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16. Abstract

An evaluation of the traffic load forecasting procedure used by the Transportation Planning Division (D-10) of the Texas State Department of Highways and Public Transportation (SDHPT) is presented in this report. Since any desired modifications to SDHPT's existing procedure are very dependent on the availability of vehicle classification and axle weight data, recommendations are made under two different scenarios: near-term (0-3 years) limitations, and long-term (3 years +) needs.

Following a general summary of the importance attached to traffic load data, the report includes an overview of the significant findings of other traffic load-related studies performed in Texas. A detailed review of the traffic load forecasting procedures used in other states is also provided. The evaluation of the Texas procedure consists of a sensitivity analysis of its input parameters and a summary of the weight data collected in Texas.

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TRAFFIC LOAD FORECASTING IN TEXAS

by

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and

C. Michael Walton

Research Report Number 352-1F

ESTIMATION OF TRUCK LOADINGS FOR HIGHWAY DESIGN AND/OR REHABILITATION

Research Project 3-8-83-352

conducted for

Texas State Department of Highways and Public Transportation

in cooperation with the

U.S. Department of Transportation
Federal Highway Administration

by the

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

November 1984

PREFACE

One important aspect of economical highway engineering is the accurate forecasting of the magnitude and frequency of axle weights expected to operate over a facility during a certain time period. Many studies have shown that a (if not the) principal cause of pavement deterioration is the amount of vehicle loadings experienced by a pavement.

For the design of new and rehabilitated pavements, the Texas State Department of Highways and Public Transportation (SDHPT) relies upon a traffic load forecasting procedure that is now over fifteen years old. This procedure is reviewed and evaluated in this report.

This is the first and final report for Project 3-8-83-352, "Estimation of Truck Loadings for Highway Design and/or Rehabilitation," a two-year study conducted at the Center for Transportation Research, The University of Texas at Austin, as part of the Cooperative Research Program with the State Department of Highways and Public Transportation and the Federal Highway Administration of the U.S. Department of Transportation. The study was supervised by Dr. C. Michael Walton.

Special recognition is extended to Messrs. Gerald Peck and Bob Mikulin of D-8 for their guidance and assistance during the project. Appreciation is also expressed to personnel in D-10 (especially Ben Barton and Bob Antilley) and D-19 (John Oliver) for their cooperation.

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November 1984

ABSTRACT

An evaluation of the traffic load forecasting procedure used by the Transportation Planning Division (D-10) of the Texas State Department of Highways and Public Transportation (SDHPT) is presented in this report. Since any desired modifications to SDHPT's existing procedure are very dependent on the availability of vehicle classification and axle weight data, recommendations are made under two different scenarios: near-term (0-3 years) limitations, and long-term (3 years +) needs.

Following a general summary of the importance attached to traffic load data, the report includes an overview of the significant findings of other traffic load-related studies performed in Texas. A detailed review of the traffic load forecasting procedures used in other states is also provided. The evaluation of the Texas procedure consists of a sensitivity analysis of its input parameters and a summary of the weight data collected in Texas.

SUMMARY

It was determined in this study that SDHPT's computer model for projecting total traffic loads (known as RDTEST68) is performing correctly. However, a sensitivity analysis showed that an improper specification of the model's user-input parameters (such as "percent trucks" and selection of a "representative" weigh-in-motion station) can have a drastic effect on the total projected traffic load over a 20-year design period.

A review of the traffic load forecasting procedures used in other states demonstrated that alternative procedures are available. Given the present quality of axle weight and vehicle classification data available in Texas, and the realization that SDHPT is committed to improving this quality over the next several years, the following near-term and long-term recommendations were developed from this two-year study:

<u>Near-Term (0-3 Years)</u>

1. SDHPT's existing forecasting procedure should continue to be used with only minor modifications (e.g., better use of lane-wise traffic load distributions).
2. It is appropriate for the forecasting model to be run by SDHPT's Transportation Planning Division (D-10) since it requires the accurate specification of traffic data (e.g., traffic volume, percent trucks, growth rate); however, district personnel should be given a greater opportunity to evaluate these input specifications.

3. One important aspect of the forecasting model is the impact of the axle weight distribution data; in order to increase the highway engineer's confidence with the regular use of the model, the computer output should include the average equivalency (18-KESAL) factor per truck for a specific highway segment (the significance of this is explained in Chapter 7).

4. Statistical summaries of the available weight data should be prepared each year in order to identify significant trends in traffic loadings.

Long-Term (3 Years +)

1. As the quality of axle weight and vehicle classification data improves over the next few years, D-10 should consider switching to a traffic load forecasting procedure that uses axle weight data by truck type rather than simply by station.

2. SDHPT's current efforts to improve and expand the Truck Weight Survey program should be continued.

A more effective weighing program would serve objectives in addition to the design of individual pavements. For example, the cost of long-term statewide rehabilitation needs in Texas cannot be accurately estimated unless traffic load and vehicle classification data representative of the entire state highway system are available.

IMPLEMENTATION STATEMENT

Economical highway engineering is dependent not only upon the availability of adequate traffic data but on the proper application of the data. This report contains specific recommendations for near-term and long-term modifications that should be made to SDHPT's existing traffic load forecasting procedure. The near-term recommendations are intended to improve user confidence with the existing procedure, whereas adoption of the long-term recommendation should result in more economical highway design.

GLOSSARY OF TERMS

AASHO Road Test: A study conducted from 1958 to 1961 to study the performance of various pavement designs subjected to loads of known magnitude and frequency.

AASHTO: American Association of State Highway and Transportation Officials, previously known as AASHO, a non-profit organization devoted to the improvement of highway standards and practices.

ADT: Average Daily Traffic, sometimes called Average Annual Daily Traffic (AADT).

ATHWLD: Average of the Ten Heaviest Wheel Loads Daily, a calculation that was used in SDHPT's pavement design procedures prior to the development of the AASHTO equivalency equations.

Axle Factor: The average number of axles per vehicle for a specified group of vehicles. A tandem axle set is treated as one axle.

Axle Weight: The weight transmitted to the pavement surface by a single axle or a tandem axle.

Combination: A truck-tractor coupled to a semitrailer; also known as a multiple unit truck.

CTR: Center for Transportation Research, The University of Texas at Austin.

D-10: Transportation Planning Division, Texas State Department of Highways and Public Transportation.

Design Period: The period of time over which a highway section is desired to perform satisfactorily before substantial rehabilitation is required.

DPS: Department of Public Safety, State of Texas.

ESAL: Equivalent Single Axle Load, usually expressed in terms of an 18,000 pound (18-Kip) standard: 18-KESAL. ESAL factors, as developed from the AASHO Road Test, are used to compare the relative wear caused by vehicles of different single and tandem axle weights.

Fatigue: Deterioration of a pavement structure resulting from repeated load applications that cause stresses and strains to develop in the structure.

FHWA: Federal Highway Administration, a division of the U.S. Department of Transportation; responsible for policy formulation and general direction of public roads operations in engineering, finance, management, and legal fields.

Flexible Pavement: A pavement structure (such as asphalt) which maintains intimate contact with and distributes loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability.

GVW: Gross Vehicle Weight. The total weight of a vehicle, including the weight of the vehicle and its load.

KESAL: Kips-Equivalent Single Axle Load, usually expressed as 18-KESAL.

KIP: One thousand pounds.

Overload: Any vehicle which is operated in excess of the legal weight limits of a 20,000-pound single axle, a 34,000-pound tandem axle, or an 80,000-pound gross vehicle weight.

Pavement Wear: Pavement damage (or deterioration) resulting from structural fatigue due to repeated applications of various single and tandem axle weights.

Percent Trucks: The percentage of the average daily traffic that is composed of heavy trucks (2-axle, 6-tired, or greater).

RDTEST68: Road Test 68, a computer program used by SDHPT to forecast traffic loads (i.e., total 18-KESALs expected over the design period).

Rigid Pavement: A pavement structure which distributes loads to the subgrade, having as one course a portland cement concrete slab of relatively high bending resistance.

SDHPT: Texas State Department of Highways and Public Transportation.

Serviceability: The ability of a pavement to serve high-speed, high-volume automobile and truck traffic.

Single Unit Truck: A truck with the body and engine mounted on the same chassis.

Static Weighing: A method of weighing in which a vehicle must first come to a stop.

Tandem Axle: Two consecutive axles less than eight feet apart.

TTI: Texas Transportation Institute, Texas A&M University.

Vehicle Class: A subdivision of the total vehicle fleet, consisting of a group of vehicles defined by similar characteristics (e.g., weight, vehicle type) for purposes of allocating costs and setting user charges.

WIM: Weigh-In-Motion, a method of weighing a vehicle that does not require the vehicle to be stopped.

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CHAPTER 1. INTRODUCTION

The Texas highway system is an essential element in the economic and social vitality of the state. The cumulative investment of the state's resources and the sustained resources required to perpetuate its investment requires prudent engineering judgment.

This report is the product of a two-year study that examined one crucial aspect of highway pavement design and rehabilitation: the characterization of the motor vehicle traffic expected to use a particular facility over a period of time. It has been widely recognized for over fifty years that the structural integrity of a highway pavement is related to the type, number, and weight of vehicles that operate over it. In addition, highway bridge structures must be designed to safely support the vehicle types and maximum gross weights expected.

Objectives

In order to design or rehabilitate a roadway expected to last for a specified number of years, it is necessary to make a reasonable forecast of anticipated traffic loadings. Concerns have been raised as to whether SDHPT's existing computerized forecasting procedure, initiated in 1968, remains adequate for this task in today's environment. With the expansion of economic activities in Texas, truck traffic is expected to continue to increase substantially. Underestimating the load experience for a highway could result in an underdesigned facility having a shorter physical and economic life than desired, leading to the need for major unanticipated repairs. An overestimate, however, could result in the construction of an overdesigned facility that ties up monies badly needed for other projects.

The overall objective of this study is to evaluate the adequacy of currently available procedures for the estimation of highway load experiences. More specifically, the purpose of this study is to explore the existing SDHPT procedures for forecasting of traffic loads and suggest improvements if needed. In order to provide the traffic information needed for optimum design and/or rehabilitation of highways, new methodologies and techniques may be warranted.

Scope and Limitations

The project was organized around five major tasks:

1. review of current traffic load forecasting procedures,
2. identification of needs for weight-related information,
3. assessment of procedures and needs,
4. matching of data products with the data requirements needed to drive the estimation needed to drive the estimation/forecasting procedures, and
5. final preparation and documentation of the estimation procedure.

It should be pointed out that this study was not an evaluation of the truck weighing program in Texas (this is the primary objective of Research Study 2-10-84-424, a two-year project initiated by the Texas Transportation Institute on February 1, 1984). However, it was necessary to examine the weight data collected in Texas since 1965 in order to assess the effectiveness of the existing traffic load forecasting procedure and alternative procedures.

Although concerns about the use of the AASHTO equivalency factors are noted, the study was not designed to address their adequacy.

The information provided in Chapter 2 serves as a historical background of the importance attached to an accurate determination of the number and magnitude of axle weights expected to operate over a highway facility during a specified time period. Chapter 3 contains a review of previous studies conducted in Texas. A detailed description of the existing traffic load forecasting procedure in Texas is provided in Chapter 4. Based largely on the responses to a questionnaire mailed to all states in November of 1983, a summary of the forecasting procedures used in other states is presented in Chapter 5. Chapter 6 focuses on an evaluation of the Texas load forecasting procedure and alternative procedures. The final chapter includes a review of the pertinent issues raised in this study and recommendations for improvements to SDHPT's existing traffic load forecasting procedure. Supplemental materials --including the documentation of an alternative forecasting procedure -- are provided in the Appendices.

CHAPTER 2. BACKGROUND

Essential data required to foster economical highway design and performance are measures which characterize vehicular traffic. This chapter provides a general background of the importance attached to accurate traffic load data. These data are included in the design of pavements and bridges, allocation of highway costs, development of appropriate transportation policies, and research.

General Design Principles

Highways are not built to last forever. Through complex interactions involving environmental (i.e., climatic) factors, vehicle loading, and the quality of materials, pavements -- no matter how well designed and constructed -- deteriorate over time. Maintenance and rehabilitation activities are necessary to extend the pavement's "life." A book on pavement management summarizes standard practice:

> Historical studies by many agencies show the concept of a 20-year new pavement design is generally fictitious. Most such pavements provide adequate service for up to 10 or 12 years, and sometimes less, without major maintenance or rehabilitation. At that time, however, they are often overlayed, sometimes more than once, to provide a total of 20 or 25 years performance or total service life (Ref 5, p. 9).

Nevertheless, highway engineers commonly work with the concept of a 20-year design period. A roadway surface built to last for a much longer (or much shorter) time is usually considered to be an inefficient use of highway funds. The design of a "20-year" pavement involves a conscious trade-off decision between increased initial costs and increased maintenance (and inconvenience) costs. For example, while rigid (concrete) pavements have the advantage of requiring less maintenance relative to flexible (asphalt) pavements, they normally require higher initial construction costs. Within each of these major pavement categories, decisions must be made as to initial surface thickness and preparation of the base and subbase.

The surface condition of a pavement can be referred to as its "serviceability," which is a measure of a pavement's ability to serve high-speed (and high-volume) automobile and truck traffic. Pavement "failure" implies that serviceability has dropped to the point where the road no longer carries out its intended function satisfactorily. Failure may be the result of a variety of distresses (Ref 5, p. 228):

1. Load-associated cracking
2. Load-associated permanent deformation (i.e., rutting)
3. Low-temperature shrinkage crackage
4. Non-load-associated distortion and cracking (freeze/thaw cycles, foundation movements)
5. Disintegration (spalling, ravelling, stripping, pot holes, etc.)
6. Interaction of the foregoing.

Although climatic factors can lead to pavement breakup, major contributors to pavement deterioration are the magnitudes and numbers of vehicle (i.e., traffic) loadings. Pavement wear resulting from flexure under repeated wheel loadings is known as fatigue. Although the mathematical application of the fatigue concept of stresses and strains to a pavement structure is not always readily understood, the importance of fatigue can be recognized by comparing a pavement that has been subjected frequently to heavy trucks to a pavement of identical design that is known to have carried fewer heavy trucks.

The AASHO Road Test

The AASHO Road Test of the late 1950's and early 1960's was conceived and sponsored by the American Association of State Highway Officials (now known as AASHTO: American Association of State Highway and Transportation Officials). It represents the most significant effort to date to determine the relative effects of different types and weights of trucks on pavements. Equations were developed to provide guidance as to "how much" reduction in performance is associated with any specific increase in axle load, and for a given load, how many loads can be applied before the serviceability of a pavement is reduced to an unsatisfactory level" (Ref 7, p. 3).

Special test loops were constructed in Ottawa, Illinois of various thicknesses of rigid and flexible pavements. From November 1958 to November 1960, each loop was driven over by one of ten vehicle types so that pavement and bridge performance could be associated with specific axle loads (one loop was kept free of traffic in order to test environmental effects). The ten vehicle types are described in Table 1. Front steering axle loads ranged from 2,000 - 12,000 pounds, single-axle loads from 2,000 - 30,000 pounds, and tandem-axle loads from 24,000 - 48,000 pounds. Except for the 4,000-pound pickup, the front steering axle was not considered as a separate axle load causing pavement damage. In other words, the damage effect of a steering axle was incorporated into the two single axles of the 2-S1 truck configuration and the two tandem axle sets of the 3-S2 truck configuration.

The vehicles were driven more than 17 million miles, resulting in the application of over one million axle loads to the pavements and bridges. Through the use of statistical procedures, 18-kip equivalent single axle load

(KESAL) equations and factors were developed for single and tandem axles. The general effect of an axle load (as shown in Figure 1) is that the amount of pavement life consumed by the passage of an axle load increases exponentially as the axle weight increases. An 18-KESAL factor of 1.00 means that the axle load in question has a "damage effect" equal to one pass of an 18,000-pound single axle load. For a single axle load of 21,000 pounds, the 18-KESAL factor doubles.

The first AASHO Interim Guide, published in 1962, covered two important areas:

1. 18-KESAL factors per axle, which varied by pavement type (rigid or flexible), terminal serviceability index, pavement strength (structural number or slab thickness), axle type (single or tandem), and axle weight
2. Nomographs for use in the design, rehabilitation, and evaluation of flexible and rigid pavements, with cumulative 18-KESALs incorporated as an input parameter

Although several Interim Guides have been prepared since 1962, the 18-KESAL factors have remained unchanged. Examples of AASHO equivalency calculations are shown in Appendix A, along with a comparison of total 18-KESALs for typical truck types. The 18-KESAL comparisons demonstrate the importance of examining axle weights rather than only gross vehicle weights.

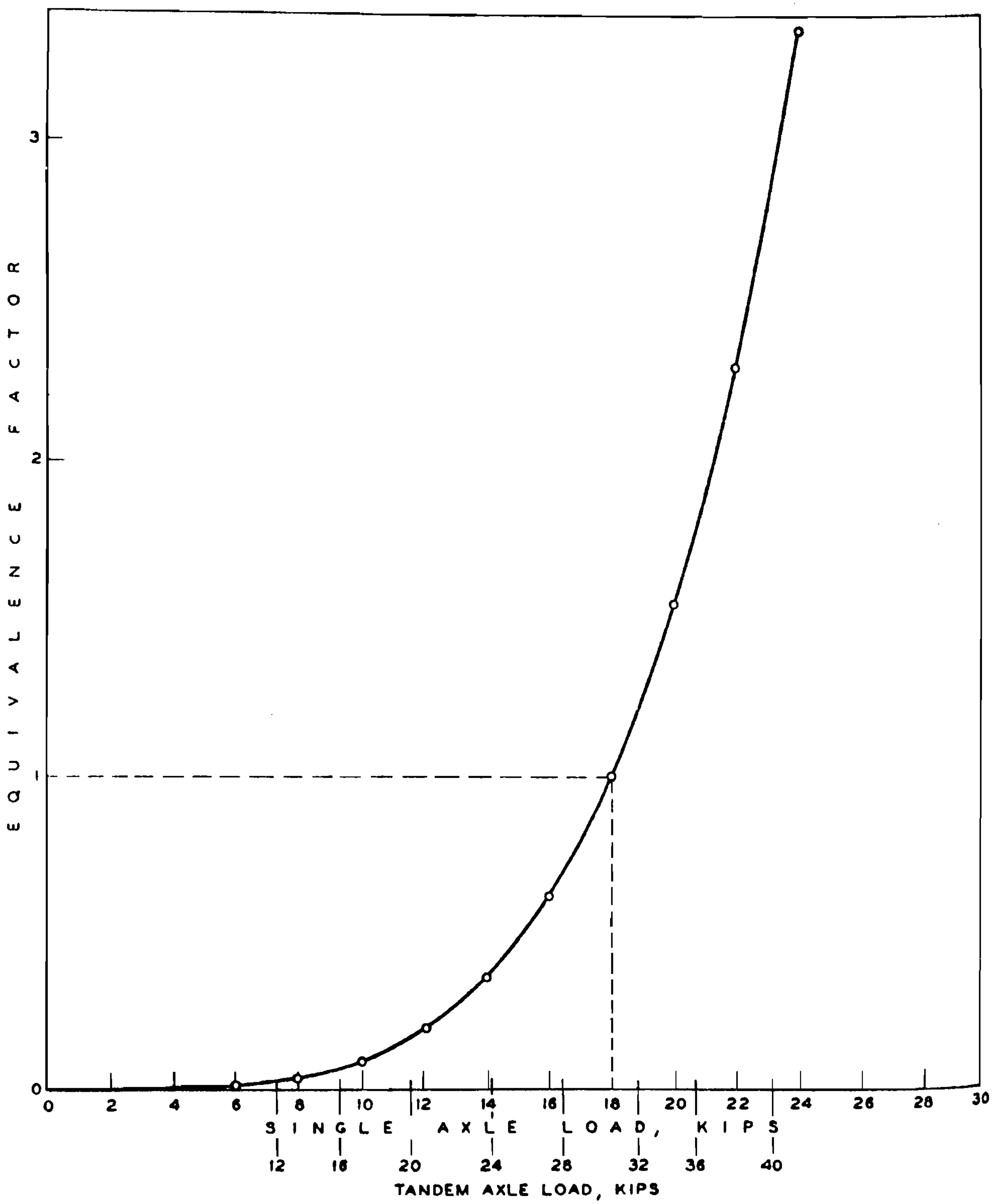
There have been many criticisms of the AASHO Road Test, mainly because of technical limitations of the $30 million study:

1. The findings relate only to the soils and materials actually used and the environmental conditions actually in effect in Ottawa, Illinois from November 1958 to November 1960.

TABLE 1. TEST VEHICLES USED IN THE AASHO ROAD TEST

WEIGHT, IN POUNDS

TRUCK TYPE	STEERING AXLE	SINGLE AXLE #1	SINGLE AXLE #2	TANDEM AXLE #1	TANDEM AXLE #2	ALL AXLES
2D	2,000	2,000				4,000
	2,000	6,000				8,000
2-S1	4,000	12,000	12,000			
	6,000	18,000	18,000			
	6,000	22,500	22,500			
	9,000	30,000	30,000			
3-S2	6,000			24,000	24,000	54,000
	9,000			32,000	32,000	73,000
	9,000			40,000	40,000	89,000
	12,000			48,000	48,000	108,000



Source: AASHO ROADTEST PROCEEDINGS (Ref 8)

Fig 1. Relation Between Axle Loads and Equivalence Factors

2. In order to examine a wide range of serviceability levels, many of the test pavements were designed to "fail" during the two-year study.
3. Long-term effects of weathering were not accounted for.
4. The effects of steering axles, axle spacing, spacing between vehicles, vehicle speed, tire pressures, and lateral placement of a vehicle within a lane were not evaluated.
5. The statistical significance of the axle load effects could not be determined since the test was only done once.

In order to account for climatic variations, the AASHTO design nomographs provide for adjustments by means of Regional Factors. However, it should be noted that the 18-KESAL factors used to determine "relative damage" caused by different axle loads are not altered by environmental conditions.

The Truck Weighing Program in Texas

The importance of accurate traffic load forecasts has been recognized in Texas for over fifty years. A systematic basis for weighing the wheel loads of trucks came in 1936, when 21 manual (i.e., static weighing) loadometer stations were designated (Figure 2). Nineteen of these stations were in rural areas and two were in urban areas. The locations of these stations have remained virtually unchanged over the years. In 1971, the total number of operating stations was reduced to ten. A further reduction came in 1976, when only five weigh-in-motion (WIM) stations were used. By 1982, six regular WIM stations were in operation.

The actual numbers of trucks weighed annually from 1960 to 1983 are shown in Figure 3. Before 1975, trucks had to be diverted from the main highway and manually weighed on static scales. In addition to the recording

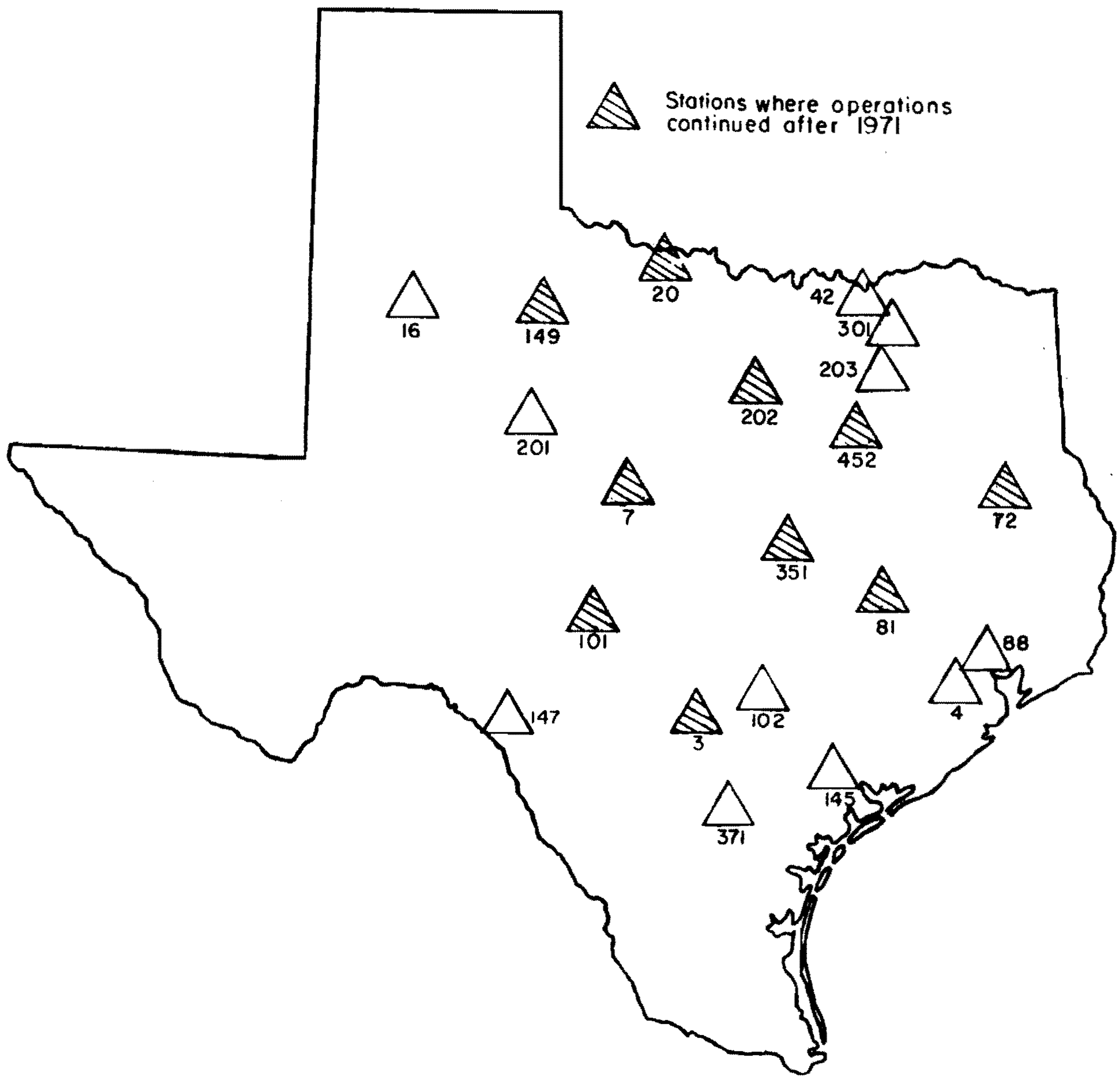


Fig 2. Location of the 21 Loadometer Stations

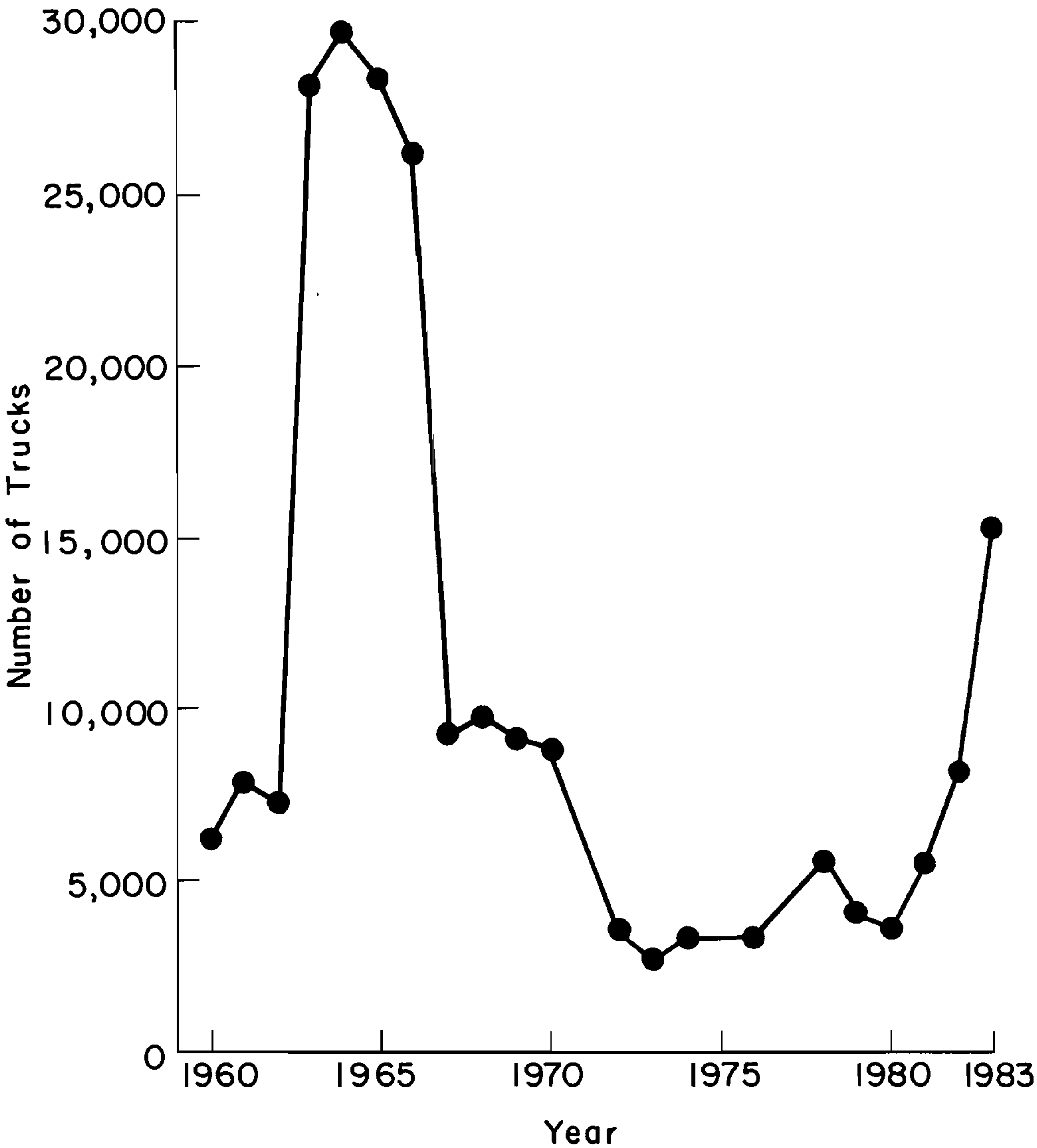


Fig 3. Numbers of Trucks Weighed Annually, 1960-1983

of the wheel weights of each stopped truck, the work crews usually obtained the following information:

1. The direction of travel (inbound or outbound),
2. the origin, destination, and length of the truck trip,
3. classification of the trip as inter- or intra-state,
4. the type of license of the truck,
5. the manufacturer's rated capacity,
6. the name and address of the truck owner,
7. the commodities carried,
8. the type of body,
9. the vehicle's classification as to type,
10. the type of fuel used,
11. the height, width, wheelbase, and axle spacing of the truck, and
12. whether the truck is loaded or empty.

The WIM system, established in 1975, significantly reduced the effort required to weigh a truck but also reduced the amount of supplemental information collected. The WIM system's major advantage is that a vehicle's operation is not interrupted. A typical operation collects the following for each truck:

1. vehicle classification,
2. axle weights and spacings,
3. gross vehicle weight and vehicle length,
4. speed,
5. lane location, and
6. time of day.

The Texas truck weight survey program follows the general format established by the Federal Highway Administration (FHWA) in its "Guide for

Truck Weight Study Manual" (Ref 4). Each year, SDHPT sends it survey data (on digital magnetic tapes) to FHWA for summary and analysis. FHWA takes the data and prepares a series of W-tables, as described in Figure 4.

<u>W1</u>. Contains a description of the location and time of operation of each weigh station and a summary of the data gathered concerning the number of vehicles weighed, the average daily traffic, and the average daily load.

<u>W2</u>. Provides a summary of the vehicles counted at each weigh station.

<u>W3</u>. Provides a summary of average gross vehicle weights by vehicle type and station.

<u>W4</u>. Provides a breakdown of single axles and tandem axles (by vehicle type) into specific weight groups, followed by 18-kip equivalencies for both rigid and flexible pavements.

<u>W5</u>. Gives the distribution of gross vehicle weight for each vehicle type and by station.

<u>W6</u>. Provides the axle weight, axle spacing, and gross vehicle weight of trucks in violation of legal weight limits.

<u>W7</u>. Provides the number and accumulative percentage of vehicles not in excess and in excess by specified percentages of legal weight limits.

Fig 4. FHWA'S W-Tables

CHAPTER 3. PREVIOUS STUDIES IN TEXAS

Over the last twenty years, a number of studies relating to traffic load forecasting have been conducted in Texas. The significant findings of these studies are examined in this chapter. Details concerning SDHPT's current traffic load forecasting procedure are presented in Chapter 4.

Distribution of Axle Weights

In 1966, a graduate engineering thesis entitled "Estimating the Distribution of Axle Weights for Selected Parameters" (Ref 6) was published, which provided the basis for SDHPT's development of the traffic load forecasting model called RDTEST68. The thesis describes a study conducted by the Planning Survey Division (now known as the Transportation Planning Division, D-10) of the Texas Highway Department (now known as SDHPT). Based on truck weight data collected at 21 permanent loadometer stations from 1960 through 1963 and at over 100 temporary stations operated in the months of June, July, and August of 1963, three methods of grouping axle weight data were analyzed:

1. by the percentage of trucks in the traffic stream,
2. by facility type (interstate, undivided primary highway, and other highway), and
3. by statewide average.

