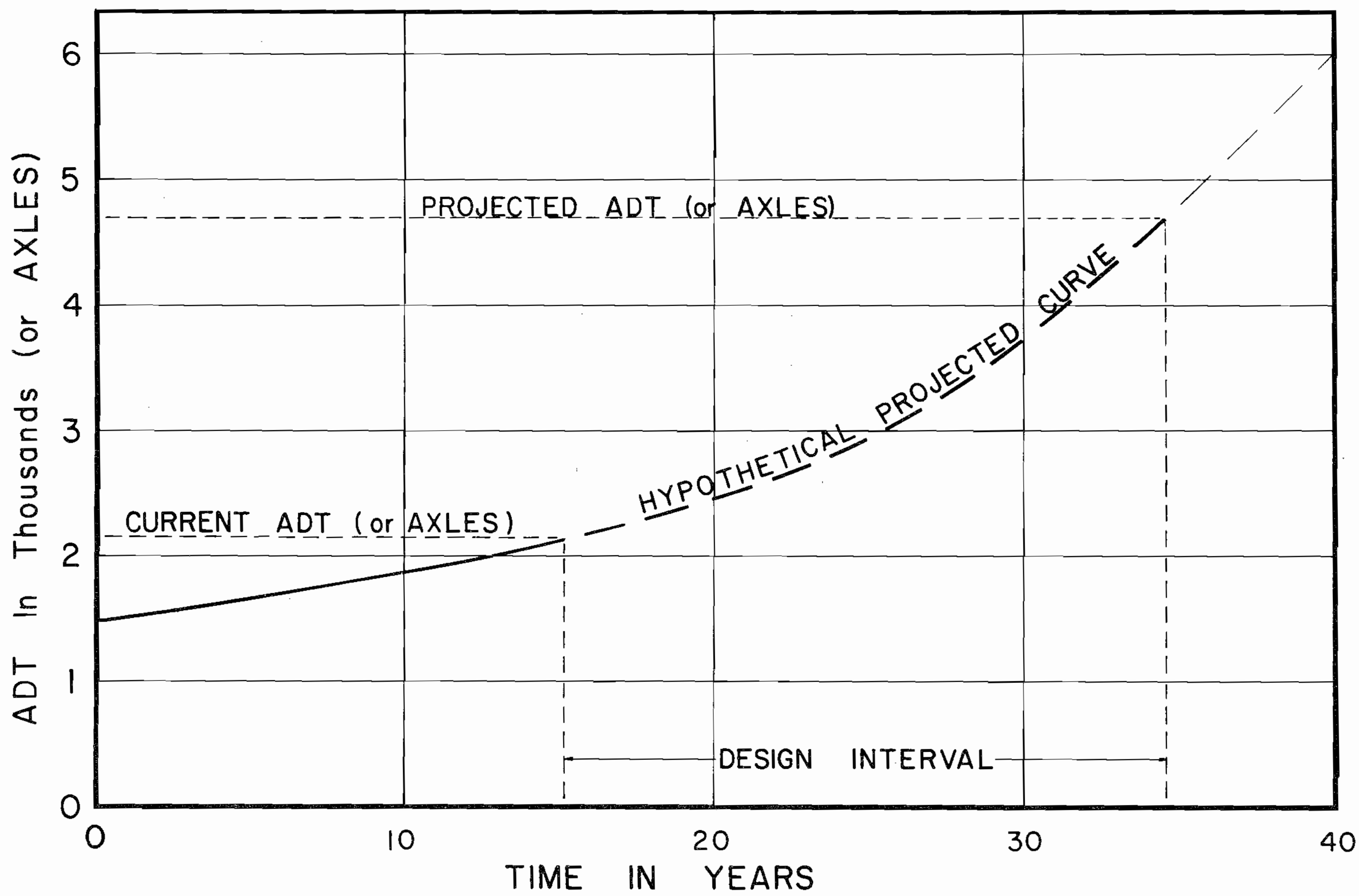

FIG. 1—TRAFFIC PROJECTION CURVE

II. EVALUATION OF TRAFFIC

Traffic Projection

The first step in the evaluation of traffic for use in highway design requires an analysis of the facility proposed. Past traffic history, land use, relationship to the area's long-range transportation plan, and other factors must all be considered. Once these factors are evaluated and weighed, a traffic projection for the design interval can be made.