The three methods were used to develop average equivalency factors per truck axle.

To convert the number of trucks projected over a design period into the number of axle loads, an axle factor was used, in which a tandem axle set was treated as one axle load. A review of the 1960-1963 weight data indicated an average axle factor of 2.75, with only a one percent variation by facility type.

In order to evaluate the three methods of grouping axle weight data, three loadometer stations (one representing each facility type) were selected. Total 18-KESALs calculated by each of the three methods were compared with the total 18-KESALs calculated from the actual weight distribution for each station. The significance of these variations were then evaluated in terms of the resulting variations in the design thickness of a flexible pavement. The findings are summarized in Table 2. The table indicates that variation in design thickness, regardless of the aggregation method chosen, is less than one inch.

Since only three stations were selected for evaluation of the three methods of grouping axle weight data, the results of this study are inconclusive. However, the following general guideline was recommended:

> In estimating the axle weight distribution for a given location, good engineering judgment should be used. If the location under consideration for pavement design purposes is located in the vicinity of a regular loadometer station and the truck traffic characteristics are very similar to those of the regular loadometer station, then the axle weight distribution of the regular loadometer station should be used to calculate the number of equivalent 18-kip single axle load applications. If the location under consideration is not in the vicinity of a regular loadometer station or the truck traffic characteristics are different, then the Type A facility axle weight distribution should be used if the location is on a Type A facility. If the location is on any other type of facility, then the state-wide area axle weight distribution should be used to calculate the number of equivalent 18-kip single axle load applications (Ref 6, p. 91).

TABLE 2. COMPARISON OF METHODS FOR GROUPING AXLE WEIGHT DATA

Station	Actual Data	State-Wide Area Method	Percent Difference	Type Facility Method	Percent Difference	Percent Truck Method	Percent Difference
			Number of Equivalent 18-Kip Single Axle Load Applications				
L-35-1	7,402,760	10,209,820	37.9	8,783,847	18.7	11,141,503	50.5
L-30-1	8,251,685	11,220,708	36.0	11,134,830	34.9	12,089,317	46.5
3-UP	5,050,296	6,686,146	32.4	7,349,439	45.5	4,683,927	-7.3
			Total Depth of Cover Required in Inches*				
L-35-1	12.3	13.2	7.3	12.7	3.3	13.4	8.9
L-30-1	12.6	13.5	7.1	13.4	6.3	13.8	9.5
3-UP	11.2	12.0	7.1	12.2	8.9	11.0	-1.8

Source: (Ref 6)

Total Load Experience

A report entitled "Procedures for Estimating the Total Load Experience of a Highway as Contributed by Cargo vehicles" (Ref 3), published by the Texas Transportation Institute (TTI) in 1970, describes the development and testing of two kinds of procedures for making 18-KESAL estimates:

1. the use of various axle weight groupings, and
2. the use of multiple regression models.

The objective was to develop procedures with less than a ten percent margin of error in forecasting. The analysis was based on weight data collected at 21 permanent loadometer stations from 1964 to 1968. While statistical evaluations were made of station-to-station variations in axle weight distributions, the study was not designed to determine the statewide "representativeness" of the available data.

A number of axle weight distribution sets were evaluated. Stations grouped according to highway system or geographical area failed to produce homogeneous distributions. The "best" axle weight frequency distribution set was generated from multi-year data by classifying the 21 stations according to highway system and vehicle type. However, it was noted that the axle weight distributions (and average 18-KESALs) by vehicle type varied significantly among the stations within each highway system.

The second estimation procedure consisted of the use of multiple regression models, with variables such as vehicle type, body type, fuel type, time of weighing (night, day of week, season, year), and load status. The procedure appears to have achieved little success.

It was suggested that the statistical reliability of the 18-KESAL calculations could be increased if multi-year weight data was used. A concern was raised, however, about the small amount of data collected on urban systems. The importance of collecting data seven days a week was also emphasized from the fact that differences were noted in weekday and weekend data for individual vehicle types. The report concluded that unless a greater amount of data was collected in the future, SDHPT "should combine data collections from all 21 of the conventional loadometer stations to obtain representative input data for load experience estimates" (Ref 3, p. 6).

In-Motion Weighing

A report entitled "Truck Weight Surveys by In-Motion Weighing" (Ref 12) was published by The Center for Transportation Research (CTR) in 1975. The report recommended that SDHPT adopt a weigh-in-motion (WIM) system in order to reduce personnel expenses, eliminate highway user costs, and reduce the traffic hazards associated with a manual weighing operation.

An evaluation of the number of WIM stations needed in Texas was based on the axle weight data collected at 21 loadometer stations in 1968, 1969, and 1970. CTR used a statistical approach similar to the one used by SDHPT in 1971 (SDHPT reduced the number of loadometer stations from 21 to 10). The SDHPT study, based on 1968-1970 data, was designed to improve the efficiency of the weighing program by eliminating loadometer stations which may have represented a duplication of effort:

1. For each station, calculate the average daily number of 18-KESALs (through the use of rigid pavement equivalency factors).
2. Calculate the percentage variation in total 18-KESALs between all possible station pairs.
3. Aggregate the 21 stations into 10 groups in such a way that the stations in each group are within a ten percent variation of each other.

4. Administratively select one station from each group.

The 1975 CTR study was based on the use of 18-KESALs on a "per axle" basis rather than on a daily basis:

1. For each station, calculate the average 18-KESAL factor per truck axle (through the use of flexible pavement equivalency factors).
2. Arrange the 18-KESAL factors/axle in descending order
3. Group the 21 stations into six groups in such a way that the 18-KESAL/axle variations within each group are small.
4. Administratively select one station from each group.

The results of the CTR approach are shown in Table 3. The particular station chosen from each group for operation as a WIM station was considered a logistical choice. It can be seen (from the table) that at least one of SDHPT's ten loadometer stations in use after 1971 was included in each of the six CTR groups. It can also be seen, however, that the six WIM stations actually selected by SDHPT came from only five of the six CTR groups (i.e., none from Group Six).

The results of the CTR procedure were summarized in the report:

> This study showed that the 21 existing stations could be grouped in such a way that there would be no statistically significant difference (at the 95 percent confidence level) between the mean number of equivalent 18-kip axles at any station in a designated group and at one of six representative stations. Thus, only six properly chosen stations are needed to obtain truck weight information that is as good as that which has, through the years, proved to be adequate for engineering practice. More stations may be necessary if weight predictive facility over the pre-1971 level is needed (Ref 12, p. VII).

It is emphasized that the study did not evaluate the statewide representativeness of the 21 loadometer stations.

The report included a schedule for operating the six WIM stations, along with this general recommendation:

TABLE 3. 18-KESAL FACTORS PER AXLE FOR THE 21 LOADOMETER STATIONS

STATION NUMBER	CONTINUED OPERATION AFTER 1971	18 KESAL/AXLE 1968-1970	CTR GROUP	WIM STATION, 1983
101	*	0.301	1	503
88		0.287	1	
452	*	0.200	2	
81	*	0.199	2	
202	*	0.190	2	
351	*	0.189	2	
201	1	0.186	2	504
203		0.186	2	
72	*	0.183	2	505
145		0.181	2	
301		0.178	2	
20	*	0.175	3	506
371		0.167	3	
42		0.162	4	
102		0.155	4	502
149	*	0.153	4	
16		0.133	5	501
7	*	0.127	5	
147		0.126	5	
3	*	0.100	6	
4		0.082	6	

> In view of the significant time-wise variations in vehicle weights detected among hours, days, and seasons, each of the six selected survey sites should initially be operated during all seasons on a 24-hour, seven-day basis. Surveys should include successive seven-day samples for each direction of traffic to detect any major differences in weight patterns that might exist (Ref 12, p. 79).

The study did not, however, provide recommendations as to how the weight data collected from the six WIM stations should be incorporated into SDHPT's forecasting procedures.

Traffic Data Acquisition

A report entitled "Texas Traffic Data Acquisition Program" (Ref 10), was published in 1980 by CTR and contains an analysis of D-10's traffic data acquisition and distribution processes and techniques. An assessment of data needs was developed through interviews with division and district personnel of SDHPT. The significance of this study is that it emphasizes the importance of vehicle classification and weight data, especially for purposes of economical (and safe) pavement design and management.

The district representatives interviewed (from Houston, Dallas-Fort Worth, San Antonio, Lubbock, Brownwood, and Lufkin) indicated a general satisfaction with the type and quality of weight information available. However, the district staff were not very familiar with the pavement design computations actually performed through departmental computer programs.

The report suggests that attention must be given to determining whether the current truck weight sampling program is adequate for characterization of truck weight patterns across the state. The magnitude of time-wise variations in traffic loading patterns must be evaluated before a sound statistical basis for a weighing program can be defined. It was recommended that seven-day samples four times a year be conducted at each existing WIM station and that additional WIM stations be constructed:

> In order to improve the adequacy of the truck weight survey program in giving quality coverage of all roads in the State, it is recommended that each year two sites which have not been previously occupied be selected, perhaps on the basis of manual vehicle classifications counts where unusual patterns of truck traffic exist, and occupied with the WIM system for one week each. These sites might be near or in metropolotan (sic) areas where it was impossible to weigh previously with static equipment. Over a period of time, important new weight survey sites can be identified and incorporated into the program (Ref 10, p. 91).

Based on the observations made by many of the district staff that the amount of cracking, spalling, punch-outs, and patching in concrete pavements appeared to differ by direction, it was recommended that trucks be weighed in both directions of a highway.

Truck Use of Highways

A major CTR research project begun in 1977 has resulted in the publication of a number of reports relating to the truck use of highways in Texas. One report entitled "Truck Weight Shifting Methodology for Predicting Highway Loads" (Ref 16) was published in 1983 and documents a procedure for prediction of future truck weight distribution factors as a result of changes in laws governing vehicle sizes and weights.

Another report published in 1983 was entitled "An Assessment of the Enforcement of Truck Size and Weight Limitations in Texas" (Ref 15). One of the tables produced in the report (Table 4) shows the trend of overweight truck movements on Texas highways from 1959 to 1980. The table, based on Texas truck weight survey data, suggests an upsurge in overweight trucks from 1974 to 1976. Although maximum legal weight limits were increased in 1975 (from 18,000 pounds single axle, 32,000 pounds tandem axle, and 72,000 pounds gross vehicle weight to 20,000 pounds single axle, 34,000 pounds tandem axle,

TABLE 4. OVERWEIGHT TRUCK MOVEMENTS IN TEXAS, 1959-1980

	Type of Highway System			
Year	Interstate Rural	Other Main Rural	Urban	All Systems
1980	22.98	32.01	NA	24.78
1979	24.57	27.88	NA	25.75
1978	20.01	22.73	NA	21.07
1976	24.50	29.41	NA	26.33
1974	5.08	8.60	4.46	7.75
1973	5.06	11.32	3.17	9.66
1972	5.82	6.86	3.20	6.36
1971	4.26	7.66	4.63	6.31
1970	2.42	6.06	3.07	4.69
1969	6.22	6.89	3.47	6.39
1968	6.22	6.00	2.52	5.62
1967	3.74	5.09	3.04	4.50
1966	4.73	4.53	3.82	4.56
1965	6.00	4.57	2.49	4.84
1964	5.11	3.79	2.88	3.98
1963	3.64	4.68	5.56	4.53
1962	4.17	6.13	5.31	5.67
1961	5.55	7.68	8.04	7.39
1960	6.06	6.25	10.93	6.60
1959	5.49	6.90	12.79	7.47

NA = not available

and 80,000 pounds gross vehicle weight), this should not have resulted in an increase in the number of overloaded trucks. Instead, the dramatic increase may be attributed to a number of events, such as the energy crisis (i.e., the subsequent recession and increased fuel costs), or the fact that the truck weighing system was changed from a static operation to an in-motion operation. It is possible that overloaded trucks have been consistently avoiding the static weighing stations due to the fear of getting an overweight fine. However, SDHPT's truck weight survey program is conducted for planning and design purposes only and is not connected with the overweight enforcement operations of the Department of Public Safety (DPS). Another possible explanation for the increased percentage of overweight vehicles is that truckers no longer see the threat of getting caught as a major economic disincentive.

Lateral Placement of Trucks

A report entitled "Lateral Placement of Trucks in Highway Lanes" (Ref 9) was published in 1984 by CTR. Two issues were addressed:

1. development of a practical technique for estimating the patterns of axle loads in each lane of multilane highways, and
2. definition of representative frequency distributions of truck wheel placement within a traffic lane.

The report also describes the value of an upgraded WIM system that has four-lane weighing and classifying capabilities.

The recommended traffic load forecasting procedure consists of the use of axle equivalency (i.e., 18-KESAL) factors for different vehicle types, with the traffic data separated by direction and by lane. For flexible pavements, special equivalency factors were recommended for steering axles and tridem axles (the AASHTO factors were still recommended for single axles and tandem axles).

The fact that failure is observed more frequently on pavement edges (especially on curves) indicates the importance of wheel load location. This suggests that distribution data on wheel load placements within a lane could be used to modify pavement design procedures.

Pavement Design

In the 1950's and early 1960's, highway pavements in Texas were designed with a widely known method referred to as the Texas Triaxial Design Method. The method makes use of the ATHWLD factor: the Average of the Ten Heaviest Wheel Loads Daily. Although it was not originally capable of considering load repetitions, the procedure could be modified to account for increases in total projected volume. Present SDHPT procedures for new and rehabilitated pavements are an extension of the design methods presented in the 1972 AASHTO Interim Guide (Ref 1) and make use of projected 18-KESAL calculations over the design period.

It should be noted, however, that SDHPT's computer program for continuously reinforced concrete pavements (CRCP-2) does not directly consider variation in fatigue effects resulting from the repetition of wheel loads (Ref 11, p. 20). Instead, the procedure makes use of a safety factor to account for greater traffic loadings.

SDHPT's Rigid Pavement Rehabilitation Design System (RPRDS-1), on the other hand, makes extensive use of traffic load data. A listing of the input traffic variables emphasizes the importance of accurate data:

1. ADT (the average number of vehicles per day presently carried by the facility,
2. ADT Growth Rate (annual rate of growth in ADT),

3. Initial Yearly 18-KESAL (both directions),
4. 18-KESAL Growth Rate (annual growth rate in 18-KESALs)
5. Design Lane Distribution Factor (percent of total 18-KESALs in one direction, carried by the design lane), and
6. Analysis Period (the number of years the facility is designed to last before extensive rehabilitation).

<u>The RENU Program</u>

The RENU computer program is an integration of the REHAB and NULOAD programs. The original Highway Rehabilitation Forecasting Model (REHAB) was jointly developed by SDHPT and McKinsey and Company in 1976 for estimation of future road rehabilitation requirements. REHAB was used in 1978 to respond to Senate Resolution 589, which called for a study of the relative costs and benefits surrounding the current and future truck use of Texas highways (Ref 2). The NULOAD program, developed under contract to the FHWA, can be used to investigate the effects of changes in configurations and weights of trucks.

The RENU program is SDHPT's current procedure for estimating total annual rehabilitation costs and makes use of Texas data-based performance and survivor curves. It was used in the 1982 Operational Planning Document Study (Ref 13) and the ongoing highway cost allocation study. One significant aspect of the RENU program is that it uses traffic load data in a format different from that used in SDHPT's traffic load forecasting procedure. For a particular highway system (Interstate, U.S., State, Farm-to-Market), pavement type (rigid, flexible), and location (urban, rural), RENU makes use of statewide axle weight data by vehicle class rather than by individual station.

CHAPTER 4. THE TEXAS FORECASTING PROCEDURE

ROAD TEST 68 (RDTEST68)

For many years pavement design in Texas employed the "design wheel load" concept, defined as the average of the ten heaviest wheel loads on an average or representative day (ATHWLD). For the last 20 years, SDHPT has used design procedures that make use of AASHTO's axle load equivalency factors. The traffic load forecasting procedure used in Texas to calculate 18-KESALs focuses on a computer program known as Road Test 68 (RDTEST68).

While the program is operated by the Transportation Planning Division (D-10) of SDHPT, the resulting 18-KESAL calculations are utilized by the Highway Design Division (D-8) and the district offices. An example of the actual output format is shown in Figure 5. A manual example of the RDTEST68 calculation procedure is detailed in Appendix B. The information contained in the rest of this chapter describes the input parameters for RDTEST68 and summarizes how they enter into the 18-KESAL calculations (an evaluation of these parameters is made in Chapter 6). A general flowchart of the forecasting process is shown in Figure 6.

Preparation of Weight Data

The Texas forecasting procedure uses the axle weight distribution data collected at six WIM stations in Texas:

1. #501, north of Lubbock on IH-27,
2. #502, west of Seguin on IH-10 (since 1981),
3. #503, east of Junction on IH-10,

CALCULATION OF EQUIVALENT 18-KIP SINGLE AXLE LOAD APPLICATIONS FOR FLEXIBLE PAVEMENT DESIGN

RDTEST68 DESIGN YEARS 84-04

BEGINNING AVERAGE DAILY TRAFFIC	10000.
ENDING AVERAGE DAILY TRAFFIC	20000.
INCREASE IN TRAFFIC PER YEAR	500.
PER CENT INCREASE IN TRAFFIC PER YEAR	5.00
PER CENT TRUCKS	10.00
DESIGN YEARS	20.00
TYPE OF FACILITY	A
USING AVERAGE DISTRIBUTIONS	NO
STRUCTURAL NUMBER	3.

EQUIVALENT 18-KIP SINGLE AXLE LOAD APPLICATIONS FOR FLEXIBLE PAVEMENT DESIGN

TWO DIRECTION	15071121.
ONE DIRECTION (TO NEAREST 1000)	7536000

AVERAGE OF TEN HEAVIEST WHEEL LOADS DAILY (POUNDS).	13700
PER CENT TANDEMS IN THE ATHWLD	50

Fig 5. Example of a Weight Distribution Table for RDTEST68

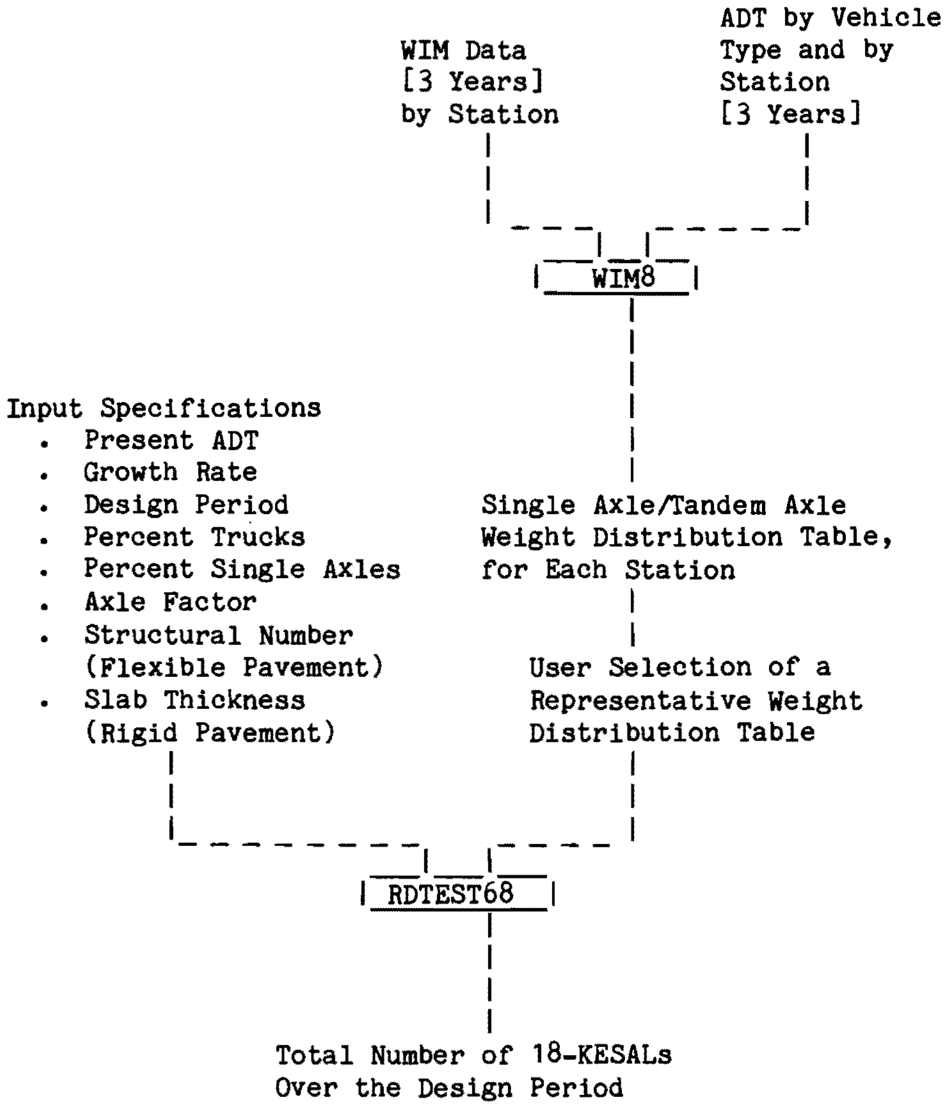


Fig 6. SDHPT'S Traffic Load Forecasting Procedure

4. #504, west of Sweetwater on IH-20,
5. #505, south of Nacogdoches on US 59, and
6. #506, west of Wichita Falls on US 287.

In 1983, data were collected in only one direction and in only one lane at each station. In 1984, several stations were equipped with special four-lane weighing, dimensioning, and classifying capabilities. Through a process involving the specification of threshold weight limits and operator selection of the vehicles to be permanently recorded, light-weight vehicles such as passenger cars and pickup trucks are excluded from the axle weight data sets.

Several computer programs are used to convert the raw weight data into a format usable by the RDTEST68 program. Due to a concern about the statistical reliability of the available weight data, standard practice is to use all axle weight data collected at each station over a three-year period. The basic steps of the WIM82 "data reduction" computer program are as follows:

1. For each vehicle type and weight group, the weight data collected over the most recent three-year period are tabulated for all single axles and all tandem axles.
2. Based on vehicle classification and count data, the number of single and tandem axles for each vehicle group is calculated.
3. The axle weight data are prorated by the count data, with all single axles combined by weight group and all tandem axles combined by weight group.
4. The number of axles in each weight group is shown as a percentage of the total.

This final table of percentages for each WIM station is known as the basic weight table. An example of the weight table data used in RDTEST68 (for 18-

KESAL calculations) is shown in Table 5. SDHPT uses the approach followed by AASHTO in treating a tandem axle set as one axle load.

Selection of a Representative Station

RDTEST68 is designed to handle a variety of axle weight data:

1. a statewide distribution table,
2. weight tables by facility type, and
3. weight tables for individual WIM stations.

The present operating procedure used by D-10 is to select one weight table from a "representative" WIM station (with three years of data) and assume that its axle weight distribution is similar to the highway segment under study. This selection process is largely based on engineering judgement. The general guidelines followed by D-10 personnel are to select a WIM station that appears to have similar traffic characteristics, such as percent trucks, average daily traffic (ADT), and highway type. The significance of this selection process to the calculation of 18-KESALs is evaluated in Chapter 6.

Percent Single Axles

D-10 has incorporated a simple mathematical routine in RDTEST68 that allows the program user to "customize" the axle weight distribution table of a representative WIM station by specifying a "percent single axles" factor. The "percent single axles" factor can be calculated from classification data collected at (or near) the highway segment under study and represents an average for all types of heavy trucks. Each tandem axle set (and each steering axle) is treated as one axle load. For example, a 3-S2 has one single axle and two tandem axles -- it therefore has a "percent single axles" factor of (100 percent) X (1/3) = 33.33 percent. A two-axle truck would have a "percent single axles" factor of 100 percent.

TABLE 5. EXAMPLE OF A WEIGHT DISTRIBUTION TABLE FOR RDTEST68

STATION 501, 1981-1983

Upper Weight Limit (pounds)	Single Axles Percent	Single Axles Cumulative Percent	Tandem Axles (Percent)
2,000	0.213	0.213	0.000
3,000	0.419	0.632	0.017
4,000	1.625	2.257	0.000
5,000	2.344	4.601	0.000
6,000	2.729	7.330	0.068
7,000	3.268	10.598	0.119
8,000	4.978	15.577	0.231
9,000	7.460	23.037	0.727
10,000	9.291	32.328	1.411
11,000	7.161	39.489	2.369
12,000	3.413	42.902	2.669
13,000	1.890	44.792	2.190
14,000	1.069	45.861	2.318
15,000	0.710	46.571	2.173
16,000	0.761	47.332	1.942
17,000	0.496	47.828	1.719
18,000	0.248	48.076	1.557
19,000	0.419	48.495	1.488
20,000	0.308	48.803	1.488
21,000	0.325	49.128	1.206
22,000	0.136	49.264	1.009
23,000	0.231	49.495	0.958
24,000	0.136	49.631	0.761
25,000	0.077	49.708	1.060
26,000	0.059	49.767	0.744
27,000	0.017	49.784	0.941
28,000	0.077	49.861	1.060
29,000	0.017	49.878	1.240
30,000	0.017	49.895	1.240

(CONTINUED)

TABLE 5. EXAMPLE OF A WEIGHT DISTRIBUTION TABLE FOR RDTEST68 (CONTINUED)

Upper Weight Limit (pounds)	Single Axles Percent	Single Axles Cumulative Percent	Tandem Axles (Percent)
31,000	0.017	49.912	1.206
32,000	0.000	49.912	1.522
33,000	0.000	49.912	1.377
34,000	0.000	49.912	1.736
35,000	0.000	49.912	1.488
36,000	0.000	49.912	1.454
37,000	0.000	49.912	1.437
38,000	0.000	49.912	1.377
39,000	0.000	49.912	1.274
40,000	0.000	49.912	1.112
41,000	0.000	49.912	0.812
42,000	0.000	49.912	0.658
43,000	0.000	49.912	0.462
44,000	0.000	49.912	0.427
45,000	0.000	49.912	0.316
46,000	0.000	49.912	0.145
47,000	0.000	49.912	0.179
48,000	0.000	49.912	0.102
49,000	0.000	49.912	0.145
50,000	0.000	49.912	0.085
51,000	0.000	49.912	0.000
52,000	0.000	49.912	0.017
53,000	0.000	49.912	0.017
54,000	0.000	49.912	0.000
55,000	0.000	49.912	0.000
56,000	0.000	49.912	0.000

An example of this "weight table adjustment" procedure is shown in Table 6. It can be seen that the adjustment consists of prorating the percentages for each axle weight group of a weight table.

18-KESALs Per Truck Axle

The actual calculation process used in RDTEST68 (as shown in Appendix B) consists of multiplying the total number of truck axles by the percentage of axles in each weight group of the weight table and by the appropriate 18-KESAL factor (one for single axles and one for tandem axles) for each weight group. However, for presentation purposes, the entire process can be simplified by changing the sequential order in which the internal calculations are actually made. For example, RDTEST68 essentially calculates an average 18-KESAL factor per axle for all trucks weighed: one for rigid pavements and one for flexible pavements. Although a terminal serviceability index of 2.5 is always assumed, the program user is able to specify the desired structural number (for flexible pavements) and slab thickness (for rigid pavements).

For a structural number of 3 and a slab thickness of 8, the AASHTO equivalency factors are calculated external to the RDTEST68 program. For all other specifications, the factors are calculated from the AASHTO equations embedded in RDTEST68. A simple method of determining the average 18-KESAL factor per axle from a weight table containing the average percentage of axles in each weight group is demonstrated in Table 7.

Axle Factor

In order to calculate an average equivalency factor per heavy truck (one for flexible pavements and one for rigid pavements), available vehicle classification data at (or near) the highway segment under study is normally utilized. Once again, a tandem axle is treated as one axle load. For

TABLE 6. ADJUSTMENT OF A WEIGHT TABLE

Original:

Percent Single Axles = 40.00
Percent Tandem Axles = 60.00

New:

Percent Single Axles = 50.00
Percent Tandem Axles = 50.00

Adjustment Factor:

Single Axles - 50.00/40.00 = 1.250
Tandem Axles - 50.00/60.00 = 0.833

Weight	Single Axles		Tandem Axles	
Group	Original	Adjusted	Original	Adjusted
1	10.00	12.50	2.00	1.67
2	14.00	17.50	6.00	5.00
3	10.00	12.50	12.00	10.00
4	4.00	5.00	30.00	25.00
5	2.00	2.50	10.00	8.33
	40.00	50.00	60.00	60.00

TABLE 7. CALCULATION OF AN AVERAGE 18-KESAL FACTOR PER AXLE

[FLEXIBLE PAVEMENT, SN=3]

Upper Weight Limit (pounds)	Single Axles Percent	18-KESAL/Axle	Amount of 18-KESAL
2,000	0.213	0.000313	0.00000
3,000	0.419	0.001230	0.00001
4,000	1.625	0.003525	0.00006
5,000	2.344	0.008244	0.00019
6,000	2.729	0.016698	0.00046
7,000	3.268	0.030359	0.00099
8,000	4.979	0.050746	0.00253
9,000	7.460	0.079336	0.00592
10,000	9.291	0.117557	0.01092
11,000	7.161	0.166857	0.01195
12,000	3.413	0.228821	0.00781
13,000	1.890	0.305305	0.00577
14,000	1.069	0.398540	0.00426
15,000	0.710	0.511211	0.00363
16,000	0.761	0.646488	0.00492
17,000	0.496	0.808051	0.00401
18,000	0.248	1.000093	0.00248
19,000	0.419	1.227323	0.00514
20,000	0.308	1.494970	0.00460
21,000	0.325	1.808788	0.00588
22,000	0.136	2.175066	0.00296
23,000	0.231	2.600640	0.00601
24,000	0.136	3.092909	0.00421
25,000	0.077	3.659846	0.00282
26,000	0.059	4.310020	0.00254
27,000	0.017	5.052609	0.00086
28,000	0.077	5.897421	0.00454
29,000	0.017	6.854909	0.00117
30,000	0.017	7.936193	0.00135
31,000	0.017	9.153071	0.00156
32,000	0.000	10.518046	0.00000
		Single Axle Total	0.10673

(CONTINUED)

TABLE 7. CALCULATION OF AN AVERAGE 18-KESAL FACTOR PER AXLE (CONTINUED)

TANDEM AXLES

Upper Weight Limit (pounds)	Percent	18-KESAL/Axle	Amount of 18-KESAL
2,000	0.000	0.000062	0.00000
3,000	0.017	0.000180	0.00000
4,000	0.000	0.000430	0.00000
5,000	0.000	0.000897	0.00000
6,000	0.068	0.001691	0.00000
7,000	0.119	0.002953	0.00000
8,000	0.231	0.004848	0.00001
9,000	0.727	0.007572	0.00006
10,000	1.411	0.011334	0.00016
11,000	2.369	0.016388	0.00039
12,000	2.669	0.022968	0.00061
13,000	2.190	0.031338	0.00069
14,000	2.318	0.041760	0.00097
15,000	2.173	0.054496	0.00118
16,000	1.942	0.069803	0.00136
17,000	1.719	0.087932	0.00151
18,000	1.557	0.109130	0.00170
19,000	1.488	0.133639	0.00199
20,000	1.488	0.161705	0.00241
21,000	1.206	0.193577	0.00233
22,000	1.009	0.229519	0.00232
23,000	0.958	0.269809	0.00258
24,000	0.761	0.314753	0.00240
25,000	1.060	0.364681	0.00387
26,000	0.744	0.419959	0.00312
27,000	0.941	0.480988	0.00453
28,000	1.060	0.548209	0.00581
29,000	1.240	0.622102	0.00771
30,000	1.240	0.703191	0.00872

(CONTINUED)

TABLE 7. CALCULATION OF AN AVERAGE 18-KESAL FACTOR PER AXLE (CONTINUED)

TANDEM AXLES

UPPER WEIGHT LIMIT (pounds)	PERCENT	18-KESAL/AXLE	AMOUNT OF 18-KESAL
31,000	1.206	0.792044	0.00955
32,000	1.522	0.889270	0.01353
33,000	1.377	0.995525	0.01371
34,000	1.736	1.111507	0.01930
35,000	1.488	1.237959	0.01842
36,000	1.454	1.375669	0.02000
37,000	1.437	1.525468	0.02192
38,000	1.377	1.688234	0.02325
39,000	1.274	1.864887	0.02376
40,000	1.112	2.056393	0.02287
41,000	0.812	2.263766	0.01838
42,000	0.658	2.488063	0.01637
43,000	0.462	2.730388	0.01261
44,000	0.427	2.991893	0.01278
45,000	0.316	3.273778	0.01035
46,000	0.145	3.577288	0.00519
47,000	0.179	3.903722	0.00699
48,000	0.102	4.254424	0.00434
49,000	0.145	4.630791	0.00671
50,000	0.085	5.034269	0.00428
51,000	0.000	5.466359	0.00000
52,000	0.017	5.928610	0.00101
53,000	0.017	6.422628	0.00109
54,000	0.000	6.950072	0.00000
		Tandem Axle Total	0.34284

AVERAGE 18-KESAL/AXLE

= Single Axle + Tandem Axle

= 0.10673 + 0.34284

= 0.44957

example, a 3-S2 (1 single, 2 tandem) would have an axle factor of 3.00, whereas a 2-axle truck would have a factor of 2.00. A depiction of axle factors and "percent single axles" for typical trucks in Texas is shown in Figure 7.

Traffic Parameters

The remaining input parameters are used to calculate the total number of trucks and other vehicles expected to operate over a facility during a certain number of years (i.e., the design period). The term "other vehicles" refers to all types of vehicles that are not included in the weighing program. The "percent trucks" factor, which is assumed to remain constant during the design period, is input in decimal form (i.e., 10 percent = 0.10). The "growth" factor, which represents the yearly percentage increase in ADT, is also input in decimal form. A linear growth rate is assumed, which means that a 2.0 percent/year increase would be treated as a 20.0 percent increase over a ten-year period.

The basic calculations for the total number of vehicles would be as follows:

Total Vehicles

= (Initial ADT) + [1 + (Growth Factor) X (Design Period)]/2

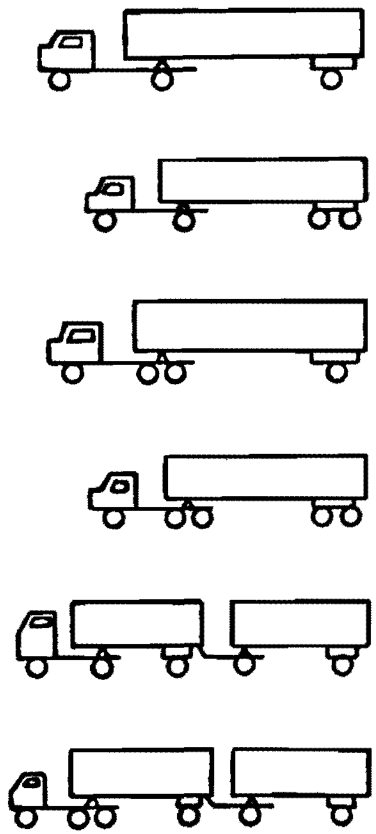
Total Trucks

= (Percent Trucks) X (Total Vehicles)

Total Other Vehicles

= Total Vehicles - Total Trucks

For all vehicles other than trucks, the average equivalency factor per vehicle is assumed to be 0.000626 for both rigid and flexible pavements. Total 18-KESALs for the design period would therefore be:



	Axle Factor	Percent Single Axles
3 AXLES	3	100
4 AXLES (2S-2)	3	67
4 AXLES (3S-1)	3	67
5 AXLES (3S-2)	3	33
5 AXLES (2-S1-2)	5	100
6 AXLES	5	80

Fig 7. Typical Truck Configurations

Total 18-KESALs = (Total Trucks) X (18-KESAL/Truck)
+ (Other Vehicles) X (0.000626)

Input Parameters Not Used

It is possible to input monthly growth rates in RDTEST68 (in order to calculate total 18-KESALs for a design period of less than one year), but this capability is seldom needed. It is also possible to use "default" parameters for the "axle factor" and "percent single axles" specifications. If desired, one could also use a "programmed" axle weight distribution table in RDTEST68 rather than the table from a "representative" WIM station.

Traffic Load Design (TLDESIGN)

The RDTEST68 program is used to forecast 18-KESALs for a specific highway segment. D-10 also runs a program called TLDESIGN (Traffic Load Design) that uses "statewide" data to estimate annual 18-KESALs for each section of roadway in Texas. This is the source of the 18-kip information found in the Roadway Information System (RIS) file. These estimates, however, are not intended for use in detailed pavement design calculations.

CHAPTER 5. PROCEDURES IN OTHER STATES

A survey of the traffic load forecasting procedures used in other states was conducted in order to examine alternatives to the Texas procedure. In addition to a review of the available literature, detailed information was obtained by means of telephone interviews and a written questionnaire.

The questionnaire mailed to each state in November of 1983 requested information about weight data collection procedures and use of weight data for prediction of expected traffic loads. The survey questions are shown in Appendix C, along with a detailed review of the responses received from 38 states.

Collection of Weight Data

The amount of weight data actually collected each year varies considerably from state to state. In Texas, a total of 8,070 trucks were weighed at six WIM stations in 1982, compared with 15,310 trucks in 1983. Data collected in Texas and 28 other states is summarized in Table 8. Although the use of WIM stations is on the increase, the majority of states relied upon manual (i.e., static) weigh stations in 1982. Virginia weighed over seven million vehicles in 1982 and Florida weighed over 180,000 vehicles (59,000 trucks), yet New York weighed less than 3,000.

The majority of states appear to weigh fewer than 10,000 vehicles per year, and some conduct weighing operations only every other year. The states of Illinois, Massachusetts, Mississippi, New York, and Rhode Island have

TABLE 8. WEIGHT DATA COLLECTED IN SELECTED STATES

STATE	YEAR	MANUAL	WIM	WEIGHED
Alabama	1982	0	10	13,534
Arizona	1982	13	0	930
Arkansas	1983	18	1	5,800
Colorado	1982	12	0	1,952
Connecticut	1981	9	0	4,038
Florida	1982	0	16	184,920*
Georgia	1982	15	0	2,777
Hawaii	1982	9	0	1,120
Illinois	1981	12	0	2,900
Iowa	1981	--	--	19,042
Kansas	1983	25	0	1,744
Maryland	1982	21	0	7,500
Mississippi	1982	13	0	3,372
Missouri	1982	10	7	3,376
Montana	1982	15	0	2,644
Nebraska	1982	13	0	3,139
Nevada	1982	3	10	3,250
New Mexico	1982	0	11	5,703
New York	1982	14	0	2,977
Ohio	1982	14	0	5,300
Pennsylvania	1982	28	0	10,932
South Dakota	1982	12	0	3,455
Tennessee	1982	16	0	2,308
Texas	1983	0	6	15,310
Vermont	1982	7	0	1,910
Virginia	1982	10	14	7,254,000**
Washington	1982	0	10	6,930
West Virginia	1980	17	0	5,400
Wyoming	1982	34	0	5,916

*58,568 trucks
**Cars and trucks

attempted to economize by combining the truck weight survey program with the overweight enforcement program, but with mixed results. For example, it was noted in Massachusetts that weight data collected during enforcement operations showed a low-side bias when compared with weight data collected by other means.

Aggregation of Available Weight Data

As described in Chapter 4, the traffic load forecasting procedure used in Texas makes use of axle weight data collected at individual stations. A traffic load forecast performed in 1984 would utilize one of the weight tables developed from all axle weight data collected at a "representative" WIM station in 1981, 1982, and 1983. As with the amount of weight data collected, the methods for incorporating weight data into traffic load forecasting procedures varies considerably among the states. The aggregation procedures used in Texas and 34 other states (for purposes of traffic load forecasting) are displayed in Table 9.

The major factor involved in choosing one aggregation procedure over another appears to be the quality (or amount) of the available data and the perceived ability to select "representative" data. For example, if relatively few trucks are weighed each year by a particular state, that state is more likely to aggregate all axle weight data collected over several years on a statewide basis or by highway type. Even if a weigh station is located at a highway segment under study, some states still prefer to utilize an aggregation of several stations.

Forecasting Procedures

The traffic load forecasting procedures used in 38 states are summarized in Appendix C. About 80 percent of the states surveyed indicated that

TABLE 9. AGGREGATION OF WEIGHT DATA IN SELECTED STATES, 1982

State	Individ. Station	Highway Type	State-Wide	Use of Multi-Year Data	Truck Breakdowns
Alabama			X		1
Arizona		X		X	5
Arkansas	X	X		X	1
Colorado			X	X	3
Florida	X	X	X	X	1
Georgia	X		X	X	2
Hawaii			X	X	1
Illinois		X		X	2
Indiana			X	X	2
Iowa		X		X	1
Kansas			X	X	10
Kentucky			X	X	1
Maine	X		X	X	2
Maryland	X				1
Massachusetts		X			1
Mississippi		X			7
Missouri	X				2+
Montana	X	X		X	1
Nebraska			X		1
Nevada	X			X	11
New Jersey	X				1
New Mexico			X	X	4
North Carolina			X		2
Ohio		X			1
Pennsylvania			X		5
South Carolina			X	X	5
South Dakota		X			10
Tennessee		X		X	7
Texas	X			X	1
Utah		X		X	2
Vermont		X			7
Virginia	X				1
Washington		X			5
West Virginia			X	X	6
Wyoming			X	X	13

AASHTO's 18-KESAL calculation procedures are used. Four of the states surveyed utilize an alternative "equivalent wheel load" concept, while four other states dispense with traffic load forecasts through the use of pavement "standards" based on criteria such as ADT, highway type, and location.

In 1972, a survey of all 50 states, plus Puerto Rico and Washington, D.C., was published as an NCHRP report (Ref 15). The overall conclusion of the survey was as follows:

1. For flexible pavement design, 38 highway departments use the 18-kip single-axle load, 8 use the California 5-kip wheel load, 4 use some other concept, and 2 do not consider load in their design.
2. For rigid pavement design, 23 highway departments use the 18-kip single-axle load, 17 use a form of the PCA design concept, 5 use standard sections, 2 base their designs on experience and 5 do not use rigid pavements (Ref 15, p. 6)

The basic forecasting approaches outlined in the 1972 AASHTO Interim Guide for Design of Pavement Structures (Ref 1, pp. 67-69) represent methodologies currently used by many states. These methodologies contain the following steps:

1. Determine the average 18-KESAL/truck factor from either a "representative" weigh station or an aggregation of several stations (e.g., by highway type).
2. Multiply this factor by the number of trucks expected to operate in the design lane during a specified time.

Most states appear to assign 100 percent of the traffic in each direction to the design lane, but some states have adopted lane distribution factors on multi-lane roadways:

Number of Lanes (One Direction)	Distribution
2	80 - 100%
3	60 - 80%

Variations to AASHTO's basic approach consist of the use of average 18-KESAL factors by truck type rather than simply by truck. The strength of this approach is that projected changes in traffic volumes and truck weights may be taken into account by truck type.

The 1972 NCHRP report describes seven methodologies for forecasting total 18-KESALs (Ref 15, pp. 21, 22, 64-66). Method A consists of the direct use of FHWA's W-4 tables for all truck types combined, in which axle loads are listed in groups that are generally in 2,000-pound increments. The 18-KESAL/axle factor for each group is based on the average axle load for the group (e.g., the 12,000 to 14,000-pound group has an average weight of 13,000 pounds). Method B categorizes all traffic into three broad vehicle types: passenger cars, single-unit vehicles, and multiple-unit vehicles. An average 18-KESAL factor is then determined for each vehicle type. Method C is similar to Method A, except that only ten axle weight groups are used:

1. Single axle, under 5 kips,
2. Single axle, 5-12 kips,
3. Single axle, 12-16 kips
4. Single axle, 16-20 kips
5. Single axle, over 20 kips
6. Tandem axle, under 18 kips
7. Tandem axle, 18-28 kips
8. Tandem axle, 28-34 kips
9. Tandem axle, 34-40 kips

10. Tandem axle, over 40 kips

Method D, similar to A and C, can take into account any significant changes expected in the future distribution of axle loads.

Method E features the use of heavy commercial ADT as a base for conversion to 18-KESALs and an evaluation of seasonal variations in traffic. Six vehicle classifications are used:

1. Single-unit, 4-tire,
2. Single-unit, 2-axle, 6-tire,
3. Single-unit, 3-axle,
4. Semitrailer, 3-axle,
5. Semitrailer, 4-axle,
6. Semitrailer, 5-axle.

Methods F and G classify trucks only by axle type: 2-axle, 3-axle, axle, 5-axle, and 6-axle. An average 18-KESAL factor is then calculated for each of the five groups.

CHAPTER 6. EVALUATION OF PROCEDURES

The traffic load forecasting procedure currently used in Texas is described in Chapter 4 and Appendix B. The example problem shown in appendix B demonstrates that the internal calculations of the RDTEST68 program are correct. A major concern, however, is the accuracy of SDHPT's procedure, given the limited amount of data available. The analysis presented in this chapter can be broken into two major components:

1. the input specifications used to calculate an average 18-KESAL/truck factor,
2. the input specifications used to calculate the number of trucks expected over the design period.

Selection of a Representative WIM Station

One of the most important considerations in all load forecasting procedures is the selection of an axle weight distribution table representative of the traffic loadings at the highway segment under study. In Texas, the choice is limited to the six WIM stations described in Table 10 and displayed in Figure 8. Problems with small samples sizes are partially compensated-for by aggregating all data collected at a WIM station over a three-year period. The selected weight table is then assumed to be representative of all truck loadings during the design period.

In order to test the sensitivity of the RDTEST68 program to the selection of a WIM station, all other input specifications were held constant. The resulting 18-KESAL calculations are shown in Table 11 on a

TABLE 10. WIM STATIONS IN TEXAS

Station	Old Number	Highway Type	Location
501	16	Interstate Rural	North of Lubbock on IH-27
502	102	Interstate Rural	West of Seguin on IH-10
503	101	Interstate Rural	East of Junction on IH-10
504	201	Interstate Rural	West of Sweetwater on IH-20
505	72	Other Rural	South of Nacogdoches on U.S. 59
506	20	Other Rural	West of Wichita Falls on U.S. 287

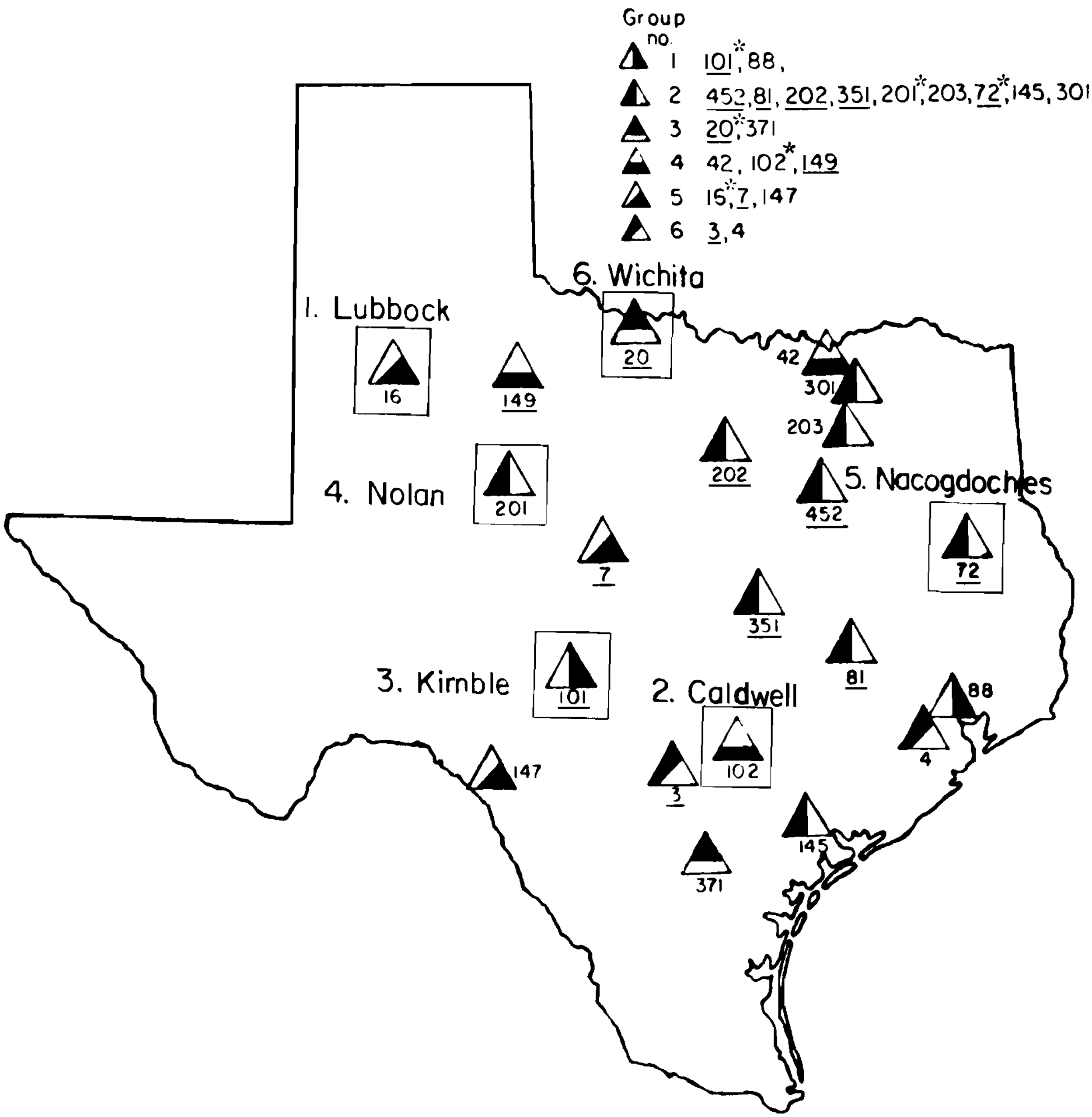


Fig 8. WIM Stations in Texas

TABLE 11. 18-KESAL/TRUCK FACTORS FOR THE BASE CASE

Three Year Average, 1981-1983

Axle Factor = 2.75

Percent Single Axles = 50.0

Terminal Serviceability Index = 2.5

Station	Flexible Pavement (Structural Number = 3)	Rigid Pavement (Slab Thickness = 8 Inches)
501	1.24	1.84
502	0.89	1.28
503	0.97	1.42
504	1.11	1.60
505	1.25	1.88
506	1.26	1.86

"per truck" basis for both flexible and rigid pavements. For flexible pavements, the 18-KESAL/truck factor for station 501 was 39 percent higher than that for station 502, yet both are on the "interstate rural" highway system. The corresponding difference for rigid pavements was 44 percent. Unfortunately, it is difficult to determine how much of these variations are due to inadequate sample sizes and how much are a result of different traffic characteristics.

The preparation of a multi-year weight table for each WIM station was briefly described in Chapter 4. Instead of simply combining all weight data collected at a WIM station, SDHPT prorates the data through the use of actual vehicle counts by truck type. Table 12 shows the WIM information collected for each truck weighed and Table 13 shows the count information collected by vehicle type. A computer program known as WIM82 is then used to develop a single/tandem axle weight distribution table for all truck types weighed at a station (pickups and other 2-axle, 4-tired trucks are excluded). For example, if 70 percent of all trucks counted at a station are of the 3-S2 (i.e., 5-axle) type, the WIM82 program creates a multi-year weight table (for all truck types combined) based on 70 percent 3-S2s. The significance of this approach is that, so long as good vehicle classification count data is available at a WIM station, the distribution of truck types actually weighed is not important. What <u>does</u> matter is that the sample of trucks weighed for each truck type are statistically unbiased.

The weight distribution table created by the WIM82 program for station 50 was shown earlier in Table 5. In Table 14, the same distribution is compared to the distribution obtained from FHWA's W-4 tables for 1981, 1982, and 1983. Although the W-4 axle weight data was not prorated by classification count data, the two distributions compare fairly closely.

TABLE 12. WEIGHT DATA RECORD, FHWA FORMAT

Column	Item
1	Card type (= 7)
2-3	State code (Texas = 48)
4-5	Highway type (interstate, rural, other main rural)
6-8	Station number (501-506)
9	Direction of travel (north = 1, east = 3, etc.
10-11	Year of data (last two digits)
12-13	Month of data (Jan. = 1, Dec. = 12)
14-15	Day of data (1-31)
16-17	Hour of day (0 through 23)
18-23	Vehicle type (FHWA classes)
24-25	Body type (FHWA classes)
42-45	Total vehicle weight, 100's of pounds
46-48	Weight of axle A, 100's of pounds
49-51	Weight of axle B, 100's of pounds
52-54	Weight of axle C, 100's of pounds
55-57	Weight of axle D, 100's of pounds
58-60	Weight of axle E, 100's of pounds
61-63	(A-B) axle spacing, tenths of feet
64-66	(B-C) axle spacing, tenths of feet
67-69	(C-D) axle spacing, tenths of feet
70-72	(D-E) axle spacing, tenths of feet
73-76	Total wheel base, tenths of feet
77-79	Card serial number
80	Continuation card (1 = additional axle data on next card)

TABLE 13. COUNT DATA RECORD FOR WIM82 PROGRAM

Column	Item
1-3	Station number (501-506
4-9	Counted: pickups
10-15	Counted: other 2-axle, 4-tire
16-21	Counted: Type 220000 (2 single)
22-27	Counted: Type 230000 (1 single, 1 tandem)
28-33	Counted: Type 321000 (3 single)
34-39	Counted: Type 331000 (2 single, 1 tandem)
40-45	Counted: Type 332000 (1 single, 2 tandem)
46-51	Counted: Type 521200 (5 single)
52-57	Counted: Type 531200 (4 single, 1 tandem)
58-63	Counted: Type 421000 (3 single)
64-69	Counted: Type 431000 (2 single, 1 tandem)
70-75	Counted: Type 433000 (1 single, 2 tandem)
77-78	Counted: Year 1
79-80	Counted: Year 2

TABLE 14. AXLE WEIGHT DISTRIBUTION, STATION 501, 1981-1983

	Percentage Distribution		Cumulative Percentage Distribution	
Axle Group	RDTEST68	W-4 Tables	RDTEST68	W-4 Tables
Single Axle				
Under 3K*	0.632	0.6667	0.632	0.6667
3- 7K	9.966	10.1706	10.598	10.8373
7- 8K	4.979	5.2435	15.577	16.0808
8-12K	27.325	26.5351	42.902	42.6149
12-16K	4.430	4.5090	47.332	47.1239
16-18K	0.744	0.8250	48.076	47.9489
18-20K	0.727	0.8814	48.803	48.8303
20-22K	0.461	0.4633	49.264	49.2936
22-24K	0.367	0.3390	49.631	49.6326
24-26K	0.136	0.1243	49.767	49.7569
26-30K	0.128	0.1017	49.895	49.8586
Over 30K	0.017	0.0113	49.912	49.8699
Tandem Axle				
Under 6K	0.085	0.0791	0.085	0.0791
6-12K	7.526	7.7410	7.611	7.8201
12-18K	11.899	12.0692	19.510	19.8893
18-24K	6.910	7.0290	26.420	26.9183
24-30K	6.285	6.3736	32.705	33.2919
30-32K	2.728	2.8930	35.433	36.1849
32-34K	3.113	2.9268	38.546	39.1117
34-36K	2.942	2.9834	41.488	42.0951
36-38K	2.814	2.7009	44.302	44.7960
38-40K	2.386	2.2601	46.688	47.0561
40-42K	1.470	1.3674	48.158	48.4235
42-44K	0.889	0.8250	49.047	49.2485
44-46K	0.461	0.4181	49.508	49.6666
46-50K	0.511	0.4407	50.019	50.1073
Over 50K	0.034	0.0226	50.053	50.1299

*K = 1,000 pounds

Computer tapes containing SDHPT's multi-year weight tables (by WIM station) prior to the 1979-1981 period are no longer available. The information presented in Table 15 indicates that, since 1979, the percentage of single axles at each WIM station has decreased.

The axle weight distributions shown in Tables 16 and 17 help to demonstrate why there are 18-KESAL/truck variations by WIM station. Table 17 differs from Table 16 in that the distribution of both single and tandem axles is adjusted to 50 percent. Station 503 had the lowest 18-KESAL/truck factor and the lowest percentage of single axles over 20,000 pounds. Stations 501, 505, and 506, which had high 18-KESAL/truck factors, also had a high percentage of tandem axles over 35,000 pounds.

Percent Single Axles and Axle Factor

For each run of the RDTEST68 program, the axle factor and the percentage of single axles are input. These truck factors allow the program user to "customize" a weight distribution table by making it more responsive to vehicle classification data obtained at the highway segment under study. For example, a high axle factor and a low percentage of single axles indicate a relatively high percentage of multiple-unit trucks among the truck traffic stream.

In order to examine the sensitivity of the RDTEST68 program to these two specifications, it is first necessary to identify the range of possible values. Based on vehicle classification data collected at over 700 locations (on Texas highways) in 1980, the percentage of single axles is plotted against the axle factor in Figure 9. The mean values and standard deviations were as follows:

TABLE 15. PERCENTAGE OF SINGLE AND TANDEM AXLES, RDTEST68 DATA

		Percentage Distribution of Axles		
Station	Years	Single	Tandem	Total
501	1980-1982	53.11	46.91	100.02
	1981-1983	49.912	50.053	99.965
502	1979-1981	48.01	51.99	100.00
	1980-1982	45.69	54.33	100.02
	1981-1983	45.243	54.724	99.967
503	1979-1981	52.09	47.90	99.99
	1980-1982	52.85	47.18	100.03
	1981-1983	44.228	55.736	99.964
504	1979-1981	48.89	51.15	100.04
	1980-1982	50.25	49.73	99.98
	1981-1983	46.096	53.872	99.968
505	1979-1981	46.28	53.71	99.99
	1980-1982	47.15	52.87	100.02
	1981-1983	45.262	54.697	99.959
506	1979-1981	48.71	51.31	100.02
	1980-1982	51.96	48.05	100.01
	1981-1983	47.425	52.542	99.967

TABLE 16. AXLE WEIGHT DISTRIBUTIONS BY WIM STATION, 1981-1983

	WIM Station					
	501	502	503	504	505	506
Single Axles						
'10K	32.328	35.660	34.411	30.892	30.332	29.994
10-20K	16.475	9.248	9.688	14.773	14.631	16.901
20K+	1.109	0.335	0.129	0.431	0.299	0.530
All	49.912	45.243	44.228	46.096	45.262	47.425
Tandem Axles						
'10K	2.573	3.825	4.607	1.574	2.417	1.392
10-20K	19.913	19.026	15.758	12.278	17.431	14.847
20-30K	10.219	15.683	14.979	20.981	13.120	15.358
30-35K	7.329	11.971	15.064	13.946	11.014	11.557
35K+	10.019	4.219	5.328	5.093	10.715	9.388
All	50.053	54.724	55.736	53.872	54.697	52.542
Total	99.965	99.967	99.964	99.968	99.959	99.967

TABLE 17. ADJUSTED AXLE WEIGHT DISTRIBUTIONS BY WIM STATION, 1981-1983

	WIM Station					
	501	502	503	504	505	506
Single Axles						
'10K	32.835	39.410	38.902	33.508	33.507	31.622
10-20K	16.504	10.220	10.952	16.024	16.163	17.819
20K+	1.111	0.370	0.146	0.468	0.330	0.559
All	50.00	50.00	50.00	50.00	50.00	50.000
Tandem Axles						
'10K	2.570	3.495	4.133	1.461	2.210	1.324
10-20K	19.892	17.384	14.136	11.395	15.934	14.129
20-30K	10.208	14.329	13.438	19.473	11.993	14.615
30-35K	7.321	10.937	13.514	12.944	10.068	10.998
35K+	10.009	3.855	4.779	4.727	9.795	8.934
All	50.000	50.000	50.000	50.000	50.000	50.000
Total	100.000	100.000	100.000	100.000	100.000	100.000

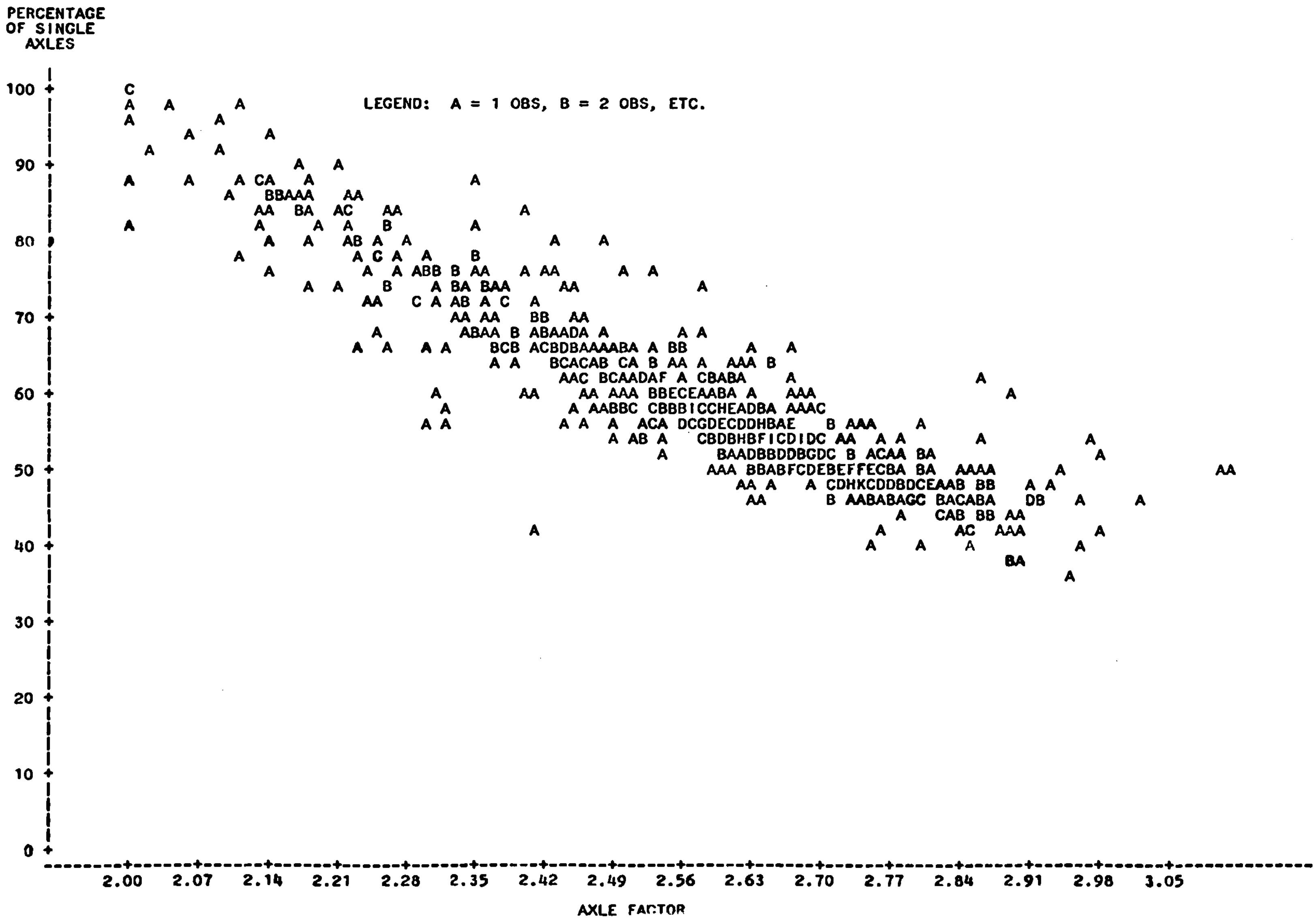


Fig 9. Percent Single Axles Versus Axle Factor, 1980 Classification Data

	Mean	Standard Deviation
Percent Single Axles	59.0	11.8
Axle Factor	2.58	0.20

The weighted average axle factor (total axles/total trucks) was 2.68 and the weighted average "percent single axles" was 52.8.

For an axle factor of 2.75, the "percent single axles" number normally ranges from 45 to 60 percent. The sensitivity of the RDTEST68 program to this range is shown in Tables 18 and 19. As the percentage of single axles increases (while the axle factor is held constant), the 18-KESAL/truck factor decreases. A change in the percentage of single axles from 50 to 60 results in an average 18-KESAL/truck decrease of 10 percent for flexible pavements and 15 percent for rigid pavements.

For a "percent single axles" number of 50 percent, the axle factor normally ranges from 2.60 to 2.90. If all other input specifications are held constant, a 20 percent increase in the axle factor results in a 20 percent increase in the 18-KESAL/truck factor.

Tables 20 and 21 demonstrate the importance of accurate specifications of the percentage of single axles and the axle factor. All of the specifications shown in the table represent the actual range of values obtained from the 1980 vehicle classification data. The resulting 18-KESAL/truck factors (for station 503) ranged from 0.34 to 1.48 for flexible pavements and 0.33 to 1.73 for rigid pavements.

Pavement Specifications

Table 22 shows RDTEST68 sensitivity to the structural number of flexible pavements. Although a structural number of 3 is normally assumed, a structural number of 6 would decrease the 18-KESAL/truck factor by less than 10 percent.