Figure 1 depicts a hypothetical traffic projection wherein a facility with a twenty year service life is being analyzed for improvement. The average daily traffic has been projected twenty-five years and the design interval has been selected as twenty years. It should be noted that Figure 1 uses the word "axles" synonymously with ADT. This does not mean to imply that these two are directly interchangeable, but rather shows that axle counts can be projected directly since the "raw" traffic data is normally obtained in axle counts. The projection of axles rather than ADT at this point would simplify the overall mechanics of this program; however, in order to stay with current

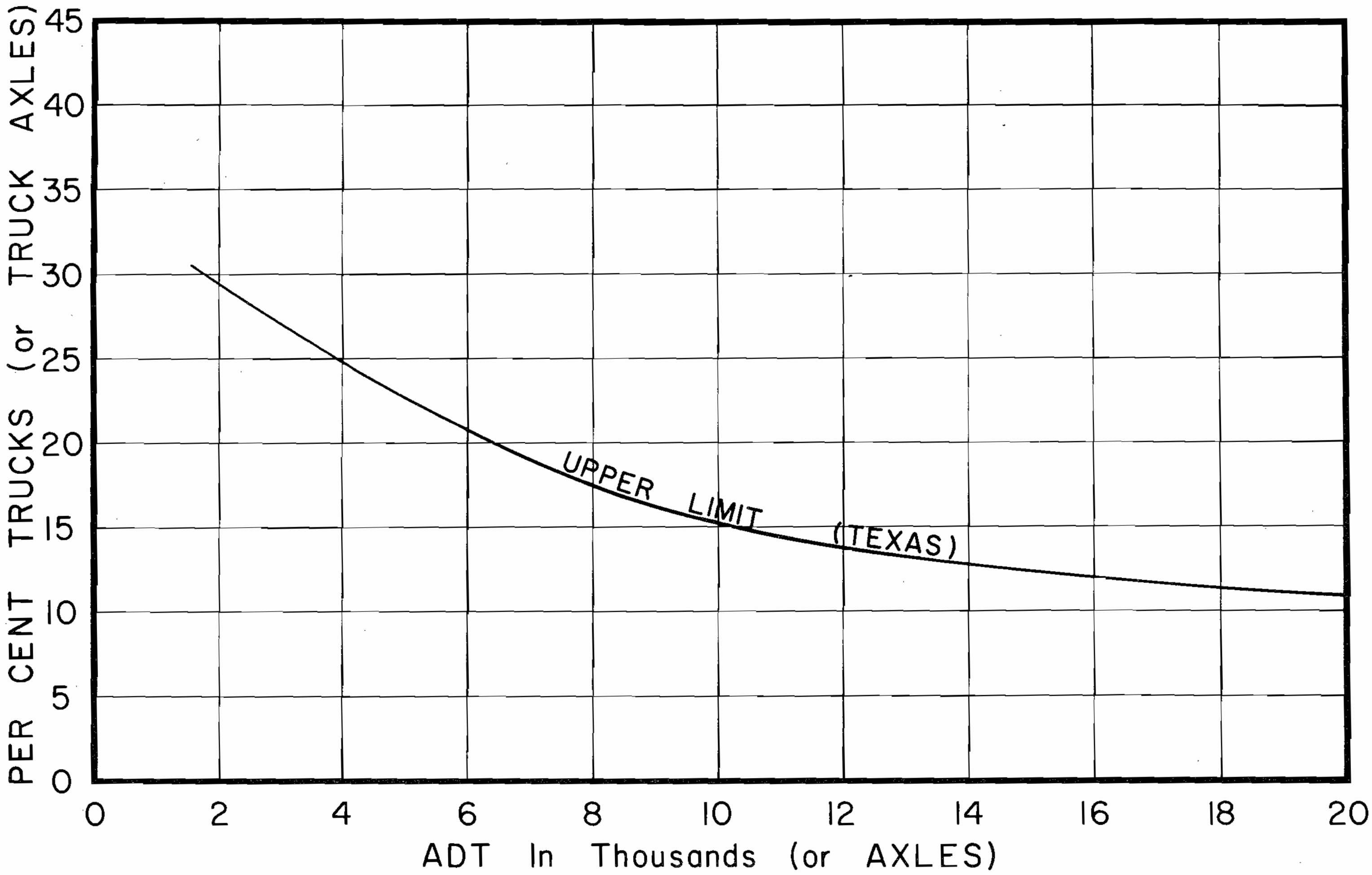

FIG. 2—RELATIONSHIP OF PER CENT TRUCKS TO ADT

terminology, ADT will be used.

Attention is called to the needed additional study of the reliability of traffic sampling and projections. Statistical analysis in the number and location of sampling stations and in the size and time of sample should be conducted on a continuing basis as should a comparison of earlier predictions with current traffic.

Relationship of Per Cent Trucks to ADT

The second step in the evaluation of traffic was to establish the characteristics of mixed traffic found on in-service roads in Texas and several states. A study of all the manual classifications and count stations in Texas for the period 1951 - 1961 was made and the per cent truck traffic was determined. Pickups and panel trucks which have relatively the same performance and weight characteristics as automobiles were not included as part of the truck traffic.

Figure 2 shows the result of this study. The "upper limit" line represents approximately the highest per cent of trucks that has been experienced for any given ADT on Texas highways during the 1959-61 period. Approximately ninety-six per cent of all the stations plotted were below

AVERAGE DAILY TRAFFIC	0-3999		4,000-7,999		8,000-11,999		12,000-15,999		16,000-19,999		20,000-24,999		25,000 & Over	
Vehicle Classification	Per Cent Trucks 20%		Per Cent Trucks 18%		Per Cent Trucks 14%		Per Cent Trucks 12%		Per Cent Trucks 10%		Per Cent Trucks 8%		Per Cent Trucks 6%	
	Single Axles	Tandem Axle Sets	Single Axles	Tandem Axle Sets	Single Axles	Tandem Axle Sets	Single Axles	Tandem Axle Sets	Single Axles	Tandem Axle Sets	Single Axles	Tandem Axle Sets	Single Axles	Tandem Axle Sets
Single Unit Vehicles:														
Passenger Cars	143.60	-	147.20	-	154.40	-	158.00	-	161.60	-	165.00	-	168.60	-
Panel & Pickup Trks.	16.40	-	16.80	-	17.60	-	18.00	-	18.40	-	19.00	-	19.40	-
Other 2-Axle Vehls.	11.60	-	10.40	-	8.20	-	7.00	-	5.80	-	4.60	-	3.60	-
3-Axle	0.40	0.40	0.40	0.40	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.10	0.10
Combinations:														
3-Axle	6.30	-	5.70	-	4.50	-	3.90	-	3.00	-	2.40	-	1.80	-
4-Axle	10.80	5.40	9.60	4.80	7.60	3.80	6.40	3.20	5.40	2.70	4.40	2.20	3.20	1.60
5-Axle	6.30	12.60	5.70	11.40	4.30	8.60	3.70	7.40	3.20	6.40	2.50	5.00	1.90	3.80

FIG. 3 - NUMBER OF SINGLE AXLES AND TANDEM AXLE SETS FOR EACH TYPE OF VEHICLE PER EACH 100 VEHICLES FOR THE PRIMARY HIGHWAY SYSTEM.

the line. The majority of the stations which were above the line had less than 4,000 ADT. Very few stations had less than four per cent truck traffic.

Whenever traffic analysis and projections are made, a curve depicting the change in per cent trucks to ADT should be established for the section of highway being considered. In Texas this curve would fall between a flat four per cent truck traffic line and the upper limit line and normally would have the characteristics of the upper limit line.

Figure 2 also uses the word "axles" synonymously with ADT. Again, the term "axles" could be used directly in lieu of the more familiar term of ADT and thereby simplify the overall mechanics of this program.

Attention is called to the need for additional study of the reliability of the data and for a sampling program to detect local trends.

Single Axles and Tandem Axle Sets Per Hundred Vehicles

The third step (Figure 3) shows the current conversion factors used on the primary highway system for changing ADT to axles. This sample tabulation has been developed from current traffic studies. It should be continually expanded and revised once this program development is completed. This step could be included later in the program if the term "axles" had been used in lieu of ADT in Figures 1 and 2. The third step would then be required to convert axles to the projected ADT and the projected per cent trucks necessary in geometric design considerations.

Distribution of Axle Loads

An investigation of the wheel load data from the twenty-one loadometer stations operated by the Planning Survey Division of the Texas Highway Department resulted in a family of curves which describes the characteristics and distribution of axle loads of mixed traffic found on in-service roads in Texas. Figures 4 and 5, Single Axle Distribution and Tandem Axle Distribution, respectively, were developed from the data of twenty-one loadometer stations operating across the state in 1960. It is necessary that both figures be used with each other in order to have a complete picture of the distribution. There are several points to be noted on these two figures.