TABLE 18. 18-KESAL VARIATIONS DUE TO THE PERCENTAGE OF SINGLE AXLES, FLEXIBLE PAVEMENT

18-KESAL/Truck
(Relative Difference, Base = 100)

Percent Single Axles

Station	45	50	55	60
501	1.31 (106)	1.24 (100)	1.18 (95)	1.12 (90)
502	0.94 (106)	0.89 (100)	0.84 (94)	0.80 (90)
503	1.02 (105)	0.97 (100)	0.91 (94)	0.85 (88)
504	1.17 (105)	1.11 (100)	1.06 (95)	1.00 (90)
505	1.33 (106)	1.25 (100)	1.17 (94)	1.10 (88)
506	1.33 (106)	1.26 (100)	1.19 (94)	1.12 (89)

TABLE 19. 18-KESAL VARIATIONS DUE TO THE PERCENTAGE OF SINGLE AXLES, RIGID PAVEMENT

18-KESAL/Truck
(Relative Difference, Base = 100)

Percent Single Axles

Station	45	50	55	60
501	1.96 (107)	1.84 (100)	1.70 (92)	1.58 (86)
502	1.47 (115)	1.28 (100)	1.19 (93)	1.10 (86)
503	1.53 (108)	1.42 (100)	1.31 (92)	1.20 (85)
504	1.72 (108)	1.60 (100)	1.49 (93)	1.38 (86)
505	2.03 (108)	1.88 (100)	1.73 (92)	1.59 (85)
506	2.00 (108)	1.86 (100)	1.72 (92)	1.58 (85)

TABLE 20. 18-KESAL VARIATIONS DUE TO THE AXLE FACTOR AND PERCENTAGE OF SINGLE AXLES, FLEXIBLE PAVEMENT

Axle Factor	Percent Single Axles	18-KESAL/Truck		Relative 18-KESAL (Base = 100)	
		503	505	503	505
2.10	85	0.43	0.54	44	43
2.10	95	0.34	0.42	35	34
2.20	75	0.54	0.69	56	55
2.20	95	0.36	0.45	37	36
2.40	60	0.74	0.96	76	77
2.40	75	0.59	0.76	61	61
2.40	90	0.44	0.55	45	44
2.60	50	0.92	1.18	95	94
2.60	60	0.81	1.04	84	83
2.60	70	0.69	0.89	71	71
2.70	45	1.01	1.30	104	104
2.70	65	0.78	1.00	80	80
2.75	45	1.02	1.33	105	106
2.75	50	0.97	1.25	100	100
2.75	55	0.91	1.17	94	94
2.75	60	0.85	1.10	88	88
2.80	40	1.10	1.43	113	114
2.80	60	0.87	1.12	90	90
2.90	40	1.14	1.48	118	118
2.90	55	0.96	1.24	99	99

TABLE 21. 18-KESAL VARIATIONS DUE TO THE AXLE FACTOR AND PERCENTAGE OF SINGLE AXLES, RIGID PAVEMENT

Axle Factor	Percent Single Axles	18-KESAL/Truck		Relative 18-KESAL (Base = 100)	
		503	505	503	505
2.10	85	0.50	0.65	35	35
2.10	95	0.33	0.42	23	22
2.20	75	0.70	0.92	49	49
2.20	95	0.34	0.44	24	23
2.40	60	1.05	1.38	74	73
2.40	75	0.76	1.00	54	53
2.40	90	0.47	0.61	33	32
2.60	50	1.35	1.78	95	95
2.60	60	1.14	1.50	80	80
2.60	70	0.93	1.22	65	65
2.70	45	1.51	1.99	106	106
2.70	65	1.07	1.41	75	75
2.75	45	1.53	2.03	108	108
2.75	50	1.42	1.88	100	100
2.75	55	1.31	1.73	92	92
2.75	60	1.20	1.59	85	85
2.80	40	1.67	2.22	118	118
2.80	60	1.22	1.62	86	86
2.90	40	1.73	2.30	122	122
2.90	55	1.39	1.83	98	97

TABLE 22. 18-KESAL VARIATIONS DUE TO THE STRUCTURAL NUMBER OF FLEXIBLE PAVEMENT

18-KESAL/Truck
(Relative Difference, Base = 100)

Structural Number

Station	2	3	4	5	6	7
501	1.25 (101)	1.24 (100)	1.20 (97)	1.18 (95)	1.19 (96)	1.19 (96)
502	0.85 (96)	0.89 (100)	0.86 (97)	0.83 (93)	0.81 (91)	0.80 (90)
503	0.92 (95)	0.97 (100)	0.94 (97)	0.90 (93)	0.88 (91)	0.87 (90)
504	1.06 (95)	1.11 (100)	1.08 (97)	1.04 (94)	1.01 (91)	1.00 (90)
505	1.24 (99)	1.25 (100)	1.21 (97)	1.18 (94)	1.18 (94)	1.18 (94)
506	1.23 (98)	1.26 (100)	1.22 (97)	1.19 (94)	1.18 (94)	1.18 (94)

Table 23 shows RDTEST68 sensitivity to the slab thickness of rigid pavements. As the slab thickness is increased from 8 inches to 11 inches, the 18-KESAL/truck factor increases. This results is conclusions are due to the form of the AASHTO rigid pavement equivalency equations rather than RDTEST68.

The 18-KESAL calculations in RDTEST68 are presently structured to handle a terminal serviceability index of 2.5 for both flexible and rigid pavements. For the purposes of this study, the internal calculations of RDTEST68 were modified in order to evaluate the sensitivity of RDTEST68 to a range of terminal serviceability specifications. The resulting 18-KESAL/truck calculations are shown in Tables 24 and 25. For an index ranging from 1.5 to 3.0, the flexible pavement 18-KESAL/truck factor increases by 7 percent for station 501 and 28 percent for station 502. For rigid pavements, the calculations indicate that the 18-KESAL/truck factor decreases as the terminal serviceability index increases, a counter-intuitive result that is due to the form of AASHTO's rigid pavement equivalency equations.

Traffic Parameters

The user-input traffic parameters for RDTEST68 include initial ADT, annual ADT growth rate, percent trucks, and design period. For all vehicles other than trucks, an average 18-KESAL/truck factor of 0.000626 is used, which is about 1600 times less than the average 18-KESAL/truck factor.

The importance of an accurate estimation of the number of trucks expected during the design period cannot be over-emphasized. For example, a specification of "10 percent trucks" instead of "20 percent trucks" would result in a total 18-KESAL forecast that is roughly half of what it should be. Based on vehicle classification data collected at over 700 stations in 1980, the percentage of trucks in the traffic stream ranged from 1.4 percent

TABLE 23. 18-KESAL VARIATIONS DUE TO THE SLAB THICKNESS OF RIGID PAVEMENT

18-KESAL/Truck
(Relative Difference, Base = 100)

	Slab Thickness (in inches)					
Station	6	7	8	9	10	11
501	1.85 (101)	1.80 (98)	1.84 (100)	1.90 (103)	1.94 (105)	1.97 (107)
502	1.33 (104)	1.31 (102)	1.28 (100)	1.35 (105)	1.36 (106)	1.37 (107)
503	1.48 (104)	1.46 (103)	1.42 (100)	1.50 (106)	1.52 (107)	1.53 (108)
504	1.65 (103)	1.62 (101)	1.60 (100)	1.67 (104)	1.69 (106)	1.70 (106)
505	1.95 (104)	1.91 (102)	1.88 (100)	2.00 (106)	2.04 (109)	2.07 (110)
506	1.90 (102)	1.86 (100)	1.86 (100)	1.94 (104)	1.97 (106)	1.99 (107)

TABLE 24. 18-KESAL VARIATIONS DUE TO THE TERMINAL SERVICEABILITY INDEX OF FLEXIBLE PAVEMENT

	18-KESAL/Truck (Relative Difference, Base = 100)			
	Terminal Serviceability Index			
Station	1.5	2.0	2.5	3.0
501	1.21 (98)	1.22 (98)	1.24 (100)	1.30 (105)
502	0.79 (89)	0.83 (93)	0.89 (100)	1.01 (113)
503	0.86 (89)	0.90 (93)	0.97 (100)	1.08 (111)
504	0.99 (89)	1.04 (94)	1.11 (100)	1.24 (112)
505	1.19 (95)	1.21 (97)	1.25 (100)	1.33 (106)
506	1.17 (93)	1.21 (96)	1.26 (100)	1.36 (108)

TABLE 25. 18-KESAL VARIATIONS DUE TO THE TERMINAL SERVICEABILITY INDEX OF RIGID PAVEMENT

18-KESAL/Truck
(Relative Difference, Base = 100)

Station	Terminal Serviceability Index 1.5	2.0	2.5	3.0
501	2.00 (109)	1.92 (104)	1.84 (100)	1.73 (94)
502	1.38 (108)	1.35 (105)	1.28 (100)	1.29 (101)
503	1.54 (108)	1.51 (106)	1.42 (100)	1.44 (101)
504	1.71 (120)	1.68 (118)	1.60 (100)	1.60 (113)
505	2.10 (112)	2.02 (107)	1.88 (100)	1.84 (98)
506	2.01 (108)	1.96 (105)	1.86 (100)	1.81 (97)

to 58.2 percent. The average was 16.8 percent, with a standard deviation of 8.6 percent.

An ADT growth factor is used by the RDTEST68 program to account for projected increases in traffic volume. However, it should always be realized that the actual growth rate in truck traffic may be higher (or lower) than the overall ADT growth rate. A higher growth rate for trucks would indicate that the "percent trucks" specification (which is assumed as a constant for the design period) should be increased. The following information (obtained from vehicle classification data) indicates that there are considerable variations:

WIM Station	Old Number	Percent 1971	Trucks 1980
501	16	13.7	17.8
502	102	19.1	36.6
503	101	11.7	23.4
504	201	20.6	27.3
505	72	17.9	16.8
506	20	19.8	34.3

An examination was also made of the relationship between the percentage of trucks and other vehicle classification data. Figure 10 shows a plot of the percentage of trucks against the percentage of single axles. Although no definite pattern exists, it appears that the percentage of trucks in the traffic stream decreases as the percentage of single axles increases. Figure 11 shows a plot of the percentage of trucks against the axle factor, and indicates a general increase in the axle factor as the percentage of trucks in the traffic stream increases.

The standard forecasting process consists of determining total design period 18-KESALs for both directions of highway. Unless directional distribution data is available, the total traffic load is divided by 2.00 in

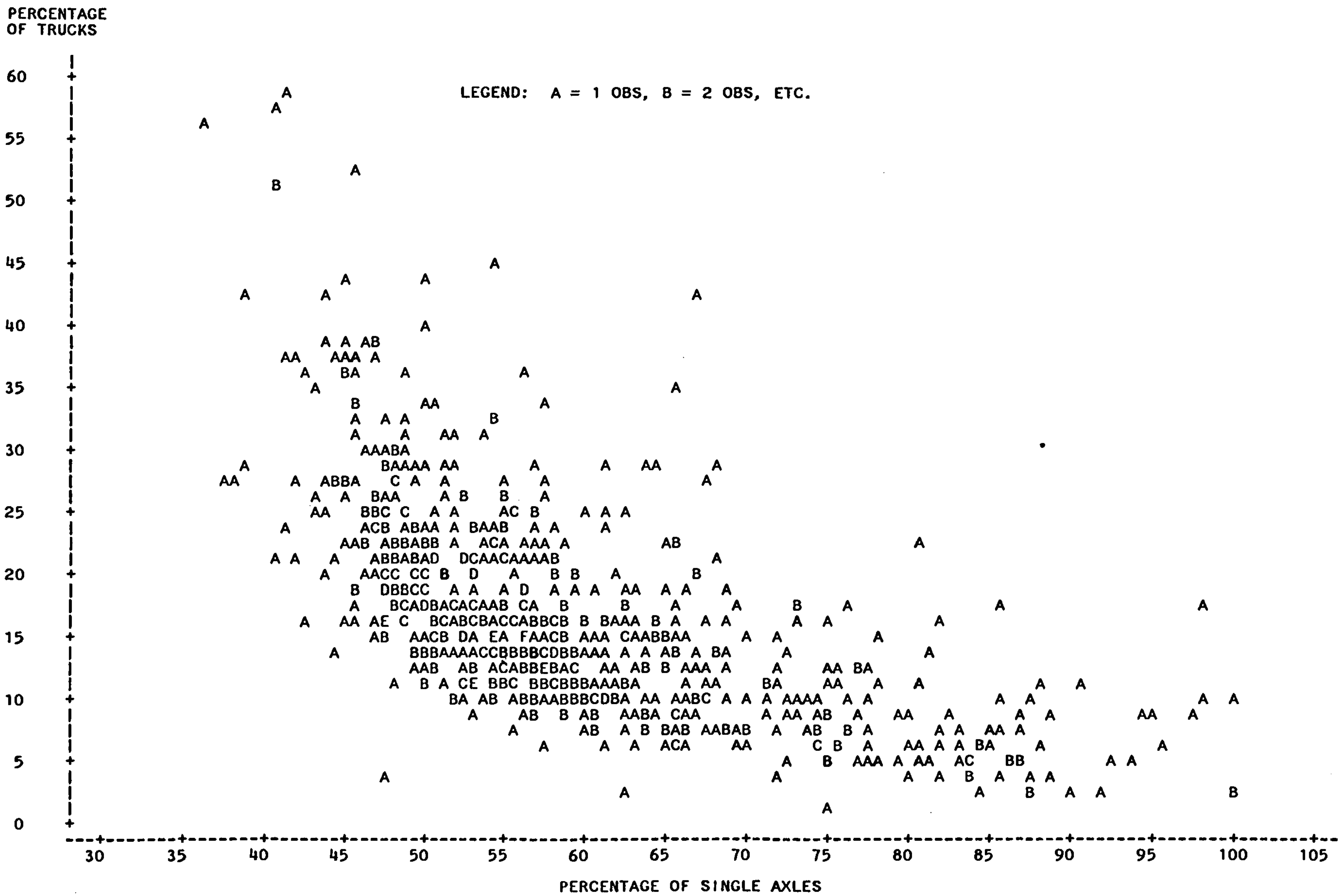


Fig 10. Percent Trucks Versus Percent Single Axles, 1980 Classification Data

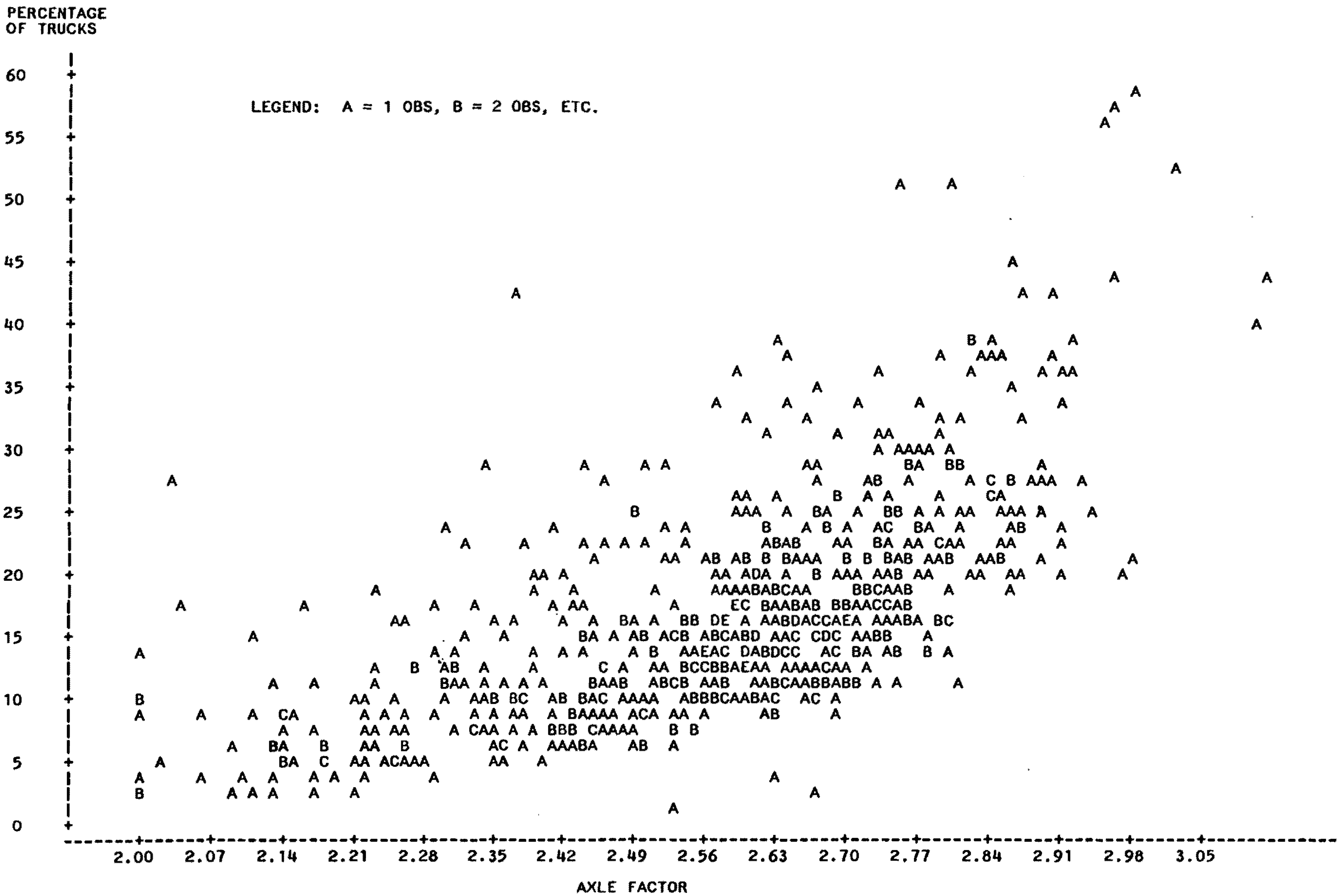


Fig 11. Percent Trucks Versus Axle Factor, 1980 Classification Data

order to obtain a directional load. If the highway has two lanes in one direction, SDHPT's normal design approach is to assume that the design lane carries 100 percent of the directional traffic.

Historical Data

The average 18-KESAL/truck factors presented in Table 11 indicate that there are substantial variations in weight data among the WIM stations. Of equal importance, however, are year-to-year variations. The best available sources for historical weight data are the W-4 and W-5 tables published each year by the FHWA. With the assumption of a terminal serviceability index of 2.5, a structural number of 5.0 (for flexible pavements) and a slab thickness of 9.0 inches (for rigid pavements), the W-4 table contains an "18-KESAL/1000 trucks" calculation for a number of truck types:

1. Single-Unit Trucks
   - 2-Axle, 6-Tire
   - 3-Axle or more,
2. Tractor-Semitrailer (multiple-unit trucks)
   - 3-Axle
   - 4-Axle
   - 5-Axle or more,
3. Semitrailer-Trailer
   - 5-Axle
   - 6-Axle, and
4. Truck-Trailer
   - 3-Axle
   - 4-Axle
   - 5-Axle or more.

In terms of the distribution of trucks weighed, the semitrailer-trailer and truck-trailer categories have historically been very small and can usually be omitted without seriously compromising a weight study.

Table 26 shows average 18-KESAL/truck data collected since 1979 at each WIM station in Texas. The yearly data was obtained from FHWA's W-4 tables (for the five major truck types) and the multi-year data was obtained from the weight program. The W-4 data indicates that there have been inconsistent year-to-year variations at each station, in some cases over 50 percent. The multi-year data used by the RDTEST68 program is probably more acceptable, for it is based on the proration of axle weight data by classification count data. The only erroneous 18-KESAL/truck factor is the 0.36 value obtained at station 501 for the 1980-1982 period (the weight data was actually obtained from pre-WIM years).

Since the RDTEST68 program operates on a "per axle" basis (i.e., the axle factor per truck is input separately), it was decided to examine all Texas weight data collected since 1965 on an "18-KESAL per axle" basis rather than on an "18-KESAL per truck" basis. An example calculation sheet (for the five major truck types) is shown in Table 27. The tables and figures in Appendix D show the 18-KESAL/axle calculations by highway system (interstate rural and other rural) for all available data from 1965 to 1983 and by WIM station for the 1976-1983 period.

Figure 12 provides a general overview of the relative damage effects of an average axle. Prior to 1976 the average 18-KESAL/axle factor was relatively stable from year-to-year. From 1974 to 1976, the 18-KESAL/axle factor increased by over 200 percent on the "interstate rural" highway system and by over 160 percent on the "other rural" highway system. Figure 13

TABLE 26. 18-KESAL/TRUCK FACTORS, 1979-1983*

	WIM Station					
	501	502	503	504	505	506
W-4 Tables						
1979	--	0.77	0.98	1.68	0.94	--
1980	--	--	0.75	1.11	1.39	1.17
1981	0.90	--	0.75	0.89	0.97	1.34
1982	0.92	0.72	0.76	1.15	0.97	1.03
1983	1.45	0.87	1.07	1.01	1.42	1.14
RDTEST68**						
1979-1981	--	0.94	0.89	1.25	1.19	1.33
1980-1981	0.36	0.83	0.98	1.16	1.13	1.03
1981-1983	1.27	0.89	0.98	1.11	1.28	1.28

*Flexible Pavement
Terminal Serviceability Index = 2.5
Structural Number = 5
Axle Factor = 2.75

**Percent Single Axles = 45.0

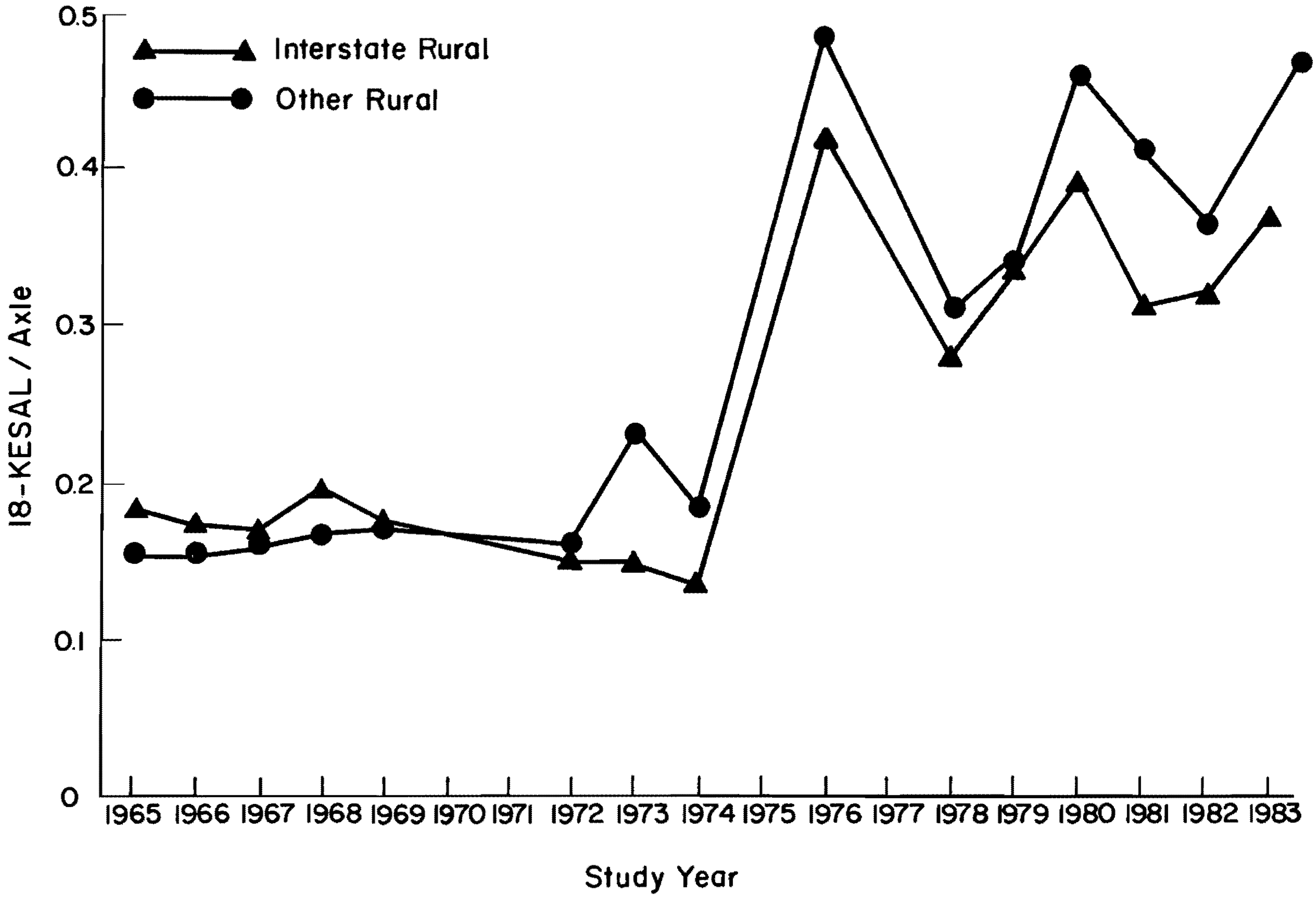


Fig 12. 18-KESAL/Axle Factors For All Truck Types, Flexible Pavement

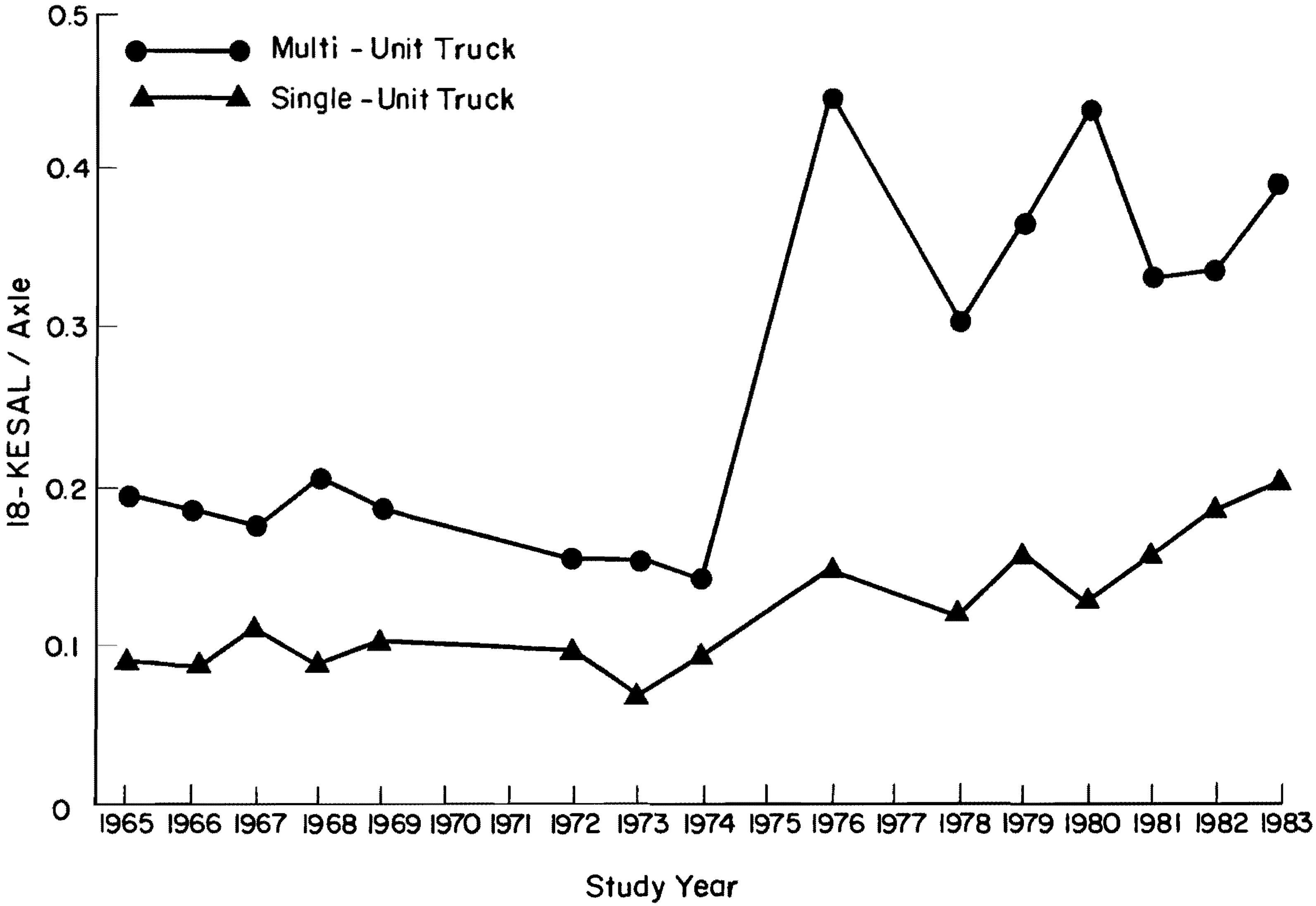


Fig 13. 18-KESAL/Axle Factors For Single-Unit and Multiple-Unit Trucks, Interstate Rural, Flexible Pavement

TABLE 27. EXAMPLES OF 18-KESAL/AXLE CALCULATIONS: RURAL INTERSTATE, 1982

	Number of Axles Single	Number of Axles Tandem	Number of Axles All	Number of Trucks	Axle Factor	Flexible Pavement* 18-KESAL Per Truck	Flexible Pavement* 18-KESAL Per Axle	Rigid Pavement** 18-KESAL Per Truck	Rigid Pavement** 18-KESAL Per Axle
Single -Unit									
2-Axle	1626	0	1626	813	2.00	0.3185	0.1592	0.3161	0.1580
3-Axle+	190	187	377	188	2.01	0.5987	0.2979	0.9320	0.4637
All	1816	187	2003	1001	2.00	0.3711	0.1856	0.4318	0.2159
Multiple -Unit									
3-Axle	273	0	273	91	3.00	0.5259	0.1753	0.5144	0.1715
4-Axle	570	287	857	286	3.00	0.7441	0.2480	0.8261	0.2754
5-Axle+	4157	8159	12316	4090	3.01	1.0518	0.3494	1.7646	0.5862
All	5000	8446	13446	4467	3.01	1.0214	0.3393	1.6790	0.5578
Total	6816	8633	15449	5468	2.83	0.9024	0.3189	1.4507	0.5126

*Structural Number = 5.0
Terminal Serviceability Index = 2.5

**Slab Thickness = 9.0 inches
Terminal Serviceability Index = 2.5

indicates that most of this increase was caused by multiple-unit trucks. Figure 14 shows, for rigid pavements, an increase from 1974 to 1976 of over 240 percent.

There are a number of possible explanations for this substantial increase in the average 18-KESAL/axle factor since 1974. For example, in 1975 the Texas Truck Weight Survey program was changed from a "stop-and-weigh" operation to a weigh-in-motion operation. It was also in 1975 that the legal weight limits in Texas were increased: from 18,000 to 20,000 pounds for single axles, 32,000 to 34,000 pounds for tandem axles, and 72,000 to 80,000 pounds for the gross vehicle weight. However, even though the legal weight limits were increased, the available weight data indicates that the percentage of overweight truck movements in Texas increased from 7.8 percent in 1974 to 26.3 percent in 1976.

Due to the energy crisis of the 1970's, the subsequent increase in fuel costs, and the lowering of the speed limit to 55 mph, truck operating costs per mile have increased. It is possible that the increased 18-KESAL/axle factor is a result of the trucking industry's desire to increase the amount of cargo hauled per mile by reducing empty backhauls, operating only at (or near) full capacity, and overloading.

If the data shown in Figures 12-14 accurately represent truck loadings in Texas from 1965 to 1983, traffic load forecasts made in the 1960's and early 1970's were probably too low. The significance of these underprojections to pavement design, however, depends on whether the error has been compounded by an under-estimate of the <u>number</u> of trucks expected during the design period. SDHPT's standard design practice of assigning 100 percent of the total projected 18-KESALs per direction of a roadway to the design lane has helped to reduce this potential problem.

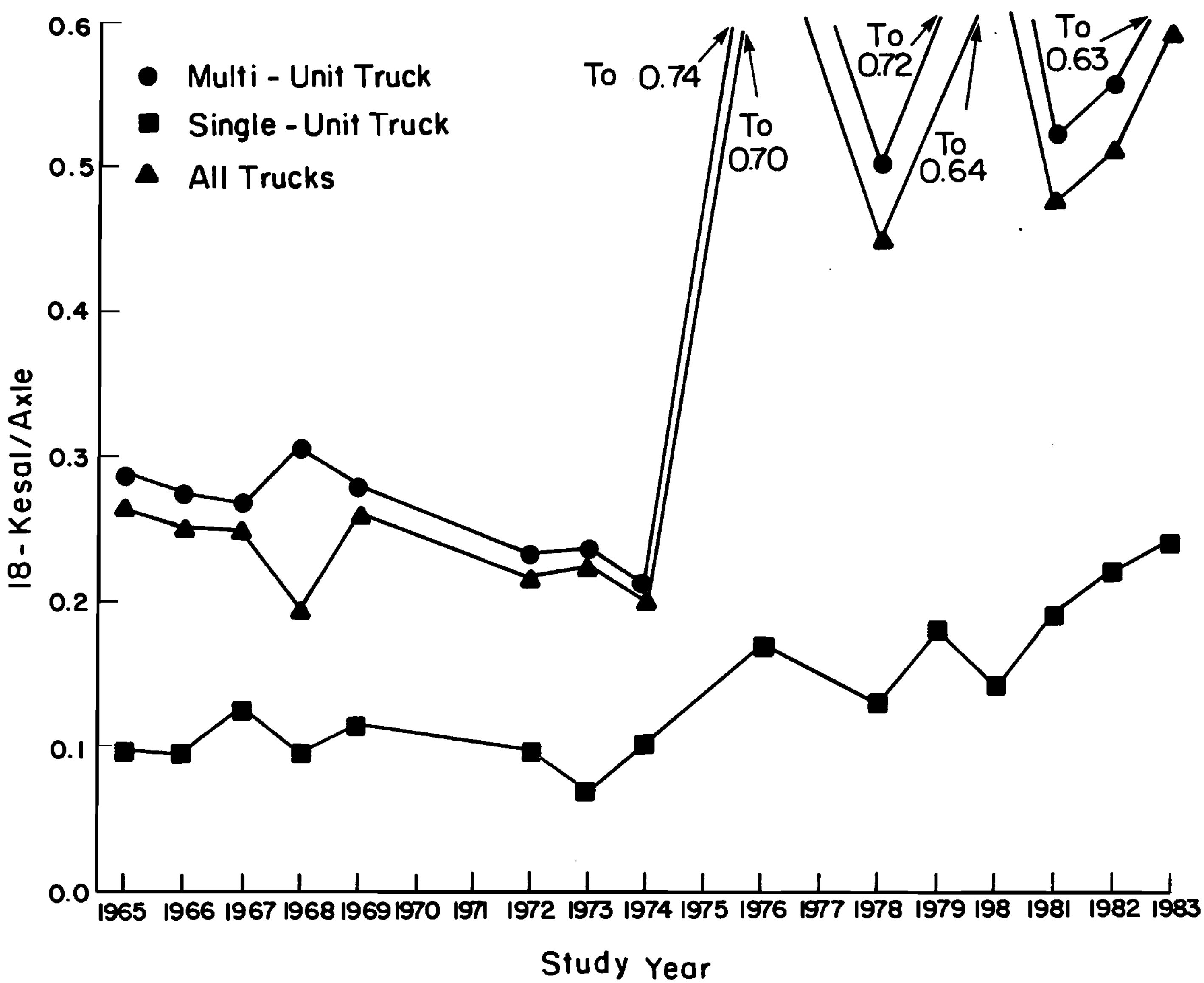


Fig 14. 18-KESAL/Axle Factors For Single-Unit and Multiple-Unit Trucks, Interstate Rural, Rigid Pavement

Figure 15 shows distributions of the five major truck types weighed since 1960. The most obvious trend is the steady increase (from 1960 to 1974) in the percentage of trucks of the 5-axle multiple-unit type. Table 28 compares the distribution of truck types weighed with the distribution of truck types actually counted in 1983, by WIM station.