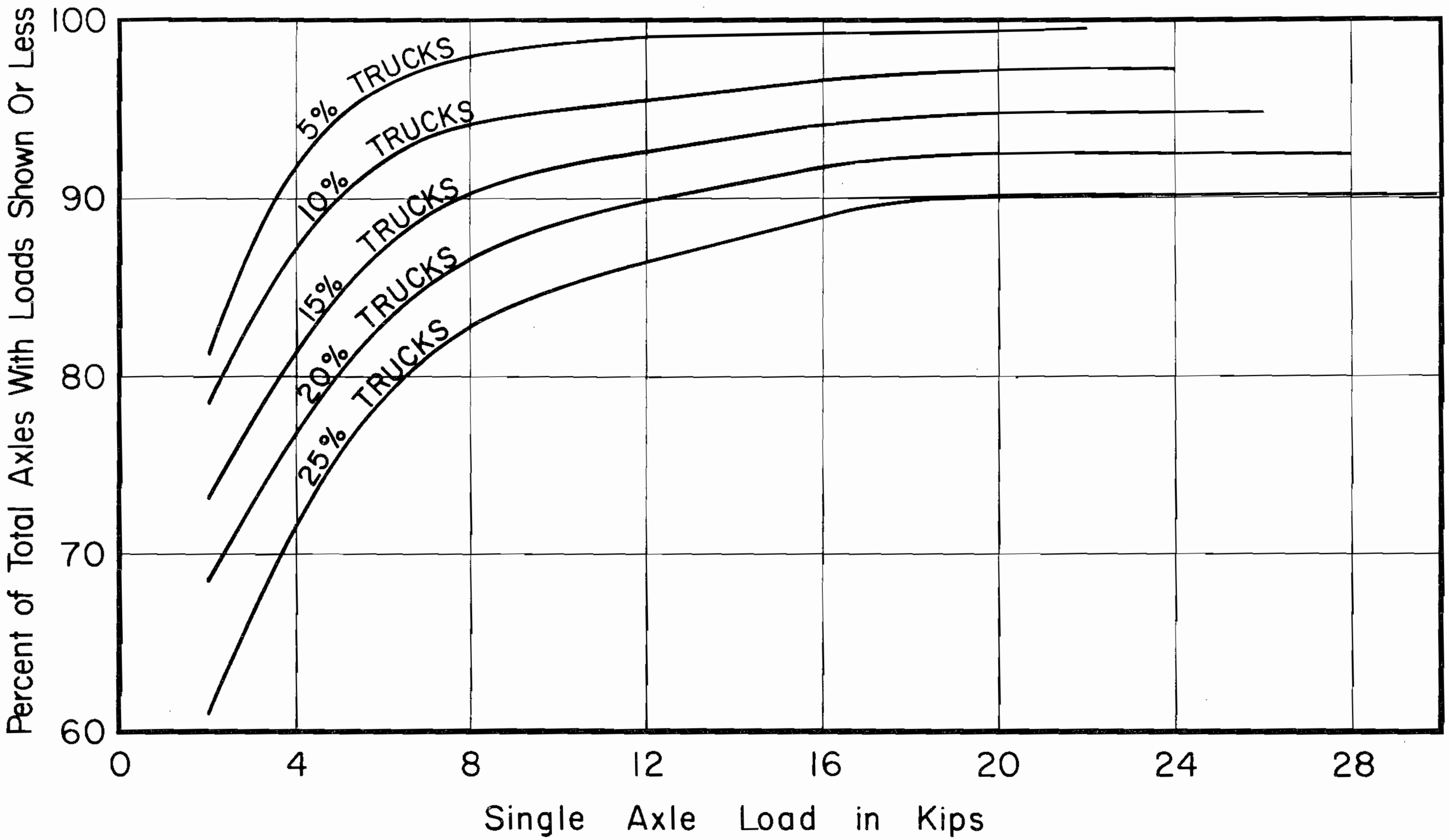

FIG. 4 – SINGLE AXLE DISTRIBUTION AT THE TWENTY-ONE LOADOMETER STATIONS IN 1960

Single Axle Distribution (Figure 4) - As would be expected a highway with a low per cent truck traffic normally has high traffic volumes. Over 80 per cent of all the axles on this road are single axles weighing less than 2 kips. Approximately 0.06 per cent of all the axles which are single axles exceed the 18 kips legal limit and these usually do not exceed 22 kips.