Figure 16 shows that, from 1960 to 1976, the percentage of single axles weighed has gradually decreased. Since 1976, however, the percentage has appeared to stabilize. The data in Table 29 show the percentage of single axles weighed from 1976 to 1983, by WIM station. Figure 17 shows the average axle factor, by highway system, from 1960 to 1983. Table 30 shows the average axle factor, by WIM station, from 1976-1983. The present factors range from 2.74 to 2.89.

<u>Equivalencies by Truck Type</u>

An alternative forecasting procedure, outlined in Appendix E, consists of the use of average 18-KESAL factors by truck type. Tables 31 and 32 display multi-year 18-KESAL truck averages (by highway system) for the five truck types. Table 33 shows multi-year averages by WIM station. Even when 18-KESAL/truck factors are examined by truck type, there are still considerable variations among the WIM stations. For example, the average 18-KESAL/truck factor for the 5-axle multiple-unit truck varies from 0.95 (station 502) to 1.45 (station 505).

<u>Sensitivity to Pavement Design</u>

Traffic load forecasts in Texas are performed for one purpose: to provide data needed for the design of flexible and rigid pavements. Table 34 provides an indication of the sensitivity of SDHPT's flexible pavement design procedure to an 18-KESAL forecast. In terms of the total depth of cover, a

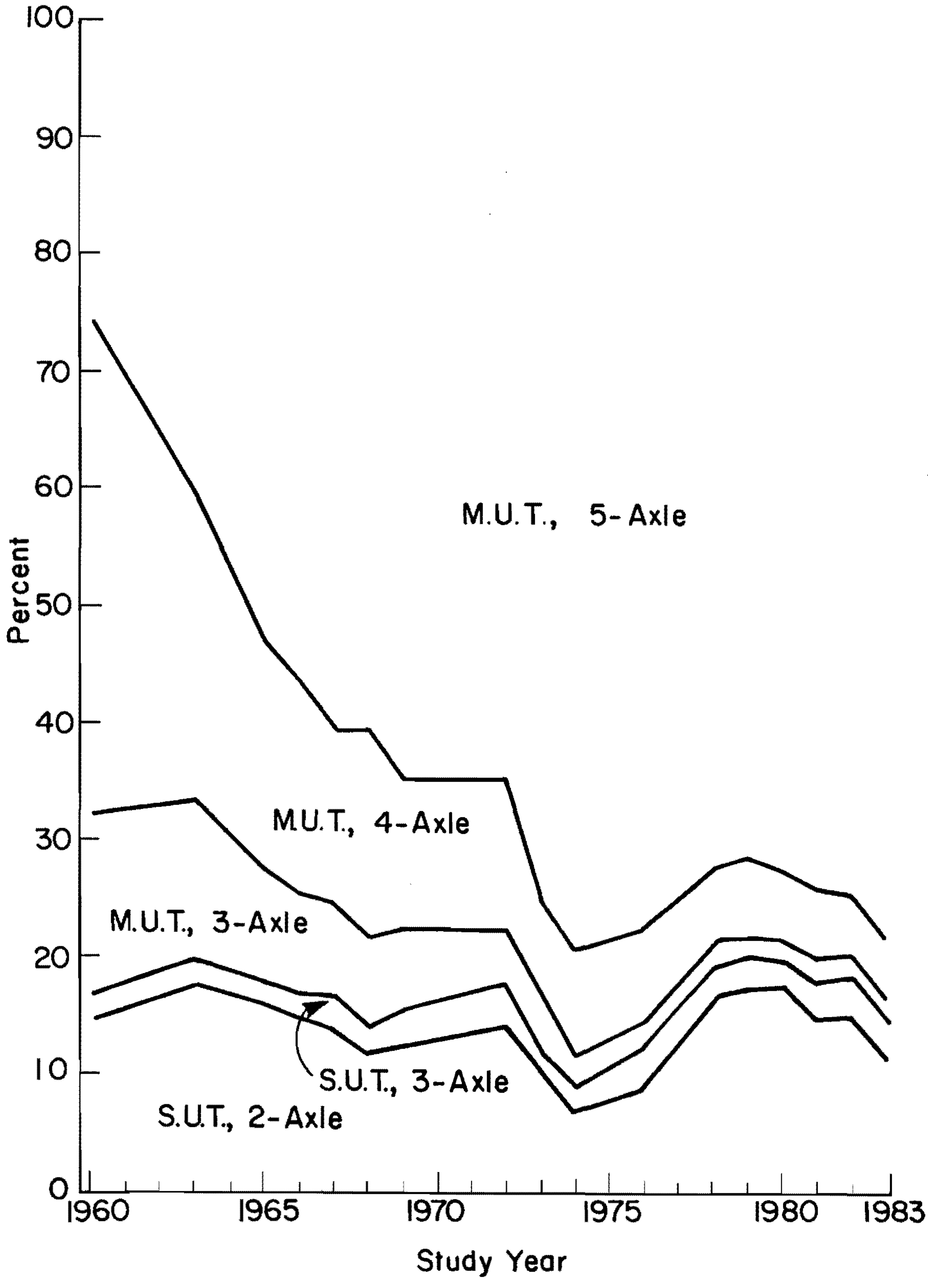


Fig 15. Distribution of Truck Types, Interstate Rural, 1960-1983

TABLE 28. VEHICLE CLASSIFICATION BREAKDOWNS, 1983 WIM DATA

Percentage Distributions, Weight Data
(Percentage Distributions, Count Data)

	Single-Unit		Multiple-Unit		
Station	2-Axle	3-Axle	3-Axle	4-Axle	5-Axle
501	21.6 (20.9)	5.5 (4.4)	1.8 (3.2)	3.7 (5.9)	67.4 (65.6)
502	11.6 (15.7)	3.7 (2.7)	2.0 (1.6)	6.4 (5.2)	76.3 (74.8)
503	9.8 (16.2)	2.4 (2.0)	1.4 (1.0)	3.7 (4.3)	82.7 (76.5)
504	9.5 (13.0)	2.8 (2.9)	1.9 (1.7)	4.3 (4.8)	81.5 (77.6)
501-504	11.2 (15.6)	3.3 (2.9)	1.8 (1.8)	4.9 (5.0)	78.8 (74.7)
505	15.6 (16.6)	4.7 (2.7)	1.8 (1.3)	4.6 (3.1)	73.3 (76.3)
506	13.2 (13.9)	3.5 (2.1)	1.5 (0.8)	3.8 (6.1)	78.0 (77.1)
505-506	14.5 (15.4)	4.1 (2.4)	1.7 (1.0)	4.2 (4.5)	75.5 (76.7)
501-506	12.1 (15.5)	3.5 (2.7)	1.8 (1.5)	4.7 (4.9)	77.9 (75.4)

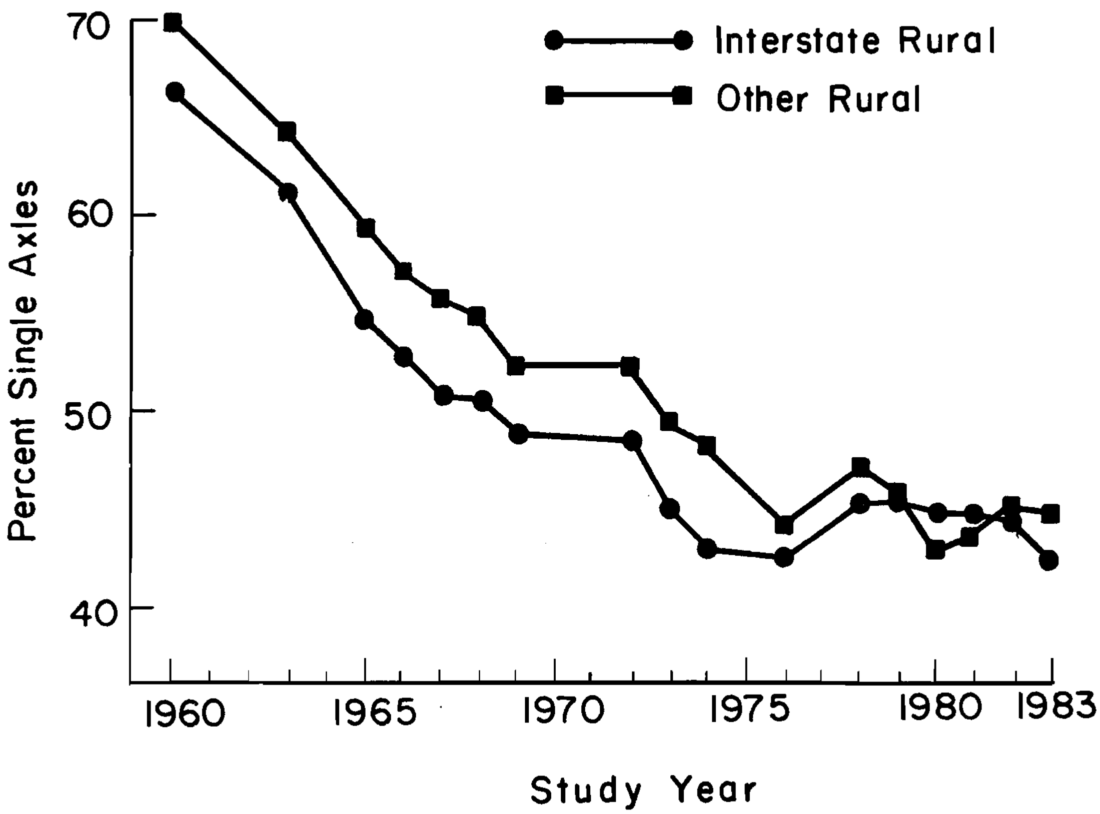


Fig 16. Percentage of Single Axles, 1960-1983

TABLE 29. PERCENTAGE OF SINGLE AXLES, FHWA DATA, 1976-1983

	WIM Station					
	501	502	503	504	505	506
1976	--	41.9	43.4	--	44.1	--
1978	--	43.0	49.1	44.6	49.2	45.6
1979	--	43.4	45.8	48.9	45.8	--
1980	--	--	41.7	46.2	43.1	42.7
1980*	52.0	45.5	50.0	48.1	46.8	45.9
1981	47.7	--	44.6	43.2	43.8	43.2
1982	46.4	44.5	44.1	42.6	44.8	44.3
1983	47.5	43.2	40.8	41.4	45.4	44.0

*From classification count data

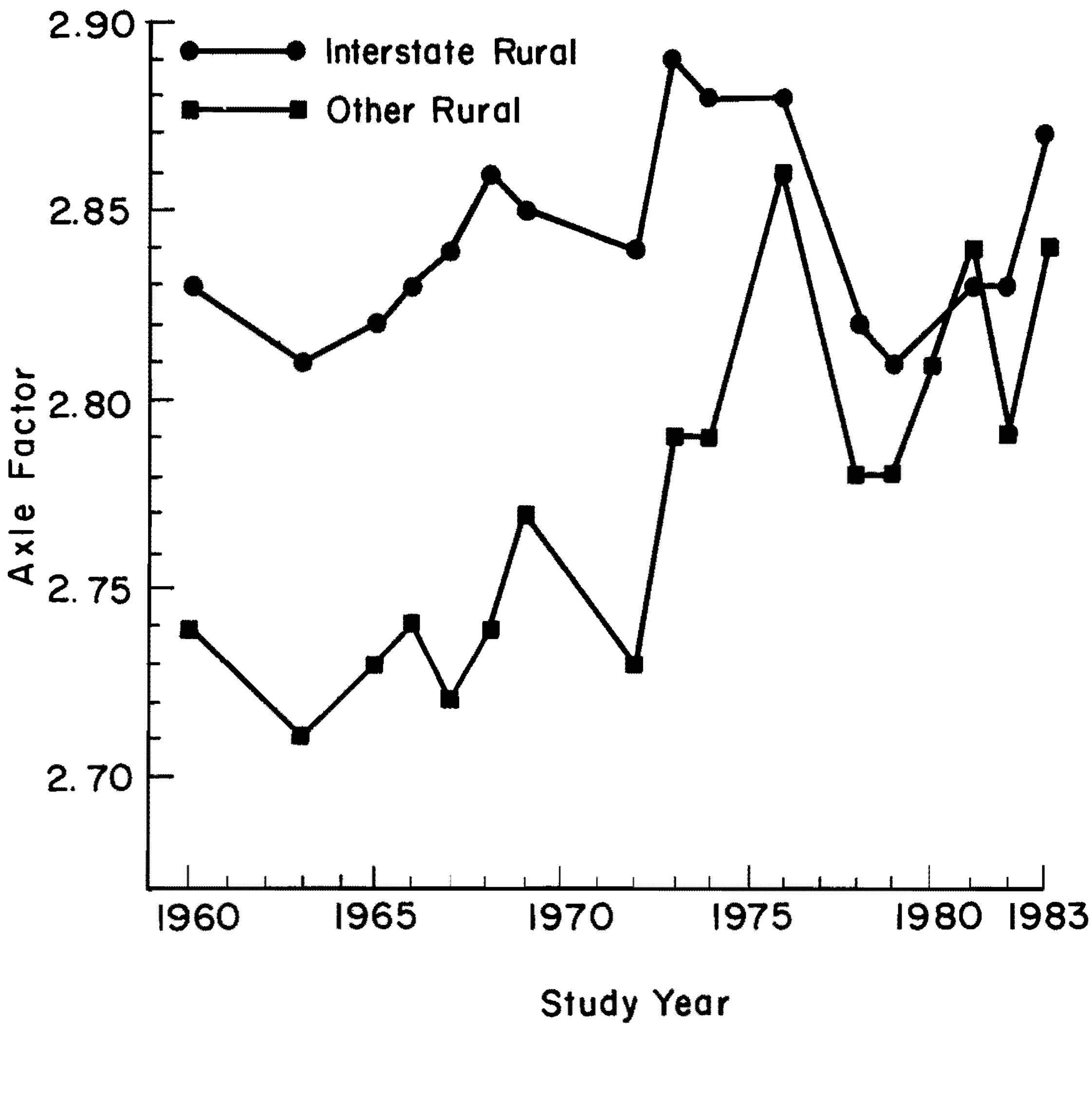


Fig 17. Axle Factors, 1960-1983

TABLE 30. AXLE FACTORS, FHWA DATA, 1976-1983

WIM Station

	501	502	503	504	505	506
1976	--	2.89	2.86	--	2.86	--
1978	--	2.85	2.77	2.85	2.77	2.78
1979	--	2.85	2.80	2.75	2.78	--
1980	--	--	2.86	2.79	2.78	2.83
1980*	2.71	2.91	2.81	2.84	2.80	2.91
1981	2.75	--	2.85	2.85	2.86	2.82
1982	2.78	2.82	2.83	2.85	2.81	2.78
1983	2.74	2.86	2.89	2.89	2.82	2.87

*From classification count data

TABLE 31. 18-KESAL FACTORS BY TRUCK TYPE, FLEXIBLE PAVEMENT

	1976-1983		1980-1983		1982-1983	
	IR*	OR*	IR	OR	IR	OR
Single-Unit						
2-Axle	0.28	0.29	0.29	0.24	0.34	0.24
3-Axle+	0.48	0.71	0.57	0.89	0.57	0.83
All	0.31	0.41	0.34	0.43	0.39	0.40
Multiple-Unit						
3-Axle	0.64	0.72	0.67	0.79	0.59	0.86
4-Axle	0.83	0.91	0.90	0.84	0.72	0.86
5-Axle+	1.16	1.36	1.15	1.43	1.12	1.41
All	1.13	1.32	1.13	1.39	1.10	1.37
Total	0.99	1.14	0.99	1.20	0.98	1.18

*IR = Interstate Rural

*OR = Other Rural

TABLE 32. 18-KESAL FACTORS BY TRUCK TYPE, RIGID PAVEMENT (INTERSTATE RURAL)

	1976-1983	1980-1983	1982-1983
Single-Unit			
2-Axle	0.28	0.29	0.35
3-Axle+	0.74	0.88	0.88
All	0.36	0.39	0.46
Multiple-Unit			
3-Axle	0.63	0.66	0.58
4-Axle	0.93	1.02	0.80
5-Axle+	1.96	1.93	1.88
All	1.84	1.83	1.79
TOTAL	1.59	1.57	1.57

TABLE 33. 18-KESAL FACTORS BY TRUCK TYPE AND WIM STATION, FLEXIBLE PAVEMENT

	WIM Station					
	501	502	503	504	505	506
Single-Unit						
2-Axle	0.45	0.33	0.18	0.31	0.26	0.23
3-Axle+	0.73	0.37	0.36	0.74	0.80	0.80
All	0.50	0.34	0.21	0.40	0.47	0.39
Multiple-Unit						
3-Axle	0.55	0.43	0.48	0.83	0.58	1.06
4-Axle	0.98	0.62	0.56	1.06	0.86	0.84
5-Axle+	1.33	0.95	1.02	1.26	1.45	1.42
All	1.30	0.92	0.98	1.22	1.40	1.39
TOTAL	1.09	0.82	0.86	1.08	1.22	1.20

TABLE 34. VARIATIONS IN DEPTH OF COVER DUE TO 18-KESALS

18-KESALs		Depth of Cover*	
Total	Relative Difference (Base = 100)	(in inches)	Relative Difference (Base = 100)
2,500,000	50	11	83
3,500,000	70	12	91
4,000,000	80	12.5	95
5,000,000	100	13.2	100
6,000,000	120	13.7	104
7,500,000	150	14.2	108
10,000,000	200	15.0	114

*Based on the Texas Flexible Design Chart

50 percent overestimate in an 18-KESAL forecast would result in an overall design error of less than 10 percent. A 50 percent underestimate would result in an overall design error of less than 20 percent.

CHAPTER 7. SUMMARY AND RECOMMENDATIONS

The major objective of this study is to evaluate SDHPT's current traffic load forecasting procedure and suggest possible improvements. Accurate 18-KESAL forecasts are important because the information is used for the design of new and rehabilitated pavements.

Background

Chapter 2 contains a description of three items: general pavement design principles, the AASHO Road Test of the late 1950's and early 1960's, and the Texas Truck Weight Survey Program (TWS). While it is true that pavements deteriorate over time due to environmental (i.e., non-load) factors, most of the pavement deterioration on Texas highways is a result of the passage of heavy traffic. Despite the many criticisms of the AASHO Road Test, the study represents the most significant effort to date to determine the effects of various axle weights on flexible and rigid pavements.

Although gross vehicle weights are important to the design of bridge structures, pavement design is based on the projection of single and tandem axle loads. As shown in Figure 1, the relative damage or "pavement wear" caused by an axle increases exponentially as the load is increased. Supplemental information provided in Appendix A shows that the pavement wear caused by a heavy truck, in which the gross vehicle weight is spread over a large number of axles, may actually be lower than that caused by a lighter truck with fewer axles.

The TWS program has undergone a number of changes over the last 20 years. In the 1960's, trucks were stopped and weighed at 21 loadometer stations. By the early 1970's, the number of manual stations was reduced to ten. Since 1975, all truck weighing (for survey purposes) has been accomplished by means of a weigh-in-motion (WIM) system. Although over 28,000 trucks were weighed in 1965, the average number of trucks weighed from 1970 to 1981 was less than 5,000 per year. In 1983, however, 15,000 trucks were weighed at six WIM stations.

Previous Studies

Other weight-related studies conducted in Texas are reviewed in Chapter 3. All of the studies emphasize the need for statistically reliable axle weight data at a number of different locations. Although 18-KESAL projections are normally used for the design of individual roadway segments, Texas weight data is also used (in the RENU computer program) to estimate statewide pavement rehabilitation requirements.

The Texas Forecasting Procedure

The traffic load forecasting procedure currently used in Texas is describe in Chapter 4 and Appendix B. Since 1968, the computer program known as RDTEST68 (Road Test 68) has been used to0 calculate total 18-KESALs per direction of a highway. The various input specifications are shown in Figure 6.

One of the key assumptions of RDTEST68 is the selection of an axle weight distribution table that might be representative of the traffic load pattern at a particular highway segment. The six weight tables currently available (one for each WIM station) are based on data collected from 1981 to 1983. The general guidelines followed by D-10 personnel are to select a WIM station that appears to be similar to a particular highway segment in terms of traffic characteristics such as the percentage of trucks, the average daily traffic, and the type of highway.

Other States

The traffic load forecasting procedures used in other states are described in Chapter 5 and Appendix C. Much of the information was obtained from the 38 responses to a questionnaire mailed to all states in November of 1983. The objective was to determine how the procedures used in other states differ from the Texas procedure.

Of the 27 states shown in Table 8, Texas has the lowest number of weigh stations. Although most states still weigh trucks manually, the trend has been to switch (at least partially) to WIM operations. While the majority of states weighed less than 5,000 vehicles a year, Virginia weighed more than 7 million vehicles in 1982.

Most state's incorporate AASHTO's 18-KESAL equations (or factors) in their load forecasting procedures. However, the methods for aggregating the available axle weight data vary considerably. Some states (including Texas) utilize multi-year weight data collected at a "representative" station, while other states aggregate all data on a statewide basis or by highway system. In many cases, traffic projections are made by truck type rather than simply by truck. In order to determine the total traffic load contribution by truck type, the number of trucks of a particular truck type is then multiplied by the appropriate 18-KESAL/truck factor.

Evaluation

An evaluation of the Texas forecasting procedure is provided in Chapter 6. Supplemental information relating to truck weight data collected in Texas since 1965 is displayed in Appendix D. In order to perform sensitivity analyses, the RDTEST68 program was set up to calculate an average 18-KESAL factor per individual truck. The analysis consisted of changing one of the RDTEST68 input specifications while holding all others constant.

One important user specification is the weight distribution table developed from a "representative" WIM station. For both flexible and rigid pavements, the average 18-KESAL/truck factor varies by more than 40 percent, depending on which station is selected.

A ten percent increase in the "percent single axles" specification causes about a five percent decrease in the 18-KESAL/truck factor for flexible pavements and an eight percent decrease for rigid pavements. A change in the axle factor, however, causes a directly proportional change: a ten percent increase in the axle factor causes a ten percent increase in the 18-KESAL/truck factor. Variations due to the terminal serviceability index, the structural number (for flexible pavements), and the slab thickness (for rigid pavements) were found to be small.

Even more important than the selection of a weight distribution table, perhaps, is the forecast of the number of trucks expected during the design period. Since passenger cars cause relatively little pavement wear, a 50 percent underestimate of the percentage of trucks in the traffic stream reduces the total 18-KESAL forecast by almost 50 percent.

An evaluation of all weight data collected in Texas since 1965 revealed some interesting trends. From 1965 to 1974, the average 18-KESAL/axle factor remained fairly constant. But from 1974 to 1976, the average equivalency factor more than doubled. Since 1976, the average equivalency factors have varied not only from year to year but from station to station. Average equivalency factors by truck type have also shown significant variations.

An underdesigned facility could lead to the need for major unanticipated repairs. An overdesigned facility, however, ties up monies badly needed for other projects. The final evaluation of this study consisted of a determination of the sensitivity of 18-KESAL forecasts to the design of flexible pavements. In terms of the depth of cover required, a 50 percent overestimate in a traffic load forecast appears to cause a pavement design error of about 10 percent (one inch). A 50 percent underestimate would result in a pavement design error of about 20 percent (two inches).

Near-Term Recommendations

Given the present quality of weight data available in Texas, substantial modifications to SDHPT's current traffic load forecasting procedure are probably not warranted. Minor changes, however, would help to increase the highway engineer's confidence with the 18-KESAL forecasts and improve overall reliability. One important concern is to eliminate the concept of a "black box" approach to forecasting.

One aspect of the forecasting model often hidden from view is the impact of the weight data. Since the selection of a representative weight table is very important, program users should always be aware of its overall effect. The RDTEST68 program should be modified so that the average 18-KESAL/truck factor is calculated and displayed for every computer run. This would give planners and engineers a better understanding of the assumptions involved in traffic load estimates. The calculation would not only provide a good historical record but would serve as an excellent means of comparing alternative RDTEST68 runs. Statistical summaries of the available weight data should be prepared each year in order to identify significant trends in traffic loadings.

It is appropriate for the forecasting model to be run by SDHPT's Transportation Planning Division (D-10) since it requires the accurate specification of traffic data such as vehicle volumes, truck percentages, and growth factors. However, district engineers should be given a greater opportunity to evaluate and comment on these parameters. Standard practice is to assume that a "percent trucks" number determined from current vehicle classification data at a highway segment will remain valid over the entire design period. A more reliable approach would be to estimate future truck percentages by means of trend-line analyses. In addition, care should be taken to ensure that the "percent trucks" number applies only to those truck types actually weighed (i.e., pickup trucks are excluded).

RDTEST68 calculates total 18-KESALs for a highway segment and divides the number by two in order to obtain 18-KESALs per direction. Since weight data is now being collected by lane, improved lanewise traffic load distributions can be utilized. At the present time, it is probably adequate to base 18-KESAL calculations on two specific pavement types: flexible pavement (structural number = 3.0, terminal serviceability index = 2.5) and rigid pavement (slab thickness = 8 inches, terminal serviceability index =2.5). If the effects of such items as tire pressures and the lateral placement of trucks within a traffic lane can be quantified, the 18-KESAL factors can be modified accordingly.

For highway segments exposed to considerable amounts of unusual or "special use" truck traffic, the RDTEST68 program should not be used. Instead, the traffic load forecast should be based on the application of average 18-KESAL factors by truck type.

Long-Term Recommendations

SDHPT's current efforts to improve and expand the Texas TWS program should be continued. Weight data is used not only to make individual traffic load forecasts but to estimate long-term statewide rehabilitation needs. An effective weighing program for Texas would probably consist of about 15 permanent WIM stations on rural highways, plus two or three additional weighing locations in urban areas.

As the quantity (and quality) of vehicle weight and classification data increase over the next few years, SDHPT may want to consider an alternative traffic load forecasting procedure. One possible alternative, which makes better use of vehicle classification data than the current procedure, is described in Appendix E.

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APPENDIX A

18-KESAL CALCULATIONS

APPENDIX A. 18-KESAL CALCULATIONS

Definitions:

EF = Equivalency (18-KESAL) Factor

LOG = Base 10 Logarithm

^ = Exponent (i.e., 2 ^ 3 = 8)

PT = Terminal Serviceability Index

SN = Structural Number (Flexible Pavement)

D = Slab Thickness (Rigid Pavement), in Inches

L = Axle Load, in Thousands of Pounds

Flexible Pavement

B18 = 0.40 + 1094/[(SN + 1) ^ 5.19]

GT = LOG [(4.2 - PT)/2.7]

Single Axles:

BL = 0.40 + 0.081 ([(L + 1) ^ 3.23]/[(SN +1) ^ 5.19]

LOG (EF) = - 6.125 + 4.79 [LOG(L + 1)] - GT/BL + GT/B18

EF = 10 ^ [LOG (EF)]

Tandem Axles:

BL = 0.40 + 0.081 [(L + 2) ^ 3.23]/[([SN +1] ^ 5.19)(9.383)]

LOG (EF) = - 7.428 + 4.79 [LOG (L +2)] - GT/BL + GT/B18

EF = 10 ^ [LOG (EF)]

Rigid Pavement

B18 = 1.00 + 16240000/[(D + 1) ^ 8.46]

GT = LOG [(4.5 - PT)/3]

Single Axles:

BL = 1 + [3.63 ([L + 1] ^ 5.2)]/[(D + 1) ^ 8.46]

LOG (EF) = - 5.908 + 4.62 [LOG (L + 1)] - GT/BL + GT/B18

EF = 10 ^ [LOG (EF)]

Tandem Axles:

BL = 1 + [3.63 ([L +2] ^ 5.2)]/[([D + 1] ^ 8.46) (11.472)]

LOG (EF) = - 6.895 + 4.62 [LOG (L + 2)] - GT/BL + GT/B18

EF = 10 ^ [LOG (EF)]

Examples

1. Flexible Pavement

PT = 2.5

SN = 3.0

Tandem Axle Load = 30,000 pounds

B18 = 0.40 + 1094/[(3 + 1) ^ 5.19]

= 1.22097

GT = LOG [(4.2 - 2.5)/2.7]

= - 0.20091

BL = 0.40

+ 0.081 [(30 + 2) ^ 3.23]/[([3 + 1] ^ 5.190)(9.383)]

= 0.87107

LOG (EF) = - 7.428 + 4.79 [LOG (30 + 2)]

+ 0.20091/0.87107 - 0.20091/1.22097

= - 0.15223

EF = 10 ^ (- 0.15223)

= 0.704

2. Rigid Pavement

PT = 2.5

D = 6

Tandem Axle Load = 30,000 pounds

B18 = 1.00 + 16240000/[(6 + 1) ^ 8.46]

= 2.15095

GT = LOG [(4.5 - 2.5)/3]

= - 0.176091

BL = 1 + [3.63 ([30 + 2]5.2)]/[(D + 1] ^ 8.46)(11.472)]

= 2.50494

LOG (EF) = - 6.895 + 4.62 [LOG (30 + 2)] + 0.176091/2.50494 - 0.176091/2.15095

= 0.04722

EF = 10 ^ (0.04722)

= 1.115

Typical Truck Types

Tables A.1 and A.2 show axle weights and 18-KESAL/truck factors for some typical truck types. It was assumed in these calculations that the front steering axle could be treated as a regular single axle. The importance of examining axle weights rather than only gross vehicle weights can be noted from the fact that a 100,000-pound 3-S1-2 causes relatively less pavement wear than an 80,000-pound 2-S2.

TABLE A.1. TYPICAL AXLE WEIGHT DISTRIBUTIONS

	Weight, in Thousands of Pounds							
Truck Type	Single Axles 1	2	3	4	5	Tandem Axles 1	2	Gross Vehicle Weight
2D	10	20	0	0	0	0	0	30
	14	26	0	0	0	0	0	40
3A	12	0	0	0	0	28	0	40
	12	0	0	0	0	38	0	50
2-S1	8	16	16	0	0	0	0	40
	10	20	20	0	0	0	0	50
2-S2	8	12	0	0	0	20	0	40
	8	16	0	0	0	26	0	50
	14	24	0	0	0	42	0	80
3-S2	10	0	0	0	0	20	20	50
	12	0	0	0	0	34	34	80
	14	0	0	0	0	43	43	100
2-S1-2	8	10	12	10	10	0	0	50
	10	18	18	17	17	0	0	80
	12	22	22	22	22	0	0	100
3-S1-2	6	10	10	10	0	14	0	50
	8	16	16	16	0	24	0	80
	10	20	20	20	0	30	0	100

TABLE A.2. EQUIVALENCIES FOR TYPICAL TRUCKS

Truck Type	Gross Vehicle Weight, Pounds	18-KESAL/Truck* Flexible Pavement	18-KESAL/Truck* Rigid Pavement
2D	30,000	1.60	1.63
	40,000	4.45	4.77
3A	40,000	0.68	1.03
	50,000	1.89	3.09
2-S1	40,000	1.28	1.25
	50,000	3.11	3.17
2-S2	40,000	0.34	0.42
	50,000	1.02	1.27
	80,000	5.91	7.87
3-S2	50,000	0.33	0.51
	80,000	2.38	3.92
	100,000	5.86	9.77
2-S1-2	50,000	0.49	0.47
	80,000	3.68	3.66
	100,000	8.92	9.28
3-S1-2	50,000	0.30	0.31
	80,000	2.16	2.31
	100,000	5.29	5.85

* Terminal Serviceability Index = 2.5
Structural Number = 5.0
Slab Thickness = 8 inches

APPENDIX B

MANUAL EXAMPLE OF THE RDTEST68 CALCULATIONS

APPENDIX B. MANUAL EXAMPLE OF THE RDTEST68 CALCULATIONS

User Input Specifications

Selection of a Weight Distribution Table:

- WIM Station #501, on IH-27 (north of Lubbock)
- Aggregation of data collected in 1981, 1982, and 1983

Present ADT: 10,000 vehicles/day

Growth Rate: 5 percent/year

Design Period: 20 years

Percent Trucks: 10

Percent Single Axles: 40

Axle Factor: 2.75

Structural Number: 3

Slab Thickness: 8

Calculation Sequence (Flexible Pavement)

1. Calculate average ADT over the design period.

AVGADT = [ADT & ADT (1 + [Growth Rate][Design Period])]/2

= [10000 + 10000 (1 + [0.05][20])]/2

= [10000 + 20000]/2

= 15000

2. Calculate average number of daily car axles.

AXLEC = [AVGADT - (AVGADT)(Percent Trucks)][2]

= [15000 - 15000 (0.10)][2]

= [15000 - 1500][2]

= 27000

3. Calculate average number of daily truck axles.

AXLET = [(Axle Factor) (AVGADT)(Percent Trucks)]

= [2.75 (15000)(0.10)]

= 4.125

4. Calculate total 18-KESALs for cars (over the design period).

CARTOF = (AXLEC) (0.000313 18-KESALs/car axle)

x (365 days/year)(Design Period)

= (27000)(0.000313)(365)(20)

= 61,692

5. Determine 18-KESAL factors for each of 55 single axle weight groups and 55 tandem axle weight groups.

   a. For structural number = 3 and slab thickness = 8, the 18-KESAL factors are determined externally from RDTEST68 and input into the program.

   b. For any other structural number or slab thickness, RDTEST68 utilizes the AASHTO equivalency equations to calculate the appropriate 18-KESAL factors. An average weight is used for each axle weight group. For example, the calculated 18-KESAL factor for the single axle weight group from 10,950 to 11,949 pounds is based on an average axle load of 12,000 pounds.

6. Calculate total annual 18-KESALs for trucks by axle weight group.

The calculations for each weight group (shown on Table B.1) consist of the following: (Percent of Total Axles)(Adjustment Factor) x (18-KESAL Factor)(AXLET)(365 days/year). There are two "adjustment" factors: one for each single axle weight group and one for each tandem axle weight group. In this example, the initial weight table has 49.912 percent single axles. Since the value for the highway segment is actually 40.0 percent, the percentage of single axles in each weight group is adjusted by a factor of (40.0/49.912) = 0.80141. The adjustment factor for tandem axles would be (60.0/[100 - 49.912]) = 1.19789.

7. Calculate total 18-KESALs for trucks (over the design period).

TRKTOF = (Total Annual 18-KESALs)(Design Period)

= (750470)(20)

= 15,009,400

8. Calculate total 18-KESALs for all vehicles, two directions.

GRNDTO = CARTOF + TRKTOF

= 61,692 + 15,009,400

= 15,071,092

9. Calculate total 18-KESALs for all vehicles, one direction.

HGRAND = GRNDTO/2

= 15,071,092/2

= 7,535,566 = 7,536,000 18-KESALs

The RDTEST68 computer output for this example problem was shown earlier in Figure 5.

TABLE B.1. 18-KESAL CALCULATIONS BY AXLE WEIGHT GROUP

SINGLE AXLES

Upper Weight Limit (Pounds)	Initial Distrib. (%/100)	Adjust. Factor	18-KESAL Factor	AXLET	Days/ Year	Total Annual 18-KESALs
2,000	0.00213	0.80141	0.000313	4125	365	0.8
3,000	0.00419	0.80141	0.001230	4125	365	6.2
4,000	0.01625	0.80141	0.003525	4125	365	69.1
5,000	0.02344	0.80141	0.008244	4125	365	233.2
6,000	0.02729	0.80141	0.016698	4125	365	549.8
7,000	0.03268	0.80141	0.030369	4125	365	1,197.5
8,000	0.04978	0.80141	0.050746	4125	365	3,048.1
9,000	0.07460	0.80141	0.079336	4125	365	7,141.4
10,000	0.09291	0.80141	0.117557	4125	365	13,179.0
11,000	0.07161	0.80141	0.166857	4125	365	14,417.5
12,000	0.03413	0.80141	0.228821	4125	365	9,423.3
13,000	0.01890	0.80141	0.305305	4125	365	6,962.5
14,000	0.01069	0.80141	0.398540	4125	365	5,140.7
15,000	0.00710	0.80141	0.511211	4125	365	4,379.6
16,000	0.00761	0.80141	0.646488	4125	365	5,936.3
17,000	0.00496	0.80141	0.808051	4125	365	4,836.1
18,000	0.00248	0.80141	1.000093	4125	365	2,992.7
19,000	0.00419	0.80141	1.227323	4125	365	6,205.0
20,000	0.00308	0.80141	1.494970	4125	365	5,555.9
21,000	0.00325	0.80141	1.808788	4125	365	7,093.2
22,000	0.00136	0.80141	2.175066	4125	365	3,569.3
23,000	0.00231	0.80141	2.600640	4125	365	7,248.8
24,000	0.00136	0.80141	3.092909	4125	365	5,075.5
25,000	0.00077	0.80141	3.659846	4125	365	3,400.4
26,000	0.00059	0.80141	4.310020	4125	365	3,068.3
27,000	0.00017	0.80141	5.052609	4125	365	1,036.4
28,000	0.00077	0.80141	5.897421	4125	365	5,479.3
29,000	0.00017	0.80141	6.854909	4125	365	1,406.1
30,000	0.00017	0.80141	7.936193	4125	365	1,627.9
31,000	0.00017	0.80141	9.153071	4125	365	1,877.5
32,000	0.00000	0.80141	10.518045	4125	365	0.0

(Continued)

TABLE B.1. 18-KESAL CALCULATIONS BY AXLE WEIGHT GROUP, Continued

TANDEM AXLES

Upper Weight Limit Pounds	Initial Distrib. (%/100)	Adjust. Factor	18-KESAL Factor	AXLET	Days/ Year	Total Annual 18-KESALs
2,000	0.00000	1.19789	0.000062	4125	365	0.0
3,000	0.00017	1.19789	0.000180	4125	365	0.1
4,000	0.00000	1.19789	0.000430	4125	365	0.0
5,000	0.00000	1.19789	0.000897	4125	365	0.0
6,000	0.00068	1.19789	0.001691	4125	365	2.1
7,000	0.00119	1.19789	0.002953	4125	365	6.3
8,000	0.00231	1.19789	0.004848	4125	365	20.2
9,000	0.00727	1.19789	0.007572	4125	365	99.3
10,000	0.01411	1.19789	0.011334	4125	365	288.6
11,000	0.02369	1.19789	0.016388	4125	365	700.2
12,000	0.02669	1.19789	0.022968	4125	365	1,105.6
13,000	0.02190	1.19789	0.031338	4125	365	1,237.8
14,000	0.02318	1.19789	0.041760	4125	365	1,745.9
15,000	0.02173	1.19789	0.054496	4125	365	2,135.8
16,000	0.01942	1.19789	0.069803	4125	365	2,444.9
17,000	0.01719	1.19789	0.087932	4125	365	2,726.2
18,000	0.01557	1.19789	0.109130	4125	365	3,064.5
19,000	0.01488	1.19789	0.133639	4125	365	3,586.5
20,000	0.01488	1.19789	0.161705	4125	365	4,339.7
21,000	0.01206	1.19789	0.193577	4125	365	4,210.5
22,000	0.01009	1.19789	0.229519	4125	365	4,176.8
23,000	0.00958	1.19789	0.269809	4125	365	4,661.8
24,000	0.00761	1.19789	0.314753	4125	365	4,320.0
25,000	0.01060	1.19789	0.364681	4125	365	6,971.9
26,000	0.00744	1.19789	0.419959	4125	365	5,635.3
27,000	0.00941	1.19789	0.480988	4125	365	8,163.2
28,000	0.01060	1.19789	0.548209	4125	365	10,480.6
29,000	0.01240	1.19789	0.622102	4125	365	13,912.9
30,000	0.01240	1.19789	0.703191	4125	365	15,726.4

(Continued)

TABLE B.1. 18-KESAL CALCULATIONS BY AXLE WEIGHT GROUP, Continued

TANDEM AXLES

Upper Weight Limit Pounds	Initial Distrib. (%/100)	Adjust. Factor	18-KESAL Factor	AXLET	Days/ Year	Total Annual 18-KESALs
31,000	0.01206	1.19789	0.792044	4125	365	17,227.8
32,000	0.01522	1.19789	0.889270	4125	365	24,410.8
33,000	0.01377	1.19789	0.995525	4125	365	24,724.1
34,000	0.01736	1.19789	1.111507	4125	365	34,801.3
35,000	0.01488	1.19789	1.237959	4125	365	33,223.3
36,000	0.01454	1.19789	1.375669	4125	365	36,075.5
37,000	0.01437	1.19789	1.525468	4125	365	39,536.1
38,000	0.01377	1.19789	1.688234	4125	365	41,927.6
39,000	0.01274	1.19789	1.864887	4125	365	42,850.5
40,000	0.01112	1.19789	2.056393	4125	365	41,242.5
41,000	0.00812	1.19789	2.263766	4125	365	33,152.9
42,000	0.00658	1.19789	2.488063	4125	365	29,527.1
43,000	0.00462	1.19789	2.730388	4125	365	22,751.0
44,000	0.00427	1.19789	2.991893	4125	365	23,041.3
45,000	0.00316	1.19789	3.273778	4125	365	18,658.2
46,000	0.00145	1.19789	3.577288	4125	365	9,355.3
47,000	0.00179	1.19789	3.903722	4125	365	12,602.8
48,000	0.00102	1.19789	4.254424	4125	365	7,826.6
49,000	0.00145	1.19789	4.630791	4125	365	12,110.4
50,000	0.00085	1.19789	5.034269	4125	365	7,717.7
51,000	0.00000	1.19789	5.466359	4125	365	0.0
52,000	0.00017	1.19789	5.928610	4125	365	1,817.8
53,000	0.00017	1.19789	6.422628	4125	365	1,969.2

APPENDIX C

RESPONSES TO THE TRAFFIC LOAD FORECASTING QUESTIONNAIRE

APPENDIX C. RESPONSES TO THE TRAFFIC LOAD FORECASTING QUESTIONNAIRE

On November 21, 1983, the questionnaire shown in Figure C.1 was mailed to 49 states. The major objective of this survey was to identify alternative procedures for prediction of traffic loads. The responses received from 38 states are summarized in this appendix.

Alabama

In 1982, 13,534 trucks were weighed at ten weigh-in-motion (WIM) stations. All data was combined in order to develop an 18-KESAL/truck factor that varied by the pavement type (structural number or slab thickness) and the terminal serviceability index. Total 18-KESALs were obtained by multiplying the 18-KESAL/truck factor by the number of trucks estimated to use the design lane over the design period. For a particular direction of travel, the following traffic distributions for the design lane are used:

3 lanes (or more)	70%
2 lanes (urban)	85%
2 lanes (rural)	95%
1 lane	100%

It was felt that not enough data existed for the development of accurate 18-KESAL/truck factors by highway class. Considerable variations, however, were noted among the ten WIM stations. For flexible pavement, the 18-KESAL/truck factors ranged from 45 percent below to 32 percent above the statewide average. For rigid pavement, the 18-KESAL/truck factors ranged from 50 percent below to 34 percent above the statewide average.

1. Person(s) filling out form (name, position/responsibility, address, telephone)

2. In 1982, how many weigh stations were in operation, and how much weight data was collected? (# of vehicles and/or axles)

3. Please describe the types of weigh stations (manual vs automated, urban vs rural, type of roadway, and which traffic lanes are covered).

4. Is the data summarized in the FHWA loadometer tables used frequently? (if no, please explain)

5. For traffic load forecasts within the state, has weight data from other states ever been used? (If yes, describe the situation)

6. Are the AASHTO equivalency equations or factors used for traffic load forecasting? (describe any modifications or alternative approaches)

7. How long has the present load forecasting procedure been in use?

8. What procedure was used before the present one, and why was it abandoned/modified?

9. Give titles of reports/documents describing the present load forecasting procedure (we would like to obtain a copy if possible).

10. When examining a roadway for which no weight data has been collected, what available weight data is used? (describe how a "representative" station is used, or what sort of station aggregations are performed; also, mention if multi-year data is used)

Fig C.1. Questionnaire On Traffic Load Forecasting

11. For a specific highway segment, briefly describe how total traffic load equivalencies would be determined from the available weight data (e.g., use of average equivalency factors per truck type or per truck axle)

12. Describe the classification count data that is utilized in the forecasting process. What sort of lane distribution factors are used?

13. Are the available classification counts and traffic volume counts considered to be adequate for use in truck weight forecasting?

14. Are current numbers such as percent trucks, axles/truck, or equivalency factor/truck held constant over the design period?

15. How are parameters such as structural number, slab thickness, and the terminal serviceability index handled?

16. Please describe any problem areas or weaknesses that have been discovered with the present procedures.

17. We would appreciate any additional comments that might help us to understand your present procedures. In particular, please describe any techniques that appear to differ from the "normal" procedures used in other states.

Fig C.1. Questionnaire on Traffic Load Forecasting, Continued

Prior to 1983, the 18-KESAL/truck factors used in traffic load forecasting had been developed from weight data collected manually in 1964. Through the use of FHWA's W-4 and W-5 tables, average 18-KESAL/truck factors were determined for four highway types. The resulting calculations indicated a maximum variation among the four averages of 25 percent. Even more significant, however, is that the statewide average 18-KESAL/truck factor doubled from 1964 to 1982.

Arizona

In 1982, only 930 trucks were weighed at 13 manual stations. Five years of axle weight data are aggregated by facility type (interstate, rural, other rural, and urban) in order to develop 18-KESAL factors for each of seven vehicle types (passenger car, bus, light truck, medium truck, tractor-semitrailer, tractor-semitrailer-trailer, and truck-trailer).

The AASHTO equivalency factors are determined directly from FHWA's W-4 tables, which means that, for flexible pavements, a structural number of 5 and a terminal serviceability index of 2.5 are always assumed. For rigid pavements, a slab thickness of 9 inches is assumed. Due to the fact that there are so many other uncertainties in the traffic load forecasting process, these assumed pavement strengths were not considered result in significant design errors. One concern Arizona does have, however, is that the W-4 tables treat a steering axle (with two tires) as a dual axle (with four tires). They believe the damage effects of the steering axle are underestimated by AASHTO. Distributions of total 18-KESALs for the design lane are as follows:

Number of Lanes (One Direction)	Design Lane Distribution
1	100%
2	100%
3	80%
4+	60%

Arkansas

In 1983, 5,800 trucks were weighed at 18 manual stations and one WIM station. A typical load forecast consists of the aggregation of the latest three years of data (e.g., 1979, 1981, and 1983) into one of four types of weight tables:

1. by individual station,
2. by route segment,
3. by location (urban versus rural), and
4. by functional class.

The selection of the appropriate weight distribution table is largely engineering judgment, for the traffic forecaster must determine which weight table best summarizes the truck characteristics of the roadway segment in question.

Equivalency factors are developed by grouping single axle weights into 3,000-pound intervals and tandem axle weights into 6,000-pound intervals. An average 18-KESAL/axle factor is then calculated from the weight table. Total 18-KESALs for the highway segment under study are determined by multiplying the 18-KESAL/axle number by the appropriate truck axle factor and number of trucks.

Colorado

In 1982, 1,952 trucks were weighed at 12 manual stations. FHWA's W-4 tables for Colorado are used to identify statewide 18-KESAL factors for pickups, single-unit trucks, and multiple-unit trucks in a particular year. Data from past years is used to identify trends in the average traffic loadings for each truck type. For example, a trend-line analysis established the following 18-KESAL factors for the three trucks types:

	1975	1999
Pickups	0.005615	0.010540
Single Unit Trucks	0.187851	0.198003
Multiple Unit Trucks	1.036566	0.987769

Total 18-KESALs are determined by multiplying the projected number of trucks of each type by the appropriate 18-KESAL factor for the mid-year of the design period. The distributions of total two-direction loadings for the design lane are based on the following:

Number of Lanes (both directions)	Percent of Loadings in Design Lane
2	60
4	45
6	30
8	25

Connecticut

In 1981, 4,038 trucks were weighed at nine manual stations. Although weight data is collected in every odd-numbered year, it is not directly used in the design of pavements. Instead, Connecticut selects pavement types and thickness according to specified standards based on:

1. highway class (expressway, local, other),
2. continuity along an existing route,
3. the location (urban or rural) of the proposed roadway,
4. the land-use abutting an urban project (residential or commercial/industrial), and
5. design traffic volume: average daily traffic or directional design hourly volume (30th highest hour).

FHWA's W-tables are used to detect trends toward increasing/decreasing axle weights or gross vehicle weights. Through a periodic review process, the highway design standards can be updated as needed.

Florida

In 1982, 184,920 vehicles were weighed at 16 WIM stations:

Passenger vehicles	- 126,352
Light trucks	- 24,861
Other Single-Unit Trucks	- 9,383
Multiple-Unit Trucks	- 24,324

Although the number of WIM stations has increased since 1982, Florida still sees a need for additional stations. It has been suggested that more stations operated part-time would provide a greater benefit than a lot of data collected at fewer stations. Average 18-KESAL/truck calculations indicate a range among stations of 0.23 to 1.49: a factor of over six times.

Present procedures consist of several choices for calculation of 18-KESAL/truck factors. The engineer performing a pavement design calculation must first attempt to relate a particular roadway project to a WIM station by inspection. If this is not possible, weight data can be aggregated by highway type or statewide average. Total traffic loadings in one direction are distributed to the design lane according to the following schedule:

Number of Lanes	Design Lane Distribution
1	100%
2	90%
3	80%
4	70%
5	60%

An alternative approach being considered is to make use of equivalency factors by truck type rather than simply per truck. Florida sees this as a more precise method, but only if good vehicle classification data can be obtained at the highway segment under study. A third approach that has been considered is the incorporation of regression techniques into the traffic load forecasting process.

Georgia

In 1982, 2,777 trucks were weighed at 15 manual stations. Due to the small sample size, all data collected over a five-year period is aggregated in order to develop average 18-KESAL factors per vehicle type (single-unit truck, multiple-unit truck, and other vehicle). Engineering judgment is used to select a station which has characteristics similar to the highway segment under study. In some cases, all stations are aggregated in order to develop statewide 18-KESAL factors by vehicle type. The lane distribution factors are as follows:

Design Lane Distribution
(One Direction)

	Trucks	Other Vehicles
Four lane rural freeway	90 - 100%	50 - 80%
Four lane urban freeway	60 - 80%	50 - 60%
Six lane urban freeway	60 - 80%	40 - 50%
Four lane rural highway	80 - 100%	50 - 80%
Four lane urban highway	60 - 80%	50 - 60%
Two lane highway	100%	100%

Hawaii

In 1981 and 1982, 1,120 trucks were weighed at nine manual stations. Traffic load forecasts are based on a statewide average of all weight data collected over a five year period. Hawaii's design procedures follow the approach used in California. Equivalent wheel loads are calculated for 2-axle, 3-axle, 4-axle, 5-axle, and 6-axle (or more) trucks.

Illinois

In 1981, 2,900 trucks were weighed at 12 manual enforcement stations. Traffic load forecasting consists of the use of average 18-KESAL factors by vehicle type (passenger vehicles, single-unit trucks, and multiple-unit trucks) and by highway class (expressway, primary, secondary/collector, and local). Illinois has been able to obtain reasonably stable numbers only when several years of data are combined. Axle weight data is grouped into 4,000-pound intervals for single axles and 6,000-pound intervals for tandem axles. The 18-KESAL factor for each weight interval is determined from the heaviest axle weight of the range.

Studies conducted by the Illinois Department of Transportation indicate that seasonal traffic variations and spring load limits can have a significant impact on the average equivalencies per vehicle type. A concern was also raised about the applicability of AASHTO's "present serviceability index" concept and performance equations to secondary and local road designs. A regression analysis was attempted, but achieved little success due to the small amount of usable data available.

Indiana

The truck weighing program in Indiana is conducted during every odd-numbered year. All weight data collected over several years is combined in order to prepare two statewide axle weight distribution tables: one for single-unit trucks and one for multiple-unit trucks. The appropriate 18-KESAL factors for a particular roadway segment will depend on its pavement type, terminal serviceability index, and structural number/slab thickness.

Once the equivalency factors for the two truck types are determined, the basic steps in the load forecasting process are as follows:

1. Design Lane Trucks (daily)

   = (direction ADT) X (percent trucks) X (lane factor)

2. Daily 18-KESALs

   = (Design Lane Trucks) X (percent multiple-unit trucks)

   X (18-KESAL per multiple-unit truck)

   + (Design Lane Trucks) X (percent single-unit trucks)

   X (18-KESAL per single-unit truck)

3. Design Period 18-KESALs

   = (Design Period, in days) X (Daily 18-KESALs)

The lane distribution factors used by Indiana are as follows:

Lanes (One Direction)	Directional Distribution
1	100%
2	90%
3	80%

Indiana follows the "standard" practice of not using weight data collected in other states. However, when the legal load limit was recently increased from 73,000 pounds to 80,000 pounds, Indiana was able to make use of North Carolina's "before-and-after" data.

Iowa

In 1981, 19,042 vehicles were weighed at 20 locations around the state. Truck weight data is manually collected on a two-year cycle. The operation of WIM stations has begun and is expected to provide a more reliable sample since no vehicles will be stopped, and the desire for drivers to circumvent weighing stations will be greatly reduced. The forecasting process consists of the combination of axle weight data collected during three consecutive weighing periods by highway system (interstate, rural primary, urban primary, secondary rural, and local urban).

Kansas

In 1983, 1,744 trucks were weighed manually at 25 locations. The weighing program is normally conducted in every odd-numbered year. All weight data collected over five weighing periods (e.g., 1975, 1977, 1979, 1981, and 1983) is combined in order to develop 18-KESAL factors for each of ten truck types:

1. single-unit (3),
2. tractor-semitrailer (2),
3. truck-trailer (2), and
4. tractor-semitrailer-trailer (3).

The actual 18-KESAL factors used in a particular highway forecast vary according to the specifications for the terminal serviceability index and the structural number/slab thickness. Due to the large number of truck classes used, detailed classification data is needed at each highway segment under study.

Kentucky

Kentucky's traffic load forecasting process consists of the combination of all truck weight data collected over the three most recent survey periods. All tandem axle sets are treated as two single axles and combined with all single axles (i.e., no distinction is made as to axle type). The pavement design process incorporates an "equivalent wheel load" concept in which the "damage effect" of axle loads over 10,000 pounds doubles for every 2,000-pound increase:

Axle Load	Equivalent Wheel Load
10,000 pounds	1
12,000 pounds	2
14,000 pounds	4
16,000 pounds	8
18,000 pounds	16
20,000 pounds	32
22,000 pounds	64

A typical forecast consists, first, of determining the number of heavy trucks expected to use a facility over the design period. An axle factor (average number of axles per heavy truck) is estimated by adjusting the initial axle factor (from available classification data) by an additive adjustment based on traffic volumes:

Average Annual Daily Traffic (AADT)	Additive Adjustment
0 - 399	0
400 - 999	0.04
1,000 - 1,999	0.08
2,000 - 2,999	0.14
3,000 +	0.19

These adjustments were based on an analysis of trend data and reflect increasing future utilization of truck types having more axles. The effect of each axle load is also slightly increased (as AADT increases) to reflect trend data which indicate that the average weights of truck axles have generally increased over time.

Maine

Truck weight data are normally collected every other year and are used to calculate 18-KESAL factors for light trucks (2-axle, 4-tire) and heavy trucks. Special studies, however, have revealed low-side biases in the data collected at manually-operated weigh stations. They have noticed that the increased use of CB radios in recent years has enabled the heavier and overweight trucks to avoid the stations. It is anticipated that recent installations of WIM equipment will eliminate this problem.

For traffic load forecasts in urban areas, average 18-KESAL/truck factors are determined from a three-year average of the three urban stations. In rural areas, a station with similar roadway and traffic characteristics is selected as a "representative" station. On interstate projects, a five-year average is used; on other projects, a three-year average is used.

Maryland

In 1982, 7,500 trucks were weighed at 21 manual stations. For an estimation of 18-KESALs on a particular highway segment, the forecaster uses professional judgment and local knowledge to select a weigh station with similar traffic characteristics. An average 18-KESAL/truck factor is then calculated.

Included in Maryland's response to the CTR questionnaire was a description of significant problem areas or concerns:

1. Portable loadometer procedures are costly and time-consuming. Truckers have a tendency to avoid loadometer crews; weighings are conducted only during the summer months; the data gathered are not representative of the truck traffic for the entire year.
2. There is a discrepancy between 12- and 24-hour count percentages of trucks.
3. The variability of truck percentages on a daily -- as well as seasonal -- basis is not known and has not been investigated since 1969.
4. Weight data is of uncertain quality as different procedures have been used to collect it within the last decade.
5. Changes in truck regulations and their effect on weight and traffic mix have not been investigated.
6. Estimates of what types of trucks and number of trips different commercial and industrial facilities generate do not exist.
7. Neither changes over time nor what influences change is known -- but it is probable that passenger traffic is growing more rapidly than freight traffic.

8. Computer program sensitivity to the number of trucks forecast is unknown; all current stations have been run for 100 trucks in each category, in hopes of seeing what differences exist for each station given identical inputs.
9. How sensitive pavement design is to the traffic load projections, and therefore how close/how much effort ought to go into forecasting (overdesign versus underdesign) is not known.
10. It would be desirable to type classify routes on easily obtained information (lanes, function, adjacent land use, type of access control, adjacent facilities, location), so as to reduce requirements for classified counts in either time or number.
11. It would be desirable to do some lane distribution studies.

Massachusetts

Trucks were not weighed in 1982 for planning purposes because of manpower and budgetary limitations. An attempt was made to collect data by observing enforcement operations that used portable WIM scales. Analysis of the data (by comparison with previous W-4 tables and national averages), however, indicated a low-side bias -- the information, therefore, was not used. Traffic load forecasting in Massachusetts consists of combining all available truck weight data by highway system. Design lane distributions are as follows:

Number of Lanes (One Direction)	Design Lane Distribution
1	100%
2	90%
3 (or more)	80%

Mississippi

In 1982, 3,372 trucks were weighed at 13 manual stations. Eleven of these stations consist of permanent platform scales used for enforcement purposes. There is, however, a concern that the data from the enforcement stations may be biased. All weight data collected in a particular year is aggregated by route or functional class. Depending on the pavement type, average 18-KESAL factors are determined for each of seven truck types.

Missouri

In 1982, 3,376 trucks were weighed at 17 locations, seven of which were WIM stations. Traffic load forecasting for flexible pavements is based on an examination of weight data, by truck type, collected at a representative station on a roadway with a similar functional classification. Rigid pavement design, however, is based on empirical data and engineering judgment.

Montana

In 1982, 2,644 vehicles were weighed at 15 manual stations. The normal traffic load forecasting procedures consists of the combination of five years of weight data, by highway type, in order to develop an average 18-KESAL/truck factor. In some cases, these statewide factors are adjusted to reflect station-specific differences. Such differences may be caused by particular industry-related activities on specific routes (logging, grain hauling, cement manufacturing, etc.). Design lane distributions for four-lane facilities are based on daily traffic volumes:

ADT	Directional Distribution
0 - 4,000	100%
4,000 - 8,000	95%
8,000 - 12,000	90%
12,000 - 20,000	85%

Nebraska

In 1982, 3,139 trucks were weighed at 13 manual stations. All weight data collected during a particular year is combined in order to develop a statewide 18-KESAL/truck factor. For a four-lane interstate, the design lane is assigned 90 percent of the traffic load in one direction. Several potential problem areas were identified in Nebraska's response to the CTR questionnaire:

1. Generalizations of truck weight frequency data are probably inaccurate.
2. Weigh stations and portable scales probably miss many overloaded vehicles.
3. Seasonal variations in the distribution of trucks need to be considered in load forecasting.

Nevada

In 1982, 3,250 trucks were weighed at 13 stations, ten of which used WIM equipment. Based on historical data, only the heaviest direction of travel was monitored at each station. A traffic load forecast for a particular highway segment consists, first, of the selection of a weigh station with similar land use, commodity flow, and traffic characteristics. Other considerations are functional classification and geographical location. Multi-year data is used if weight data for the current year is deemed insufficient due to a lack of variety in vehicle types weighed or an inadequate sample size. For each of the 13 stations, average 18-KESAL factors are calculated for eleven truck types:

1. Single unit, 2-axle
2. Single unit, 3-axle
3. Semi-trailers, 3-axle
4. Semi-trailers, 4-axle
5. Semi-trailers, 5-axle
6. Full trailers, 5-axle
7. Full trailers, 6-axle
8. Multiple trailers, 5-axle
9. Multiple trailers, 6-axle
10. Multiple trailers, 7-axle
11. Multiple trailers, 8-axle

Standard practice in Nevada is to assign 100 percent of all truck traffic in one direction to the design lane.

New Jersey

Truck weight data in New Jersey is collected in odd-numbered years. In 1983, 26 manual weigh stations were in operation. The program consists of State Troopers directing trucks onto the roadway shoulder. The traffic load forecasting procedure uses average 18-KESAL/truck factors for each weigh station. If a station is not on the same route (or in the same geographical area) as the highway segment under study, a station with similar traffic characteristics (ADT and percentage of trucks) is chosen.

New Mexico

In 1982, 5,703 trucks were weighed at 11 WIM stations. All weight data collected in one year is combined in order to develop statewide 18-KESAL factors for four truck types: 2-axle, 3-axle, 4-axle, and 5-axle. Equivalency factors for future years are based on a trend line analysis of the factors obtained in recent years.

New York

In 1983, a total of 2,977 vehicles were manually weighed at 14 locations in cooperation with the State Police. The last regular truck weight survey program was in 1978, when 19 manual stations were in operation. New York's basic concern about the use of truck weight data is that no state can afford more than a handful of sites (either manual or automatic), which makes the data highly unrepresentative of operations on specific highway segments.

The primary use of New York's truck weighing program is to satisfy federal requirements. Pavement design practice is based on the application of highway design standards that vary according to ADT, design hour volume (30th highest volume in a year), and highway type. Weight data is used to check the design standards and for research on specific pavement problems.

North Carolina

Prior to 1984, the last truck weight survey program was conducted in 1979 and consisted of 24 manual stations. This data is currently used to develop statewide 18-KESAL factors by truck type (single-unit truck and multiple-unit truck). For multi-lane facilities, the design lane distribution factor (per direction) is typically 80 percent. Although current traffic classification and volume counts are considered satisfactory, projected traffic volumes and truck weight forecasts are felt to be "educated guesses" at best.

Ohio

In 1982, 5,300 trucks were weighed at 14 manual stations. For traffic load forecasting purposes, an average 18-KESAL factor per heavy truck is calculated by highway type (interstate or primary). Lane distribution factors (other than 100 percent for one direction) are not normally incorporated into the design process.

Oklahoma

In 1981 and 1983, truck weight data was gathered at eight manual stations primarily to satisfy federal requirements. Although Oklahoma's current pavement design procedures do not rely on AASHTO's recommended procedures, traffic loading equivalencies are developed on a statewide basis as a part of their design charts. The AASHTO equivalency equations are occasionally used as a check on roadway projects where design questions exists.

The Oklahoma design method utilizes a zone or region approach, in which manual classification counts are used to determine wheel load criteria. A Traffic Factor, consisting of the number of overloaded axles per day, is determined as follows:

1. Multiply the ADT by the percent of heavy commercial truck traffic.
2. Multiply the result of number 1 by the number of overloaded axles per one hundred commercial trucks.

The Oklahoma Department of Highways also made this additional comment:

> There is much misunderstanding as to exactly how to define an adequate highway. An adequate highway is considered to be one that fulfills the responsibility of the State to furnish satisfactory road service to the public at a reasonable cost. There seems to be a widespread opinion that the problem is to build a road so strong that it will last forever regardless of cost. This is far from the truth. The highway problem is to furnish a satisfactory surface for traffic to travel over as long as the public requires roads. The best highway design and construction is the one that enables the State to do this at the lowest cost per mile per year.

Pennsylvania

In 1982, 10,932 trucks were weighed at 28 locations with manually-operated portable scales. Although enforcement practices are not carried out during the survey, the State Police direct traffic at all weighing operations. Pennsylvania believes that the citizens' band (CB) radio, the presence of mobile weight enforcement teams, the current overweight truck fine structure, and even the national economy, have had an effect on the distribution of heavy trucks actually surveyed. They believe that the statistical reliability of the weighing program could be improved if a covert WIM system was used in lieu of the present system of stopping and weighing trucks with portable scales. Traffic load forecasting consists of the determination of a statewide 18-KESAL factor for each of five truck types:

1. Single-unit 2-Axle
2. Single-unit 3-Axle
3. Multiple-unit 3-Axle
4. Multiple-unit 4-Axle
5. Multiple-unit 5-Axle

Rhode Island

Since the mid 1970's, no truck weighing for planning purposes has been conducted. All truck weighing in Rhode Island is conducted by the State Police for enforcement purposes. The present pavement design practice consists of the use of standard pavement make-ups by highway type. Serious consideration, however, is being given to the use of axle weight data collected by the State Police.