A highway with a high per cent of truck traffic normally has low traffic volumes. Less than 60 per cent of all the axles are single axles weighing less than 2 kips. There is a considerable increase in the number of single axles, approximately 0.15 per cent, that exceed the 18 kips legal limit with the maximum axle weight usually not exceeding 30 kips.

Tandem Axle Distribution (Figure 5) - A highway with low per cent truck traffic has a very low per cent, approximately 0.74 per cent of the total axles, of tandem axle sets. The tandem axle sets that are overweight, approximately 0.05 per cent, usually do not exceed 42 kips. Conversely, a highway with a high per cent truck traffic normally has low traffic volumes. Approximately 10.10 per

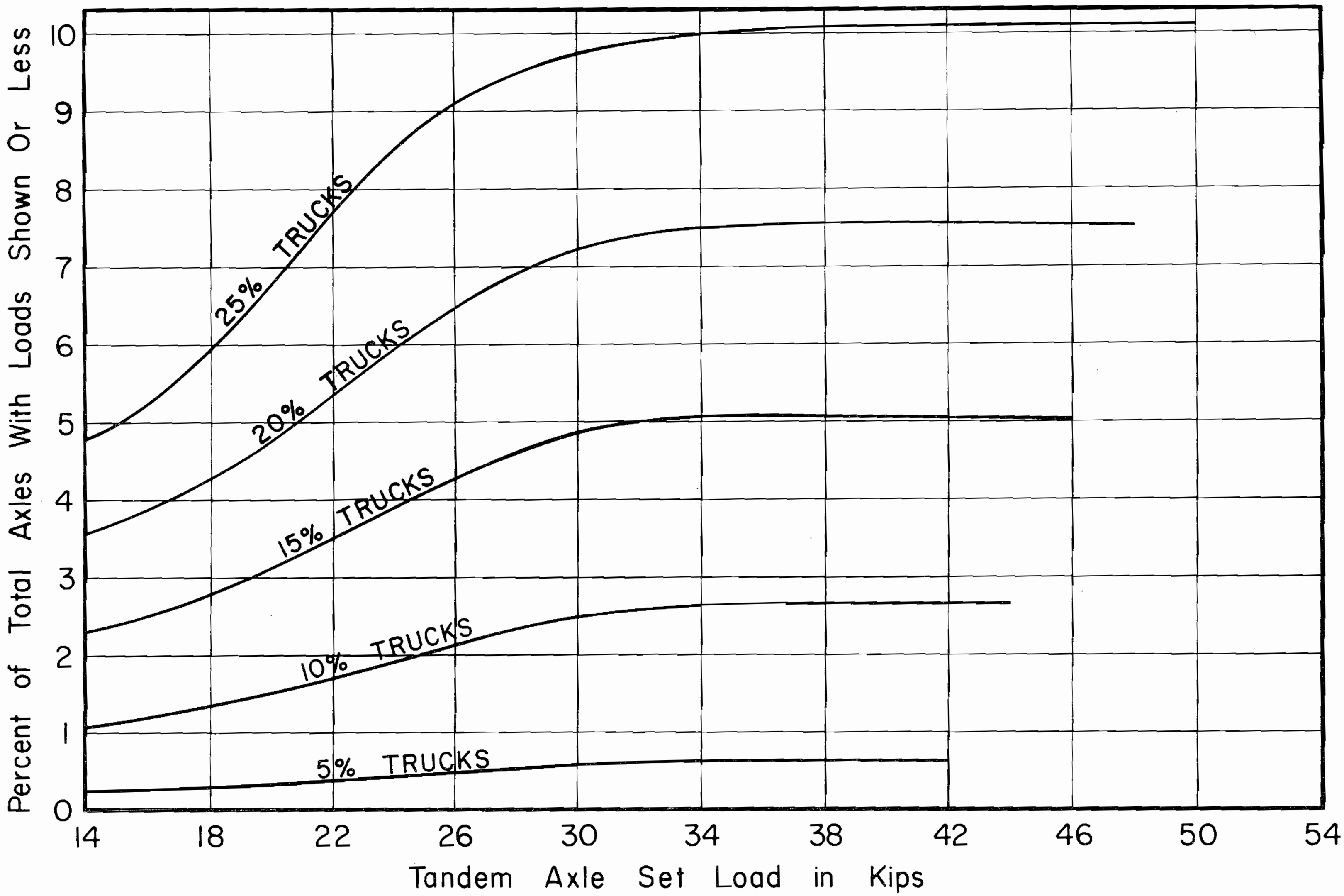

FIG. 5 — TANDEM AXLE SET DISTRIBUTION AT THE TWENTY-ONE LOADOMETER STATIONS IN 1960

cent of the total axles are tandem axle sets. Those that are overweight, approximately 0.16 per cent, usually do not exceed 50 kips.

Attention is called to the need for additional study on a recurring basis of: (1) the reliability of loadometer sampling, (2) the statistical analysis of the number and location of sampling stations, and (3) the size and time of sample.

In the past, high traffic volumes have generally been associated with heavy wheel loads. This relationship appears to be changing. Following the 1959 legislative raising of the maximum legal gross load limit to 72,000 pounds per truck, there has been an appreciable increase in the number of tandem axle sets and accordingly a decrease in single axles.

The addition of tandem axle sets was the only practical way in which the gross load could increase and still conform to the unchanged requirements of a maximum load of 18,000 pounds per single axle and 32,000 pounds per tandem axle set.

The relationships described above in axle load weight and the arrangement of axles, must be continually reviewed and revised for these curves to be representative and for changes in them to be recognized.

Program Block Diagram

A cursory review of the degree of accuracy with which the parameters involved in designing pavement structures are presently defined reveals that it is unnecessary, and impractical as well, to determine the effect of every specific axle load to which a road will be subjected during its design life. Likewise, to determine the exact number of axles of each magnitude and to multiply each specific axle by its respective equivalent factor would be un-necessary in view of the accuracy desired.

Pavement design will not require such a refinement in traffic evaluation without further improvement in other phases pertinent to highway construction. However, caution must be exercised to insure that designers do not continue to minimize traffic analysis now that the relative destructive effect of wheel loads can be evaluated.

The development of a computer program by which traffic may be analyzed and converted to an equivalent number of 18,000 pound single axle load applications by simple calculations is now in order,utilizing the previously dis-