South Carolina

No truck weight survey data was collected in 1982. The present load forecasting procedure makes use of statewide 18-KESAL factors for each of five trucks (two for single-unit trucks, three for multi-unit trucks). If detailed classification count data is not available for the highway segment under study, one of the default truck distribution factors can be used. Distribution factors for the design lane are as follows:

Number of Lanes (one direction)	Design Lane Distribution
1	100%
2	75 - 100%
3	60 - 75%

South Dakota

In 1981, 3,455 vehicles were weighed at 12 manual stations. The truck weight data (for the latest year) is categorized into three groups: main rural, interstate, and urban. Average 18-KESAL factors are developed for 12 vehicle types: passenger car, bus, panel and pickup, other 4-tire truck, 2-axle, 6-tire truck, 3-axle truck, 3-axle semitrailer, 4-axle semitrailer, 5-axle semitrailer, 4-axle full trailer, 5-axle full trailer, and 6-axle full trailer. For pavement design, the design lane is assumed to carry all of the traffic in one direction.

Tennessee

In 1982, 2,308 trucks were weighed at 16 manual stations. Since 1976, weight data has been collected in even-numbered years only. An analysis of data collected from 1967 to 1982 was made in order to project the appropriate 18-KESAL factors (by highway and vehicle type) for the mid-year of a design period. An example of Tennessee's "daily 18-KESAL" calculation sheet is shown in Figure C.2. For the rural interstate highway system, the 18-KESAL/truck type factors determined from a trend-line analysis are increased by 14 percent to allow for the influence of enforcement stations on the weight data actually collected. A study by Tennessee indicated that, where enforcement activities were undertaken, the average measured truck weights were 14 percent lower than the "actual" averages.

Utah

Trucks are weighed each year at seven manual stations. Based on the available data, average 18-KESAL factors are calculated (by highway type) for heavy trucks and light trucks. A trend-line analysis is made in order to estimate the factors for any specified future year. For a four-lane urban roadway, the design lane is assumed to carry 70-80 percent of the one-way traffic.

PROJECT NO. ______________________ ROUTE NO. __________
COUNTY ______________________ CITY __________
PROJECT DESCRIPTION ______________________

Interstate Rural

Pavement Structural Design

Calculation of Equivalent Daily 18 Kip Single Axle Loads

	Type Vehicle	ADT (No. counted)	Flexible 18-kip Factor	Flexible ADL	Rigid 18-kip Factor	Rigid ADL
	Pass. cars, and motorcycles		0.001		0.001	
	Buses		0.300		0.300	
Single-Unit	Panel, and Pick-up Trucks		0.004		0.005	
Single-Unit	2-axle, 4-tire		0.006		0.010	
Single-Unit	2-axle, 6-tire		0.170		0.170	
Single-Unit	3-axle or more		0.700		1.000	
Tractor Semi-Trail.	3-axle		0.700		0.880	
Tractor Semi-Trail.	4-axle		0.700		0.780	
Tractor Semi-Trail.	5-axle or more		1.100		1.780	
	Totals					

Suggested Percentages of Trucks in Design Lane

5,000 or less ADT	95%
5,000 - 10,000 ADT	90%
10,000 - 15,000 ADT	85%
15,000 - 20,000 ADT	80%
20,000 - 30,000 ADT	75%
30,000 - 40,000 ADT	70%
40,000 plus	60%

No. of Lanes ______________
% Trucks in Design Lane ______________
ADL in Design Lane FLEX 0.5 X ______________
RIGID 0.5 X ______________

ADL Calculations By: ______________ Date: ______________
Reviewed by: ______________ Date: ______________

Fig C.2. Tennessee's 18-KESAL Calculation Sheet

Vermont

In 1982, 1,910 trucks were weighed at seven manual stations. The most recent year's data is aggregated (by highway type) in order to develop average 18-KESAL factors for each of nine vehicle types (passenger cars, buses, and seven truck types). For rigid pavement design, the Portland Cement Association method is used as an alternative to the AASHTO method.

Virginia

Virginia has 14 permanent WIM stations and ten mobile weight crews. The mobile weight crews collect data wherever it is needed. In 1982, over seven million vehicles (cars and trucks) were weighed. About 100,000 of these vehicles were weighed by the mobile crews. If a traffic load forecast is needed on a highway segment not covered by a WIM station, a mobile crew is sent to make site-specific weighings for 24 to 48 hours. On multi-lane facilities with two or more lanes for each direction of travel, it is assumed that the heaviest traveled lane will carry 80 percent of the traffic in each direction.

For a particular highway segment under study, the expected number of trucks and the expected number of truck axles over the design period is determined. From the appropriate weight data, an average 18-KESAL factor per truck axle is determined (one for flexible pavement and one for rigid pavement). Total 18-KESALs during the design period will thus be equal to (total truck axles) X (18-KESAL per truck axle) + (total passenger car axles) X (18-KESAL factor per car axle).

Washington

In 1982, 6,930 vehicles were weighed at ten WIM stations. Pavement design procedures make use of average wheel load equivalency factors determined from an aggregation of all weight data. Five truck types are used: 2-axle, 3-axle, 4-axle, 5-axle, and 6-axle.

West Virginia

In 1980, 5,400 vehicles were weighed at 17 manual stations. Although no weighing was done in 1982 (due to financial constraints), West Virginia established ten WIM stations in 1984. Through the use of multi-year data, statewide equivalent wheel load (EWL) factors are calculated for six truck types. On multi-lane facilities, all traffic in one direction is assumed to be carried by the design lane.

Rigid pavement design is currently based on the Portland Cement Association procedures, but they anticipate adoption of the AASHTO procedures. For flexible pavements, California's Hveem method is now utilized and will probably be replaced by the VESYS mechanistic empirical design procedure. However, AASHTO equivalencies will continue to be used to estimate traffic loadings.

Wyoming

In 1982, 5,916 trucks were weighed at 34 manual stations. Multi-year weight data (1978, 1980, 1981, and 1982) is combined in order to develop statewide 18-KESAL factors by vehicle type. The basic traffic load forecasting procedure is shown in Figure C.3. Wyoming presently has two concerns about their procedures:

1. They lack specific data for projects; and
2. Data is sometimes lacking for projecting individual vehicle types.

Road I-25 US 87 Natrona County
Section at Rancho Rd Int. Starting Milepost 188.47 Ending Milepost 188.66
1982 DHV 10 % 2003 DHV 10 %

Vehicle Type	Base Year Traffic 1982 AADT	Projected Traffic AADT		Mean Year AADT	Design Lane AADT	18 - KIP Equivalent Single Axle Application	18 - KIP Single Axle Loads Per Day
		1983	2003				
Passenger Car	12,600	13,548	32,504		11,513	0.00080	9.21
Panel & PU	5,600	6,022	14,446		5,117	0.00445	22.77
Buses	50	52	85		34	0.23500	7.99
2D - 6 Tire	539	557	913		368	0.28746	105.79
3 Axle SUT	210	218	356		144	0.75350	108.50
4 Axle SUT	5	5	8		3	3.75180	11.26
3 Axle Com	50	52	85		34	0.50136	17.05
4 Axle Com	44	45	75		30	0.48648	14.59
5 Axle Com	91	94	154		62	1.78378	110.59
2S1 - 2	7	7	12		5	1.65090	8.25
3S2	750	775	1,270		511	1.31154	670.20
6 Axle Com	34	35	58		23	1.01118	23.26
3S3	8	8	14		6	1.97049	11.82
7 Axle Com	7	7	12		5	1.55600	7.78
3S2 - 2	3	3	5		2	1.80000	3.60
Over 7 Axle	2	2	3		1	5.59504	5.60
TOTAL	20,000	21,430	50,000	35,715	17,858		1,138.26

Fig C.3. Wyoming's 18-KESAL Calculation Sheet

APPENDIX D

EXAMINATION OF TEXAS WEIGHT DATA, 1965-1983

APPENDIX D. EXAMINATION OF TEXAS WEIGHT DATA, 1965-1983

The accuracy of any traffic load forecasting process is based largely on the quality of the available weight data. The tables and figures in this appendix provide an overview of the Texas Truck Weight Survey program since 1965. The analysis is limited to five major truck types:

1. 2-Axle Single-Unit Truck (2-axle, 6-tire)
2. 3-Axle (or more) Single-Unit Truck
3. 3-Axle Multiple-Unit Truck (tractor-semitrailer only)
4. 4-Axle Multiple-Unit Truck (tractor-semitrailer only)
5. 5-Axle (or more) Multiple-Unit Truck (tractor-semitrailer only)

Tables D.1, D.2, and D.3 show the numbers of trucks (of each type) that were actually weighed from 1965 to 1983 on the "interstate rural" and the "other rural" highway systems. Tables D.4, D.5, and D.6 show the average 18-KESAL/axle factors for flexible pavements, based on a structural number of 5 and a terminal serviceability index of 2.5. An axle, for these calculations, can be a front steering axle, a regular single axle, or a tandem axle. The factors are shown on a "per axle" basis since this is how SDHPT'S RDTEST68 forecasting program makes use of axle weight distribution tables. Tables D.7 and D.8 show the numbers of trucks (by type) that were actually weighed since 1976 at each of the six WIM stations. Tables D.9 and D.10 show the corresponding 18-KESAL/axle factors.

Figures D.1 through D.7 depict the flexible pavement 18-KESAL/axle factors graphically for the "interstate rural" and the "other rural" highway systems. The graphs indicate a dramatic increase in the "relative pavement wear" effects of an average truck axle since 1974, especially for multiple-unit trucks. Unfortunately, it is not possible to identify how much of this

TABLE D.1. NUMBER OF TRUCKS WEIGHED, INTERSTATE RURAL, 1965-1983 (BY AXLE TYPE)

	Single-Unit		Multiple-Unit		
Year	2-Axle	3-Axle	3-Axle	4-Axle	5-Axle
1965	1089	126	653	1325	3647
1966	1063	151	607	1315	4088
1967	298	60	167	330	1317
1968	284	54	191	438	1496
1969	298	77	173	321	1605
1972	61	15	21	57	283
1973	44	5	25	31	317
1974	49	14	14	43	388
1976	168	61	48	144	1471
1978	533	91	70	219	2376
1979	508	91	52	193	2150
1980	307	44	26	105	1294
1981	398	91	49	169	2036
1982	813	188	91	286	4090
1983	1219	355	200	534	8539

TABLE D.2. NUMBER OF TRUCKS WEIGHED, OTHER RURAL, 1965-1983 (BY AXLE TYPE)

	Single Unit		Multiple-Unit		
Year	2-Axle	3-Axle	3-Axle	4-Axle	5-Axle
1965	3944	626	1478	3449	7161
1966	3155	537	1176	2579	6807
1967	1136	192	328	708	2425
1968	1092	221	337	672	2593
1969	923	215	284	660	2814
1972	478	101	92	237	1197
1973	336	77	86	202	1172
1974	399	80	78	213	1466
1976	138	28	33	89	856
1978	426	86	41	114	1470
1979	173	44	14	42	663
1980	88	53	9	34	529
1981	351	77	33	110	1885
1982	362	167	47	102	1767
1983	1219	355	200	534	8539

TABLE D.3. NUMBER OF TRUCKS WEIGHED, 1965-1983 (SINGLE-UNIT AND MULTIPLE-UNIT)

	Interstate Rural			Other Rural		
Year	Single Unit	Multiple Unit	Total	Single Unit	Multiple Unit	Total
1965	1215	5625	6840	4570	12088	16658
1966	1214	6010	7224	3692	10554	14246
1967	358	1814	2172	1328	3461	4789
1968	338	2125	2463	1313	3603	4915
1969	375	2099	2474	1138	3759	4897
1972	76	361	437	579	1526	2105
1973	49	373	422	413	1460	1873
1974	63	445	508	479	1757	2236
1976	229	1663	1892	166	978	1144
1978	624	2665	3289	512	1625	2137
1979	599	2395	2994	217	719	936
1980	351	1425	1776	141	572	713
1981	489	2254	2743	428	2028	2456
1982	1001	4467	5468	529	1916	2445
1983	1574	9273	10847	1574	9273	10847

TABLE D.4. 18-KESALS/AXLE, INTERSTATE RURAL, 1965-1983 (BY AXLE TYPE)*

	Single-Unit		Multiple-Unit		
Year	2-Axle	3-Axle	3-Axle	4-Axle	5-Axle
1965	0.0862	0.1242	0.1591	0.2032	0.1991
1966	0.0824	0.1242	0.1592	0.1767	0.1920
1967	0.0998	0.1694	0.1495	0.1596	0.1865
1968	0.0821	0.1194	0.1761	0.1927	0.2132
1969	0.0988	0.1184	0.1373	0.1662	0.1948
1972	0.0954	0.1036	0.1259	0.1035	0.1693
1973	0.0714	0.0486	0.1003	0.1043	0.1643
1974	0.0935	0.0880	0.1678	0.1353	0.1416
1976	0.1364	0.1779	0.2068	0.2351	0.4730
1978	0.1169	0.1394	0.1897	0.2172	0.3181
1979	0.1477	0.2226	0.2111	0.2769	0.3795
1980	0.1100	0.2284	0.3367	0.4351	0.4420
1981	0.1159	0.3399	0.1618	0.2895	0.3423
1982	0.1592	0.2979	0.1753	0.2480	0.3494
1983	0.1852	0.2664	0.2163	0.2319	0.3939

*Flexible Pavement
Structural Number = 5
Terminal Serviceability Index = 2.5

TABLE D.5. 18-KESALS/AXLE, OTHER RURAL, 1965-1983 (BY AXLE TYPE)*

	Single-Unit		Multiple-Unit		
Year	2-Axle	3-Axle	3-Axle	4-Axle	5-Axle
1965	0.0826	0.1244	0.1476	0.1847	0.1733
1966	0.1034	0.1154	0.1473	0.1791	0.1652
1967	0.0979	0.1462	0.1442	0.1715	0.1765
1968	0.1232	0.1347	0.1355	0.1582	0.1873
1969	0.1305	0.1334	0.1584	0.1763	0.1881
1972	0.1109	0.1812	0.1132	0.1979	0.1680
1973	0.1355	0.1528	0.1677	0.3371	0.2406
1974	0.1250	0.1462	0.1336	0.2043	0.1968
1976	0.3097	0.2319	0.3062	0.4589	0.5172
1978	0.1245	0.2156	0.1220	0.2600	0.3607
1979	0.1054	0.2714	0.1899	0.2816	0.3912
1980	0.1404	0.6011	0.2227	0.2936	0.5035
1981	0.1062	0.3540	0.2568	0.2580	0.4620
1982	0.1249	0.4401	0.2642	0.2852	0.3983
1983	0.1182	0.3863	0.3087	0.2844	0.5298

*Flexible Pavement
Structural Number = 5
Terminal Serviceability Index = 2.5

TABLE D.6. 18-KESALS/AXLE, 1965-1983 (SINGLE-UNIT AND MULTIPLE-UNIT)*

	Interstate Rural			Other Rural		
Year	Single Unit	Multiple Unit	Average	Single Unit	Multiple Unit	Average
1965	0.0902	0.1954	0.1823	0.0884	0.1734	0.1560
1966	0.0876	0.1853	0.1739	0.1052	0.1666	0.1550
1967	0.1115	0.1782	0.1701	0.1049	0.1724	0.1588
1968	0.0880	0.2057	0.1946	0.1251	0.1775	0.1668
1969	0.1028	0.1857	0.1768	0.1311	0.1837	0.1752
1972	0.0970	0.1563	0.1488	0.1232	0.1698	0.1601
1973	0.0691	0.1555	0.1487	0.1385	0.2494	0.2316
1974	0.0922	0.1418	0.1377	0.1286	0.1949	0.1844
1976	0.1474	0.4447	0.4209	0.2966	0.5045	0.4840
1978	0.1202	0.3063	0.2811	0.1398	0.3475	0.3112
1979	0.1590	0.3676	0.3376	0.1390	0.3820	0.3409
1980	0.1257	0.4396	0.3942	0.3135	0.4866	0.4609
1981	0.1580	0.3343	0.3120	0.1508	0.4475	0.4113
1982	0.1856	0.3393	0.3189	0.2244	0.3902	0.3647
1983	0.2036	0.3899	0.3702	0.1775	0.5121	0.4692

*Flexible Pavement
Structural Number = 5
Terminal Serviceability Index = 2.5

TABLE D.7. NUMBER OF TRUCKS WEIGHED BY STATION, 1976-1983 (BY AXLE TYPE)

		Single-Unit		Multiple-Unit		
Station	Year	2-Axle	3-Axle	3-Axle	4-Axle	5-Axle
501	1981	90	18	6	16	272
501	1982	138	28	9	33	494
501	1983	173	44	14	29	538
502	1976	93	48	34	94	986
502	1978	176	51	24	89	1109
502	1979	120	29	10	78	710
502	1982	336	88	40	125	1643
502	1983	459	148	79	252	3008
503	1976	75	13	14	50	485
503	1978	273	25	24	88	791
503	1979	279	36	28	82	1106
503	1980	51	11	6	17	340
503	1981	127	18	14	54	633
503	1982	147	18	16	48	716
503	1983	151	35	21	56	1257
504	1978	84	15	22	42	476
504	1979	109	26	14	33	334
504	1980	256	33	20	88	954
504	1981	181	55	29	99	1131
504	1982	192	54	26	80	1237
504	1983	436	128	86	197	3736
505	1976	138	28	33	89	856
505	1978	205	32	21	65	603
505	1979	173	44	14	42	663
505	1980	36	37	5	16	231
505	1981	186	35	20	77	1047
505	1982	188	61	18	54	875
505	1983	342	102	40	102	1604
506	1978	221	54	20	49	867
506	1780	52	16	4	18	298
506	1981	165	42	13	33	838
506	1982	174	106	29	48	892
506	1983	250	66	28	72	1467

TABLE D.8. NUMBER OF TRUCKS WEIGHED BY STATION, 1976-1983 (SINGLE-UNIT AND MULTIPLE UNIT)

Station	Year	Single Unit	Multiple Unit	Total
501	1981	108	294	402
501	1982	166	536	702
501	1983	217	581	798
502	1976	141	1114	1255
502	1978	227	1222	1449
502	1979	149	798	947
502	1982	424	1808	2232
502	1983	607	3339	3946
503	1976	88	549	637
503	1978	298	903	1201
503	1979	315	1216	1531
503	1980	62	363	425
503	1981	145	701	846
503	1982	165	780	945
503	1983	186	1334	1520
504	1978	99	540	639
504	1979	135	381	516
504	1980	289	1062	1351
504	1981	236	1259	1495
504	1982	246	1343	1589
504	1983	564	4019	4583
505	1976	166	978	1144
505	1978	237	689	926
505	1979	217	719	936
505	1980	73	252	325
505	1981	221	1144	1365
505	1982	249	947	1196
505	1983	444	1746	2190
506	1978	275	936	1211
506	1980	68	320	388
506	1981	207	884	1091
506	1982	280	969	1249
506	1983	316	1567	1883

TABLE D.9. 18-KESALS/AXLE, BY STATION, 1976-1983 (BY AXLE TYPE)*

		Single-Unit		Multiple-Unit		
Station	Year	2-Axle	3-Axle	3-Axle	4-Axle	5-Axle
501	1981	0.1619	0.3450	0.2027	0.3287	0.3669
501	1982	0.1259	0.2150	0.1102	0.2943	0.3852
501	1983	0.3812	0.5364	0.2389	0.3596	0.5723
502	1976	0.1360	0.2086	0.3340	0.2433	0.4828
502	1978	0.1232	0.0963	0.2310	0.1869	0.3062
502	1979	0.1569	0.1354	0.2223	0.2270	0.3048
502	1982	0.1676	0.2079	0.1239	0.2059	0.2829
502	1983	0.1666	0.1662	0.1617	0.2118	0.3481
503	1976	0.1368	0.0646	0.1679	0.2199	0.4546
503	1978	0.0852	0.1984	0.1441	0.2486	0.3243
503	1979	0.1548	0.0879	0.2426	0.2501	0.4048
503	1980	0.1204	0.1243	0.1763	0.1901	0.2974
503	1981	0.0613	0.1750	0.1483	0.1402	0.3181
503	1982	0.0926	0.1306	0.1631	0.2107	0.3107
503	1983	0.0954	0.2779	0.1538	0.2116	0.4277
504	1978	0.2068	0.1878	0.1946	0.2158	0.3347
504	1979	0.1190	0.3758	0.1400	0.4649	0.4531
504	1980	0.1092	0.2631	0.3849	0.4824	0.4932
504	1981	0.1313	0.3906	0.1599	0.3647	0.3484
504	1982	0.2196	0.5461	0.2844	0.3181	0.4455
504	1983	0.1581	0.2854	0.2791	0.2439	0.3925
505	1976	0.3097	0.2319	0.3062	0.4589	0.5172
505	1978	0.1612	0.2655	0.1103	0.2947	0.4155
505	1979	0.1054	0.2714	0.1899	0.2816	0.3912
505	1980	0.1837	0.8040	0.1687	0.3263	0.5277
505	1981	0.1096	0.2285	0.1316	0.2297	0.3957
505	1982	0.1298	0.2026	0.2099	0.2968	0.3999
505	1983	0.1065	0.3560	0.2640	0.3004	0.5984
506	1978	0.0905	0.1860	0.1342	0.2140	0.3227
506	1980	0.1104	0.1316	0.2892	0.2646	0.4848
506	1981	0.1024	0.4585	0.4494	0.3240	0.5449
506	1982	0.1196	0.5768	0.2979	0.2721	0.3981
506	1983	0.1344	0.4330	0.3726	0.2632	0.4532

*Flexible Pavement
Structural Number = 5.0
Terminal Serviceability Index = 2.5

TABLE D.10. 18-KESALS/AXLE, BY STATION, 1976-1983 (SINGLE-UNIT AND MULTIPLE-UNIT)*

Station	Year	Unit	Unit	Total
501	1981	0.1924	0.3613	0.3278
501	1982	0.1409	0.3761	0.3350
501	1983	0.4126	0.5535	0.5261
502	1976	0.1607	0.4546	0.4327
502	1978	0.1172	0.2959	0.2765
502	1979	0.1527	0.2961	0.2804
502	1982	0.1760	0.2740	0.2606
502	1983	0.1665	0.3343	0.3156
503	1976	0.1262	0.4259	0.3972
503	1978	0.0947	0.3119	0.2727
503	1979	0.1472	0.3905	0.3551
503	1980	0.1210	0.2904	0.2734
503	1981	0.0757	0.3019	0.2742
503	1982	0.0968	0.3013	0.2765
503	1983	0.1299	0.4144	0.3898
504	1978	0.2039	0.3198	0.3066
504	1979	0.1685	0.4424	0.6109
504	1980	0.1268	0.4543	0.4034
504	1981	0.1917	0.3452	0.3283
504	1982	0.2912	0.4347	0.4196
504	1983	0.1870	0.3827	0.3655
505	1976	0.2966	0.5045	0.4840
505	1978	0.1752	0.3945	0.3535
505	1979	0.1390	0.3820	0.3409
505	1980	0.4981	0.5078	0.5054
505	1981	0.1284	0.3798	0.3517
505	1982	0.1476	0.3903	0.3540
505	1983	0.1638	0.5749	0.5161
506	1978	0.1092	0.3129	0.2797
506	1980	0.1154	0.4700	0.4252
506	1981	0.1746	0.5352	0.4863
506	1982	0.2927	0.3888	0.3738
506	1983	0.1968	0.4442	0.4146