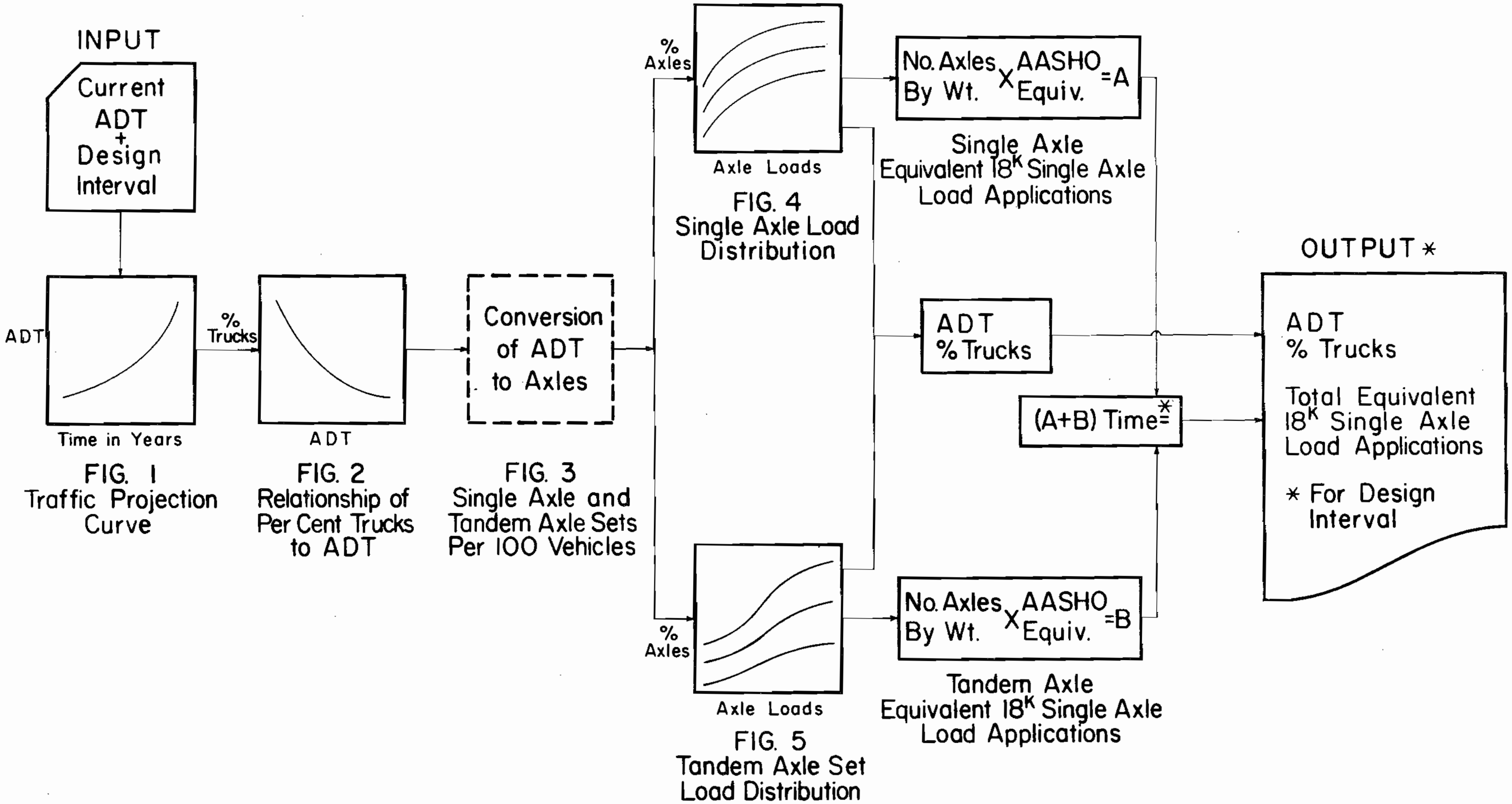

FIG. 6—PROGRAM BLOCK DIAGRAM

cussed relationships. Figure 6, Program Block Diagram, schematically ties these relationships together.

Input - Input will normally consist of the initial year's ADT and the design interval along with established boundary conditions for traffic projections (Figure 1) and per cent trucks (Figure 2). It should be pointed out that relationships established in these first two figures will have been based on the analysis of past experience and at this point it will be a matter of selecting the desired boundary.

Traffic Projection Curve (Figure 1) - ADT is projected by one or more selected curves for the selected design (time) interval.

Relationship of Per Cent Trucks to ADT (Figure 2) - The per cent trucks is projected by one or more selected curves not exceeding the "upper limit" line. Entering Figure 2 with the ADT projected from Figure 1, one can find the corresponding per cent trucks on the ordinate axis.

Single Axle and Tandem Axle Sets Per 100 Vehicles (Fig. 3) -

ADT is converted to axles based upon the following parameters; ADT volume group, per cent trucks, and highway classification.

Distribution of Axle Loads (Figures 4 and 5) - The total number of axles are distributed according to type and weight with single axles in 2 kip increments and tandem axle sets in 4 kip increments.

Equivalent 18 Kip Single Axle Load Application - The total number of single axles in each single axle weight group is multiplied by its respective AASHO Road Test equivalence factor. Similarly, the total number of tandem axle sets in each tandem axle set weight group is multiplied by its respective AASHO Road Test equivalence factor. All these equivalent 18 kip single axle load applications are added for the total design interval to provide the "total equivalent 18 kip single axle load applications" for which to design the pavement structure.

The ADT and per cent trucks necessary for geometric design considerations are also provided for the design interval selected.

The traffic analysis developed in this study provides a practical method of evaluating the effects of all wheel loads on roads subjected to mixed traffic. The analysis for mixed traffic developed herein can be adapted for use with any currently accepted design procedure.

III. DISCUSSION AND CONCLUSIONS

The primary purpose of this study was to develop a practical method of evaluating the effects of all wheel loads on roads which carry mixed traffic. Equivalence factors derived from experience at the AASHO Road Test were used to convert wheel loads of the type observed on Texas roads to an equivalent number of 18,000 pound single axle loads.

It may be pointed out that the analysis of traffic reported herein is based on data collected at twenty-one loadometer stations in Texas during 1958 and 1960. As more experience in analyzing mixed traffic is gained, modifications to the limits selected for axle weight groups and to the magnitude of the equivalence factors used might be required; however, the techniques employed in the traffic analysis as developed in this report can be used to make these modifications.

The wheel load analysis is suitable for evaluating all traffic on present inter-city highways in Texas. The method of analysis is adaptable to all types of roads, irrespective of volume or wheel load size. Traffic on urban expressways with large traffic volumes and relatively few heavily loaded trucks, primary highways with medium traffic volumes and heavy axle loads may be considered. The analysis could also be utilized for county roads with extremely low traffic volumes and an occasional heavy load, or a city street with high traffic volumes and almost no heavy loads.

The analysis provides a research tool by which old traffic records can be used to analyze past pavement performance. The backlog of experience and data from old roads should be used to further check and improve this analysis.

The new analysis of traffic when compared with current design procedures results in the following general trends:

(1) Design life will now be considered as that time period required for design traffic to develop. In designing the pavement structure, engineers can design for a selected number of repetitions of wheel loads rather than for a selected period of time.

(2) Stage construction can now be a programmed item. A structure may be designed to full standards; however, the

construction of part of the surface course may be delayed until traffic volumes merit additional surfacing.

(3) A realistic pavement rating system can perhaps now become a reality. A serviceability index defined at the AASHO Road Test and the AASHO Road Test equation which rated the performance (the trend of serviceability with load applications) of pavements on the Road Test may now be applied to satellite road tests and studies.

IV. RECOMMENDATIONS

In concluding this study the author recommends that the following studies should be conducted in order to refine the traffic analysis developed in this report.

(1) Loadometer sampling techniques should be re-evaluated in conjunction with this analysis since extensive coverage and statistically sound data will be necessary to adequately determine axle load distribution for use in the analysis.

(2) Future traffic studies should investigate the character of axle loads on the various lanes of multi-lane facilities in order to properly determine the total number of equivalent 18 kip single axle load applications for which each lane of the roadway should be designed. Although it is a relatively safe assumption that the heavier units travel over the slower lanes, current speed studies indicate heavy trucks are capable of maintaining average speeds on the order of fifty miles per hour. The normally faster, interior lanes are now experiencing heavier wheel loads.

(3) A computer program as recommended to analyze past and future traffic data should include the development of equations from which projects of ADT, per cent trucks and axle load distribution could be made.

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APPENDIX

GATHERING OF TRAFFIC DATA IN TEXAS

The Planning Survey Division, usually referred to as File D-10, collects all traffic data for the Texas Highway Department. The Division's data gathering operation can be divided into three sections.

(1) Twenty-one permanent loadometer (vehicle wheel weighing) stations located in the eastern two-thirds of the state. Although the station locations inadvertantly give the appearance of being geographic, the criteria for selecting station sites are based on inter-city traffic volumes. Each station is operated for one eight-hour period each month, four hours for incoming traffic and four hours for outgoing traffic. The sampling periods are scheduled from 6 AM to 2 PM, 2 PM to 10 PM, and 10 PM to 6 AM. Every three months a complete twenty-four hour cycle is completed. The stations are operated thirty-six hours in each direction for a total of seventy-two hours per year. During each four-hour session all trucks and approximately 10 per cent of all pickups are weighed. Cars are not weighed. The loadometer crew is composed of six men: a party chief supervises the operations; a flagman directs

traffic approaching the station; two men weigh the outside half of each axle with a portable pit scale, measure the height of the vehicle and interview the driver as to the commodity carried and the origin and destination of the trip; and one man makes a visual, two-directional traffic count and classifies the vehicles by type, number of axles and axle configuration.

(2) One hundred and forty automatic continuous count stations are located throughout the state. Recording counters are used at each station to count and record all axles, twenty-four hours a day all year long. The count is photographed every hour on film strips. These film strips are mailed to Austin every week.

(3) One hundred and sixty-eight permanent manual traffic count and classification stations are located throughout the state. A visual traffic count and vehicle classification by type, number of axles and axle configuration is made at each station. Forty-eight of these stations are operated six times a year for twenty-four hour periods. The permanent manual count and classification stations are often supplemented by periodic spot counts of all roads on the state system. Reports and projections based on these data are prepared by the Planning Survey Division for use by the Department.

ACKNOWLEDGMENTS

The research reported in this paper was conducted under the supervision of Mr. M. D. Shelby, Research Engineer, and the general supervision of Mr. T. S. Huff, Chief Engineer of Highway Design.

The author wishes to acknowledge with thanks the able assistance of Messrs. Frank McCullough and Kenneth Heathington of the Highway Design Division.

Also acknowledgment of the help of Mr. Charles Davis and other members of the Planning Survey Division under the supervision of Mr. George Carver.

Thanks is also given to Dr. Clyde E. Lee, Professor of Civil Engineering at the University of Texas who directed the author's graduate studies and Masters thesis on which this report is based.