*Flexible Pavement
Structural Number 5.0
Terminal Serviceability Index = 2.5

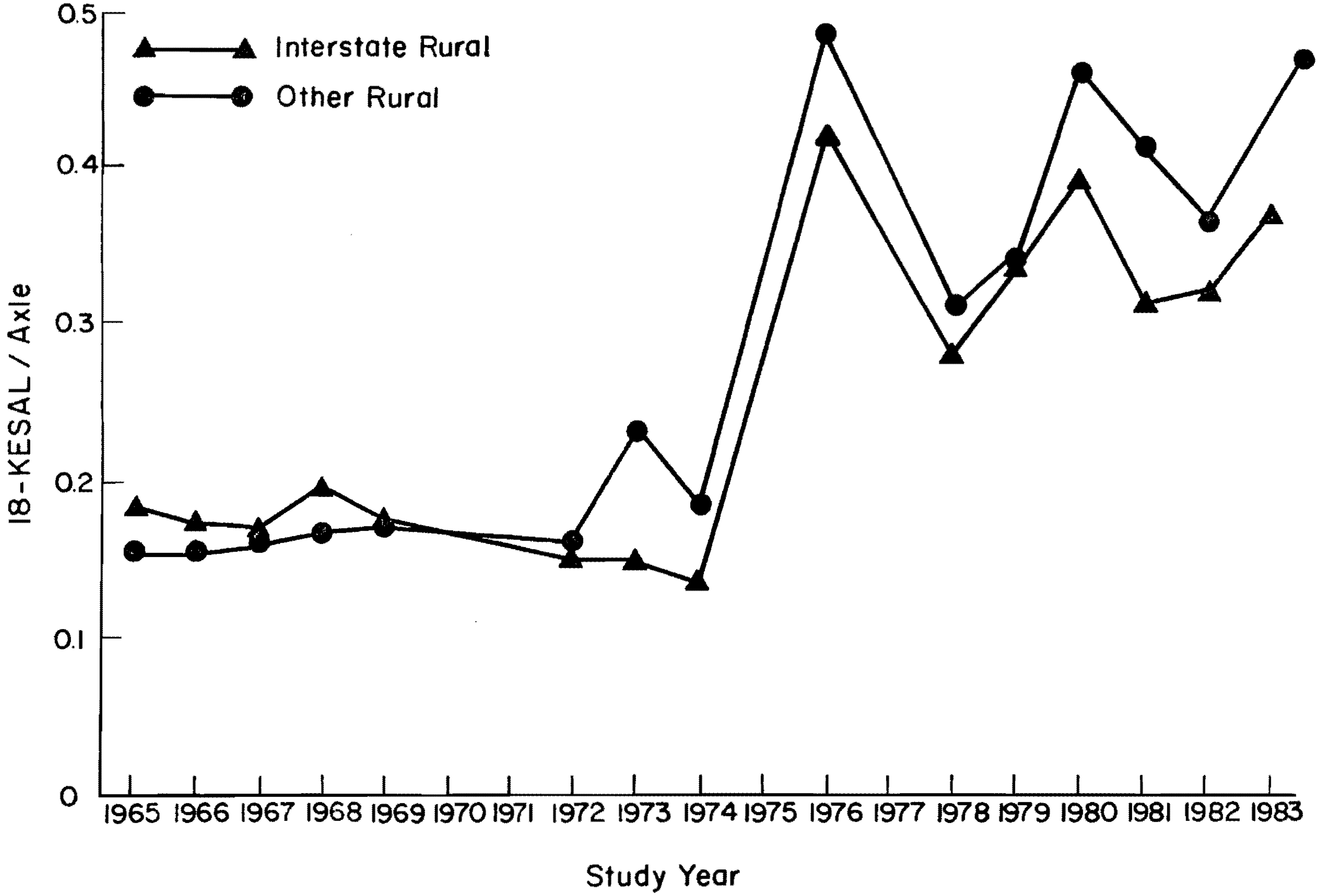

Fig D.1. Interstate Rural Versus Other Rural, 1965-1983

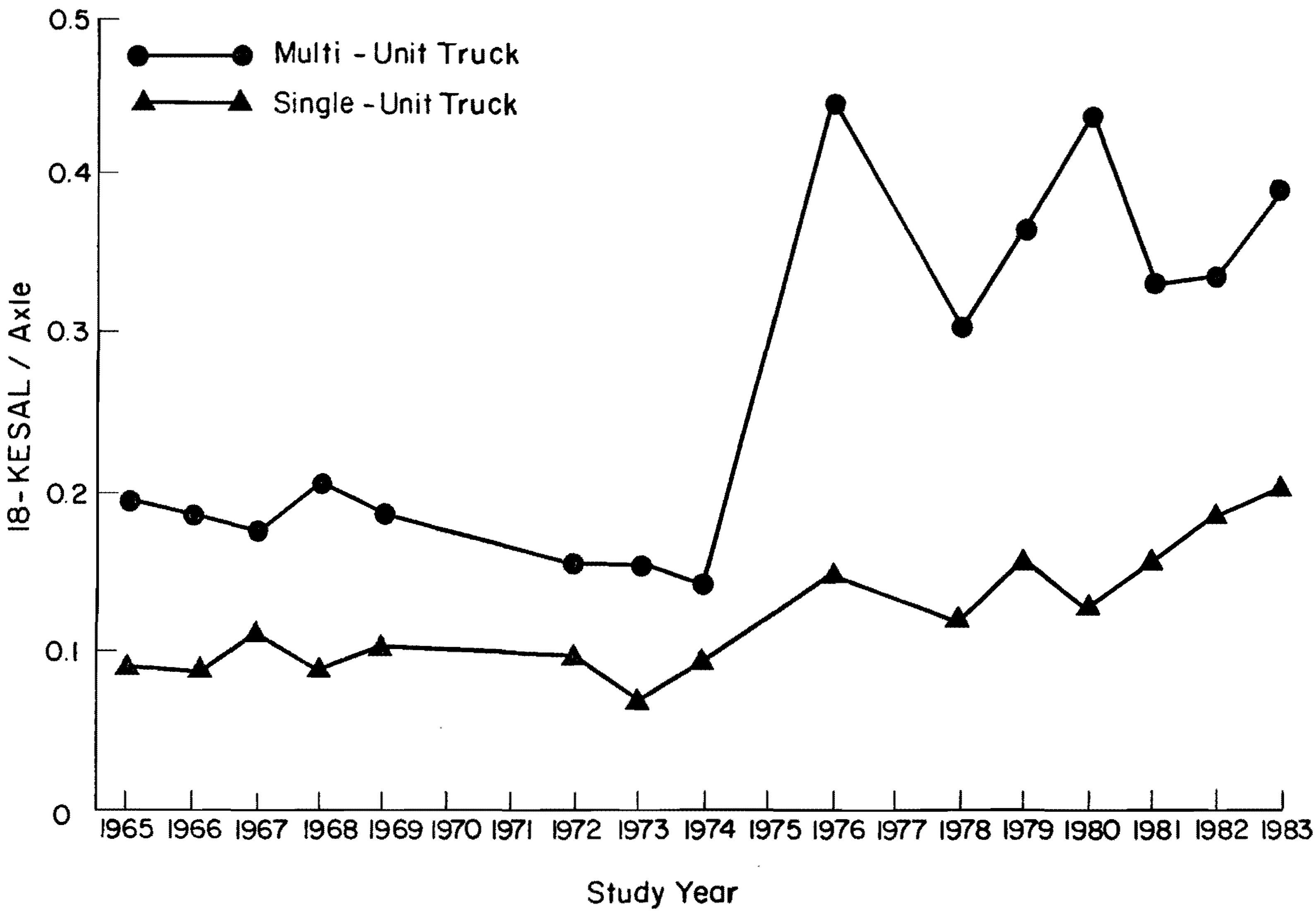

Fig D.2. Interstate: Multi-Unit Trucks Versus Single-Unit Trucks, 1965-1983

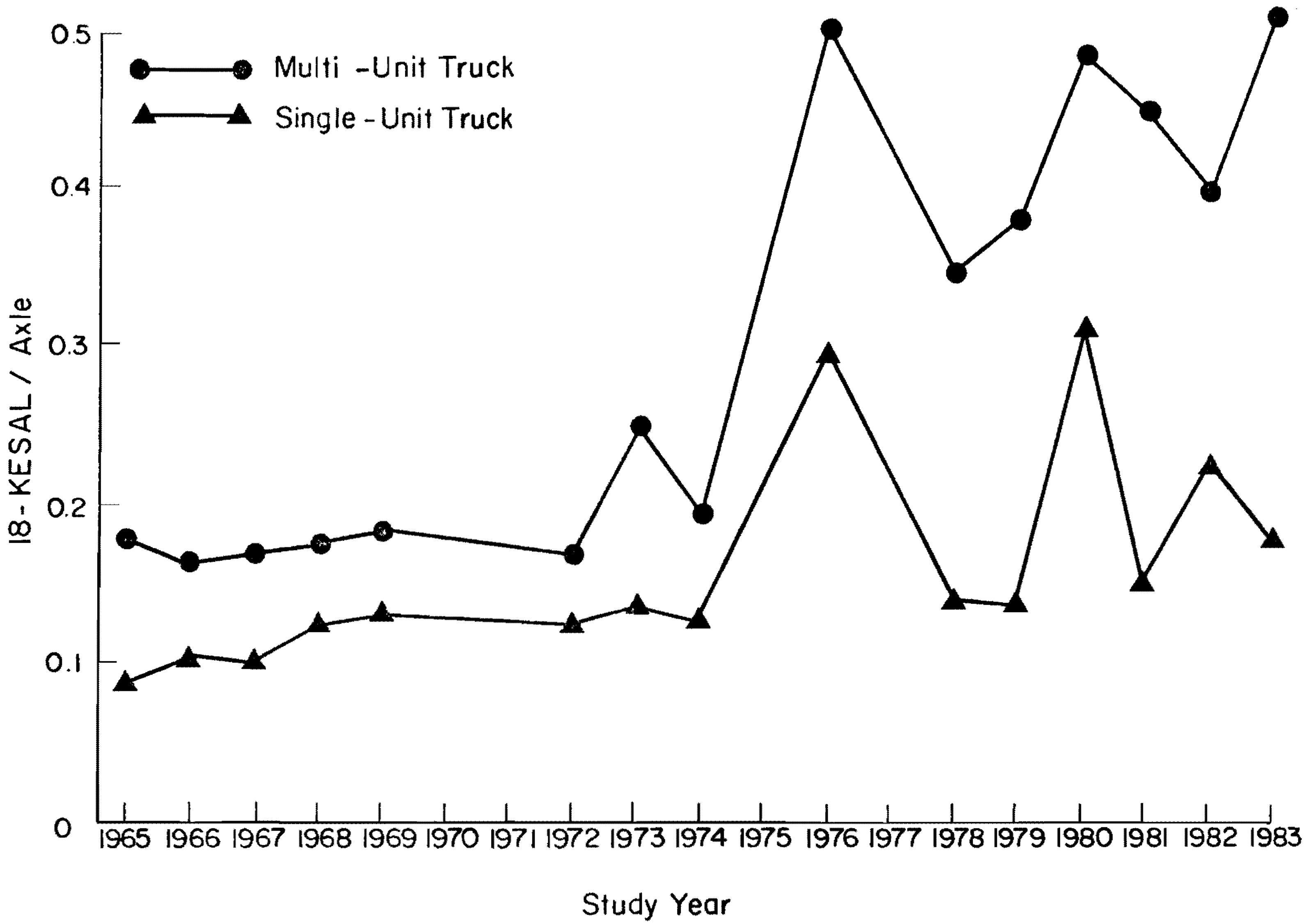

Fig D.3. Other Rural: Multi-Unit Trucks Versus Single-Unit Trucks, 1965-1983

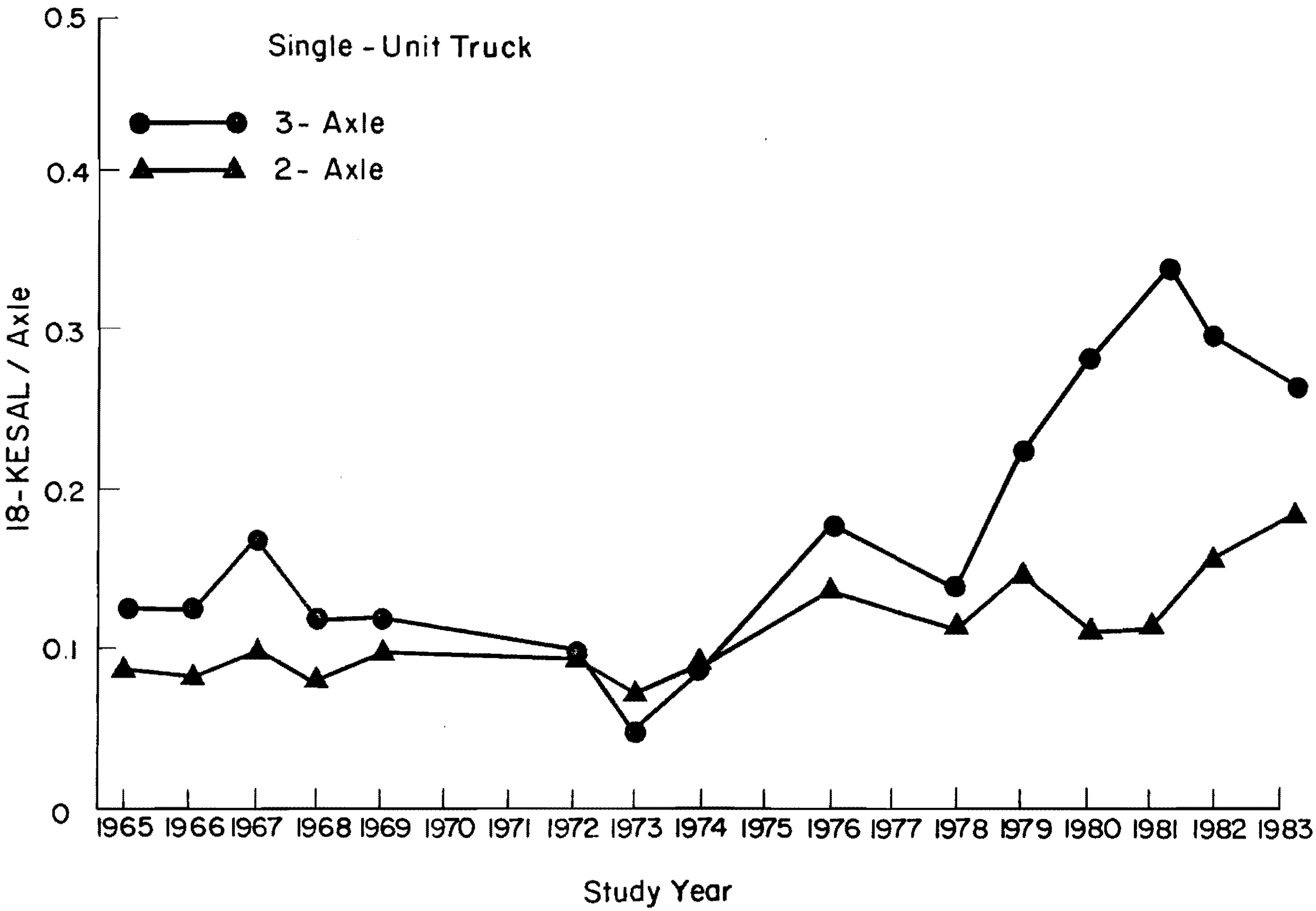

Fig D.4. Interstate, Single-Unit Truck: 2-Axle Versus 3-Axle, 1965-1983

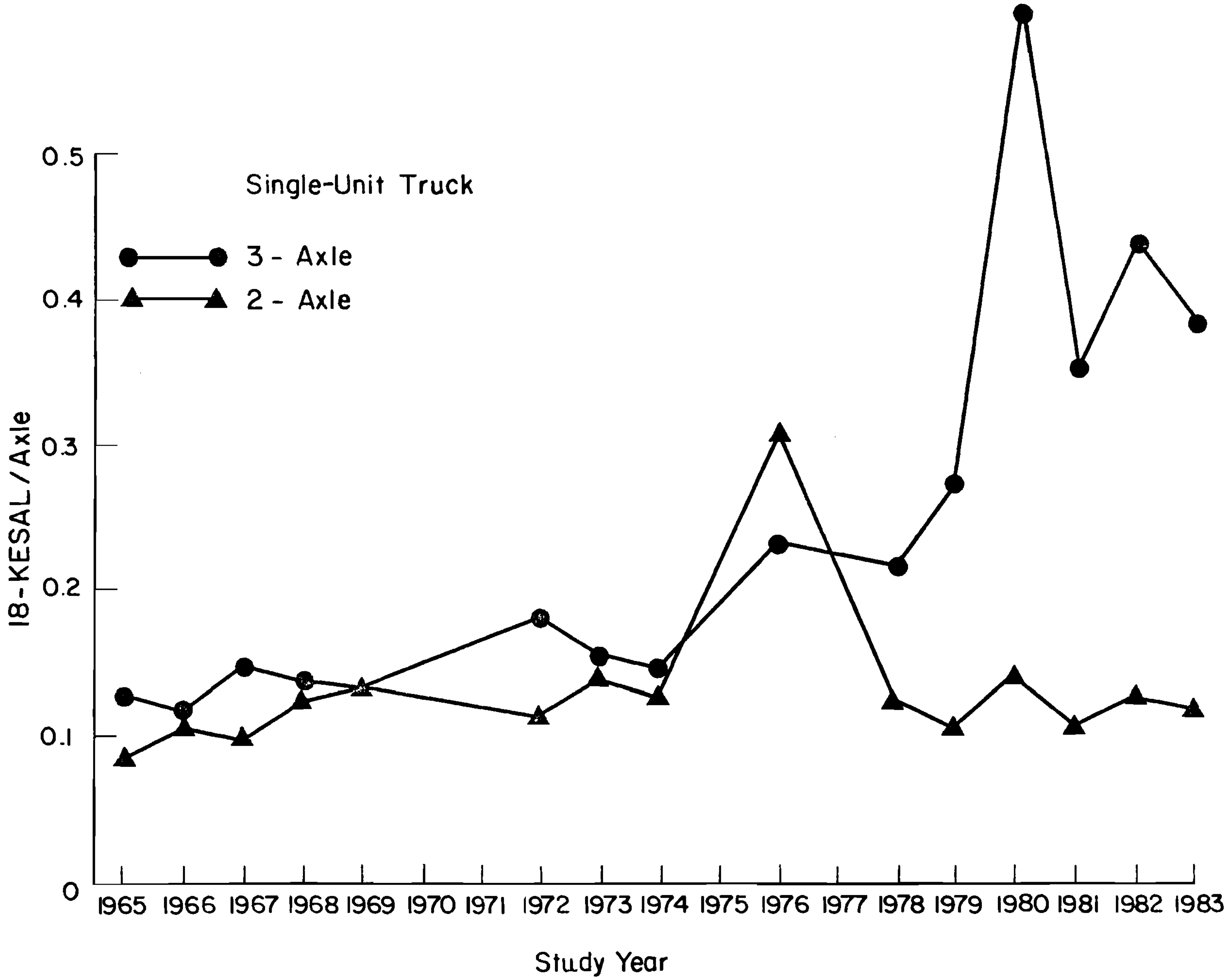

Fig D.5. Other Rural, Single-Unit Truck: 2-Axle Versus 3-Axle, 1965-1983

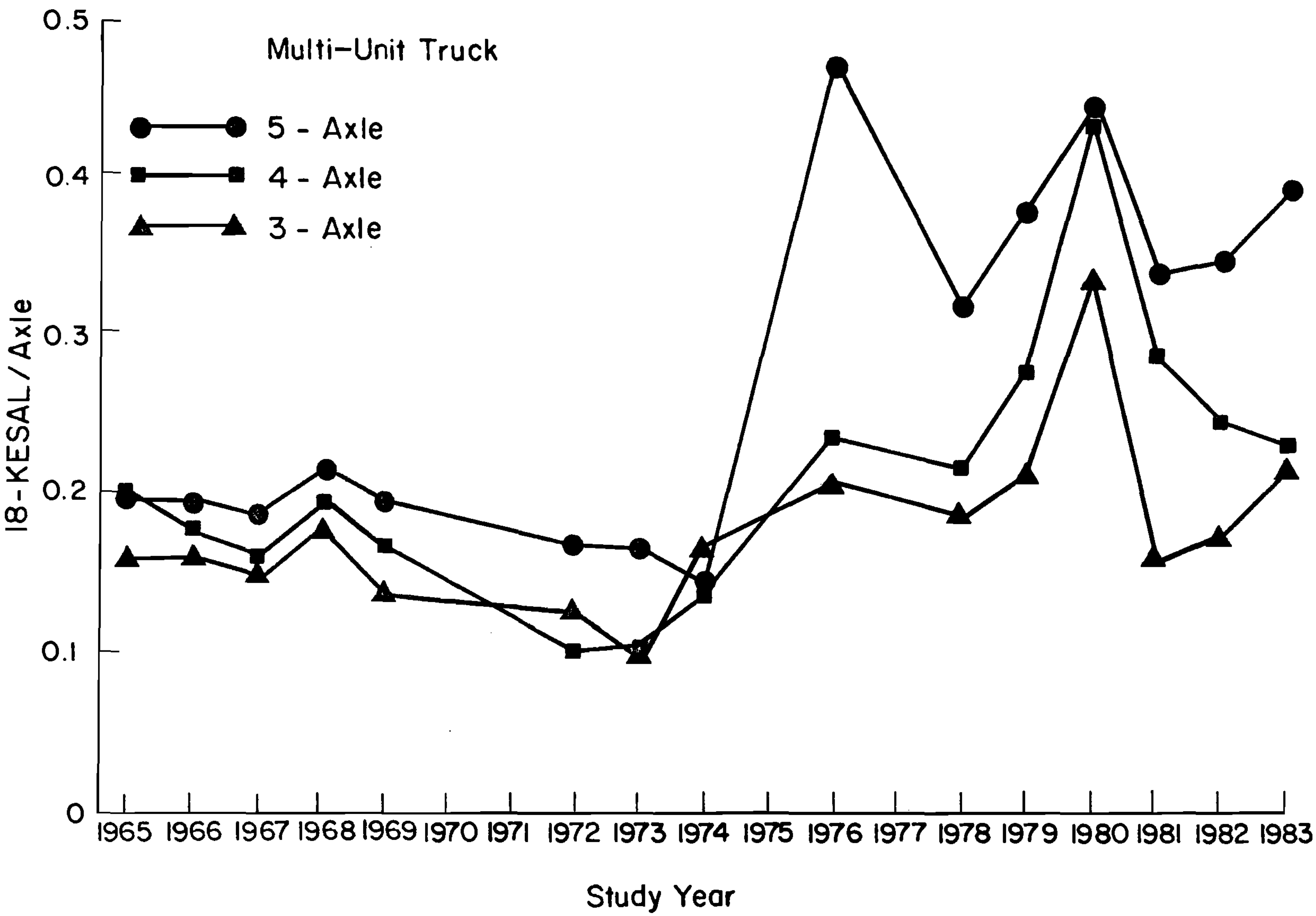

Fig D.6. Interstate, Multi-Unit Truck: 3-Axle, 4-Axle, And 5-Axle, 1965-1983

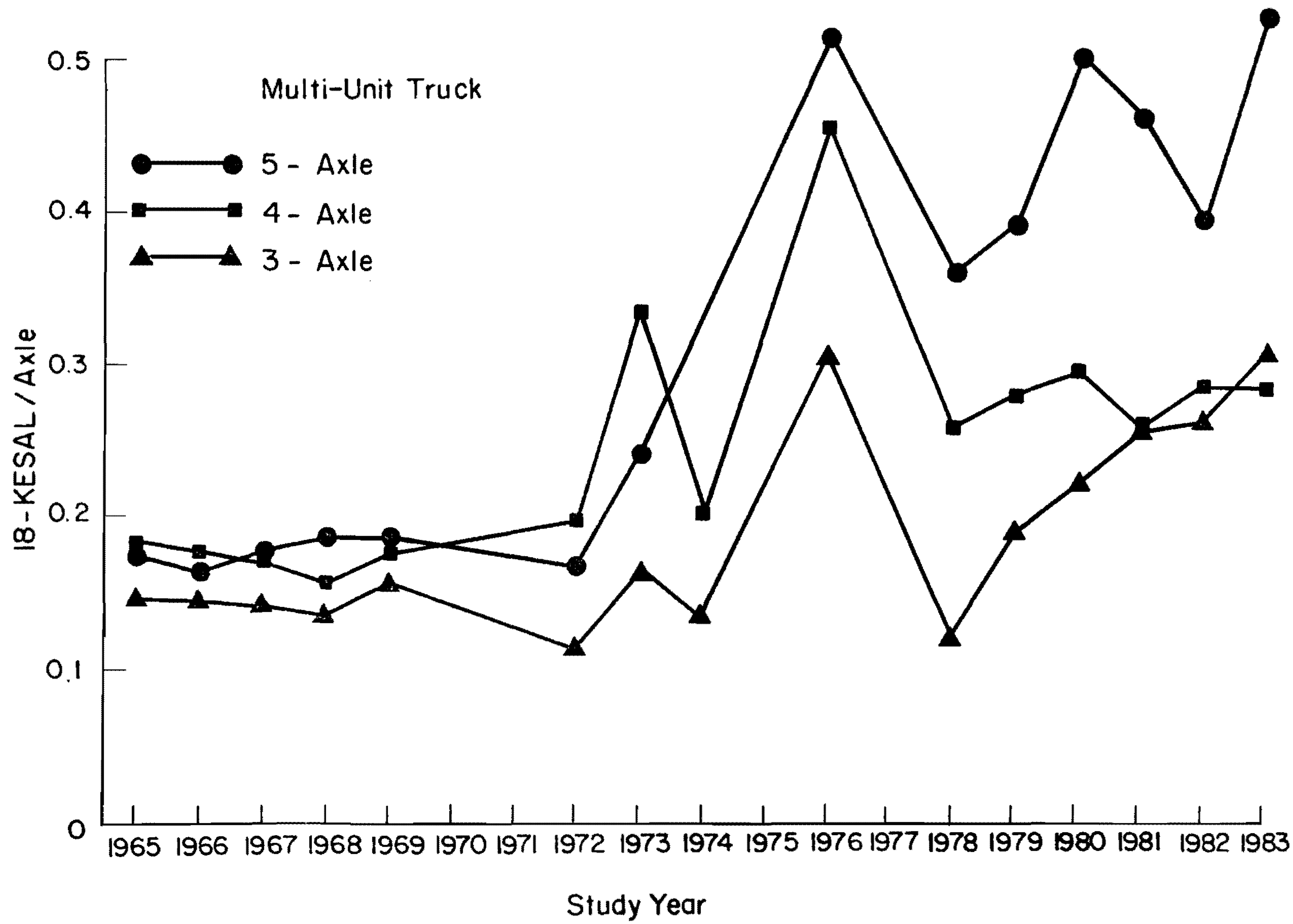

Fig D.7. Other Rural, Multi-Unit Truck: 3-Axle, 4-Axle, And 5-Axle, 1965-1983 increase represents a statewide increase in average truck weights and how much is due to the switch in 1975 from a manual weighing program to a WIM program.

The flexible pavement 18-KESAL/axle factors, by WIM station, are shown graphically in Figures D.8 through D.10, for all truck types combined. For the period from 1976 to 1983, there does not appear to be a significant upward or downward trend in axle load equivalencies. However, there are significant year-to-year variations, possible due to small samples sizes. Figures D.11 through D.31 show 18-KESAL/axle factors, by station, for the various truck types. While significant year-to-year variations can be detected at each station, it is interesting to note that station-to-station variations (by truck type) are not much larger.

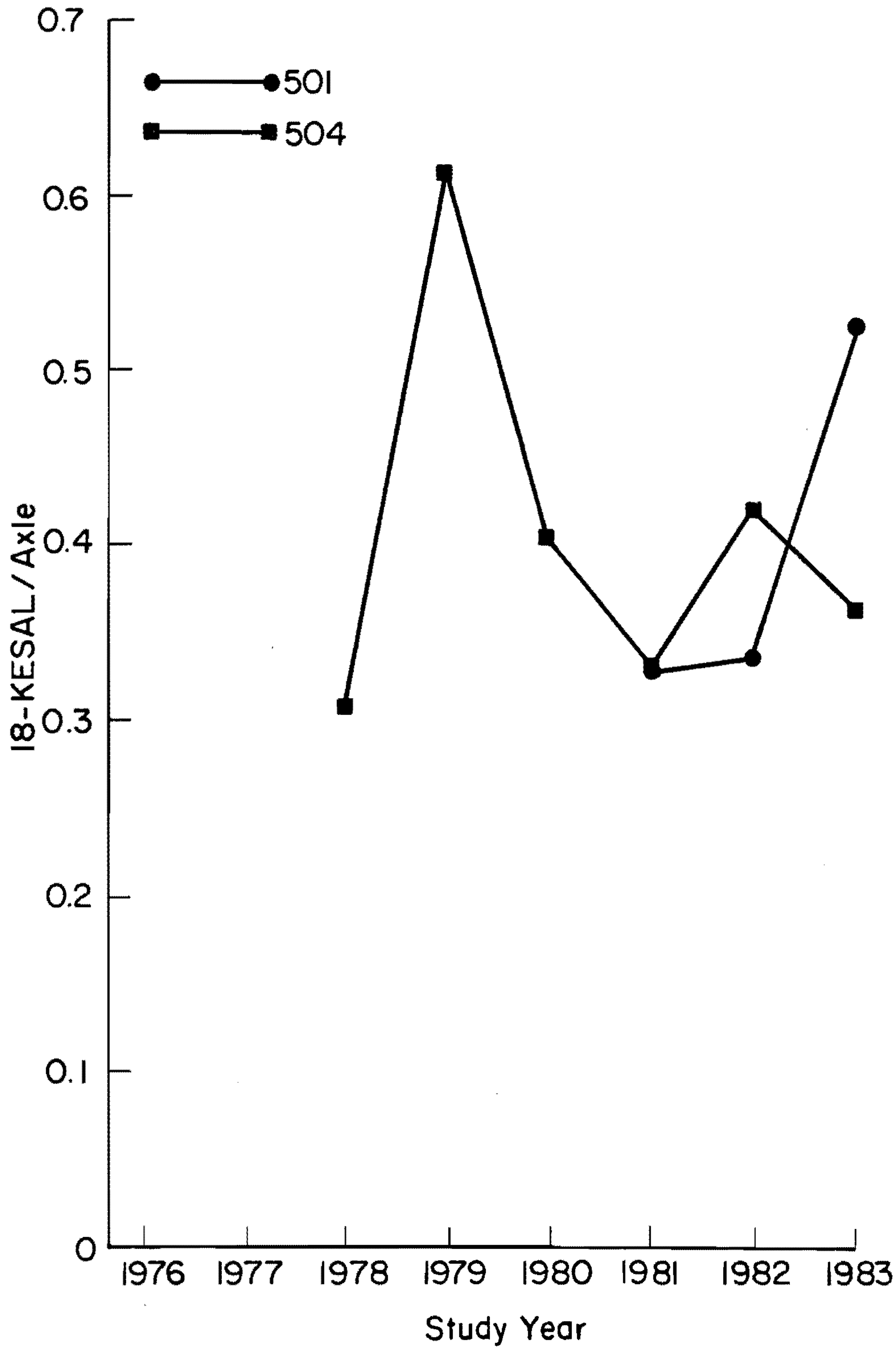

Fig D.8. All Trucks: Stations 501 and 504, 1978-1983

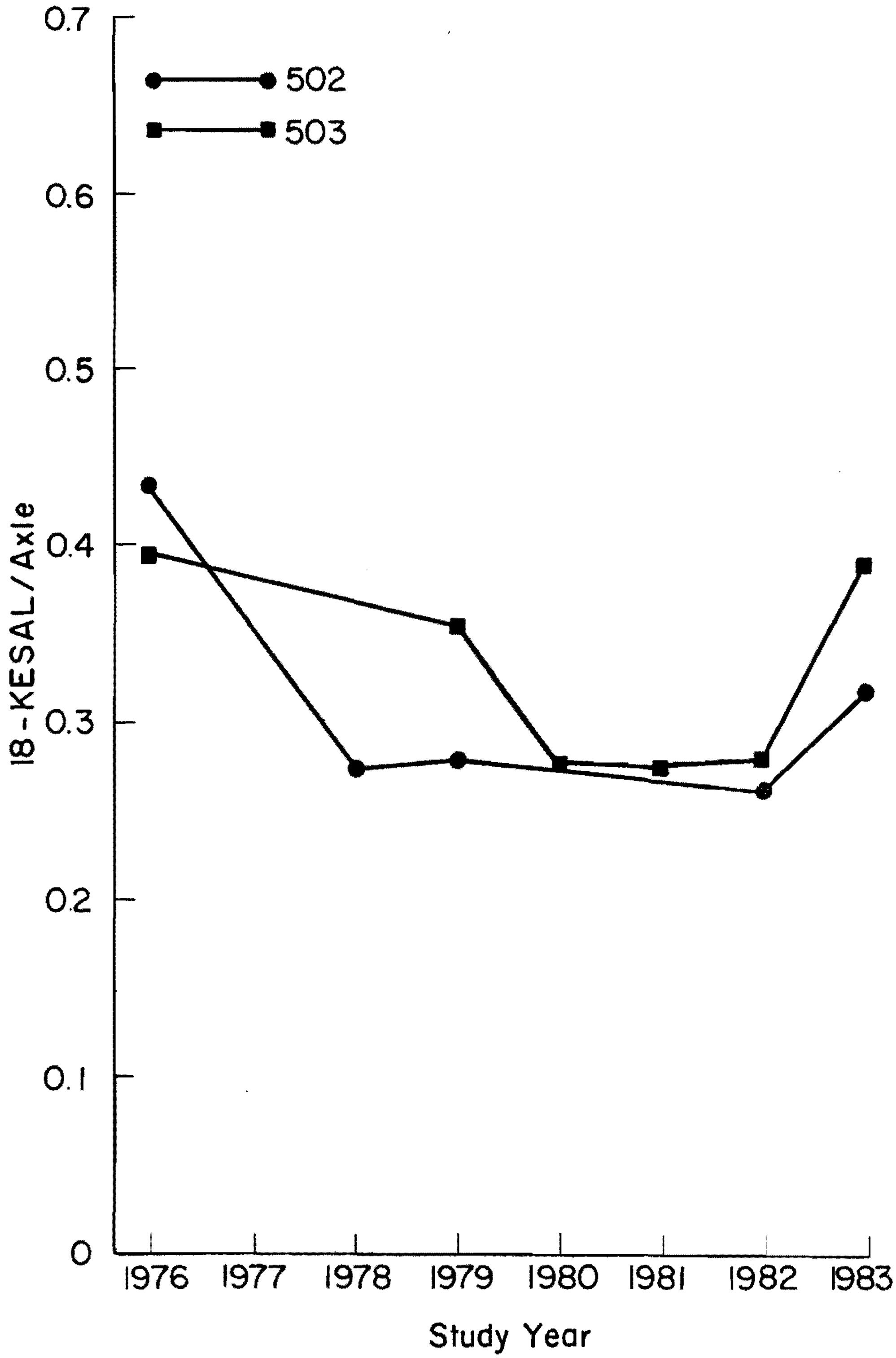

Fig D.9. All Trucks: Stations 502 And 503, 1976-1983

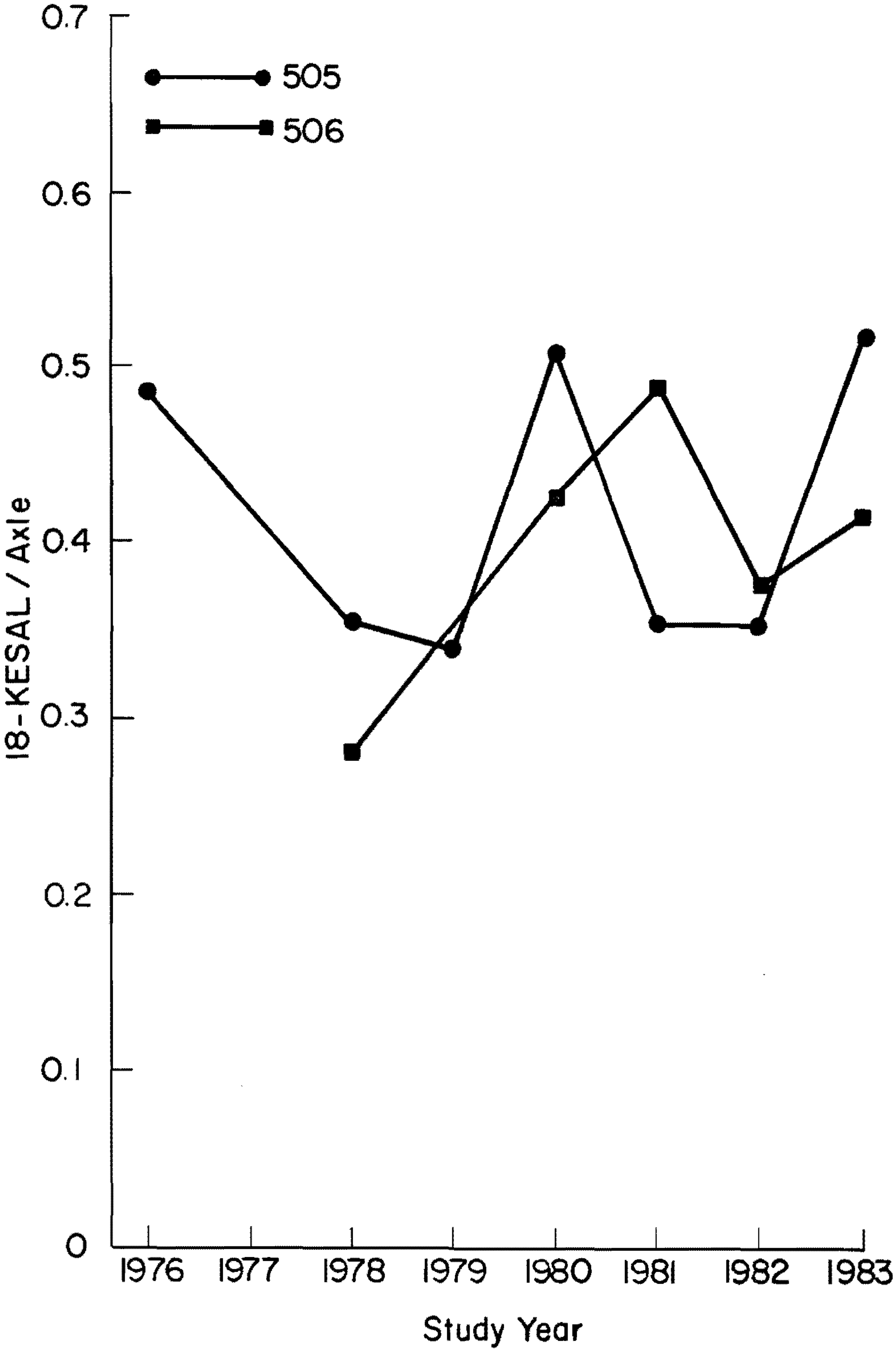

Fig D.10. All Trucks: Stations 505 And 506, 1976-1983

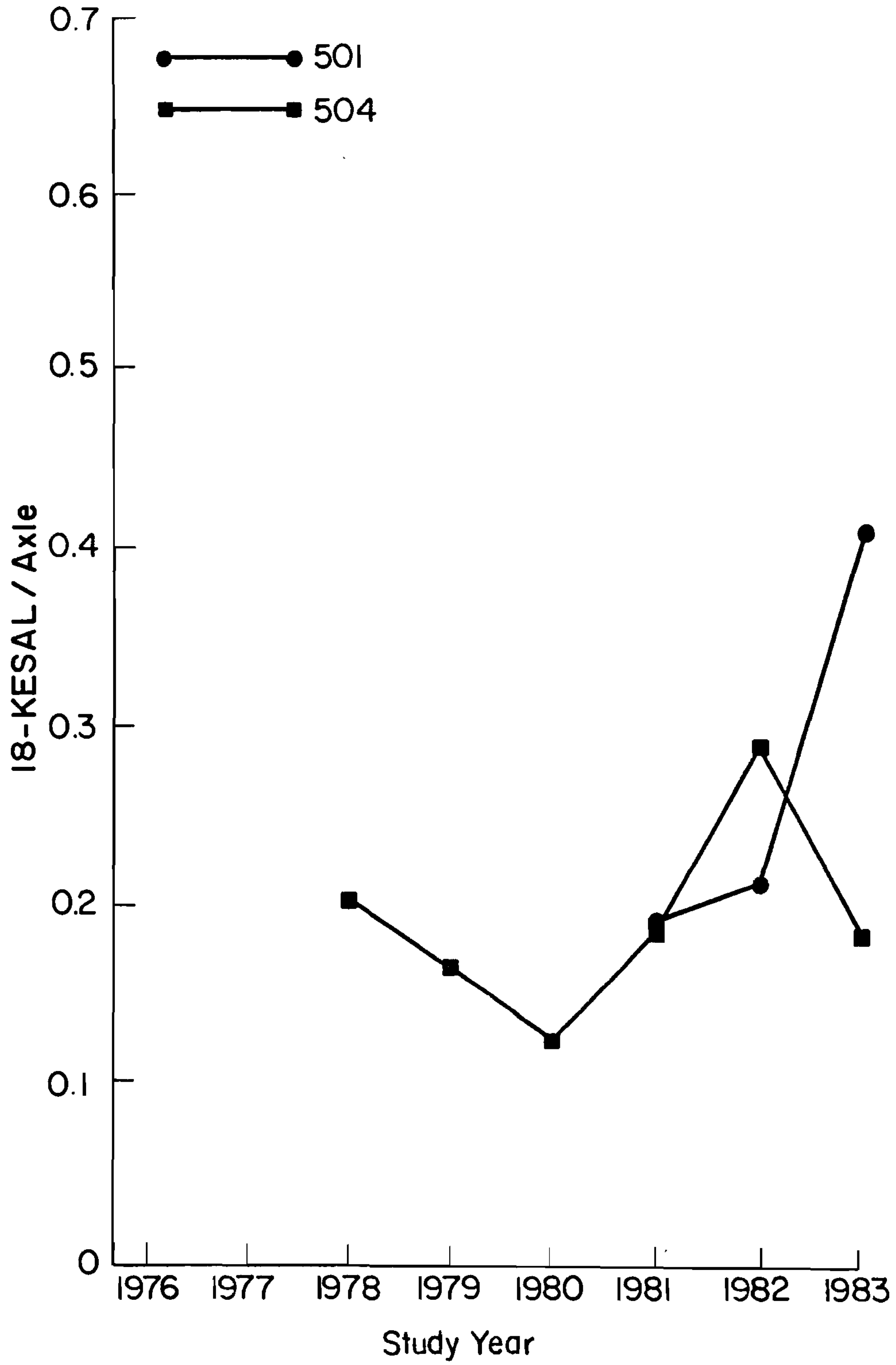

Fig D.11. Single-Unit Trucks: Stations 501 And 504, 1978-1983

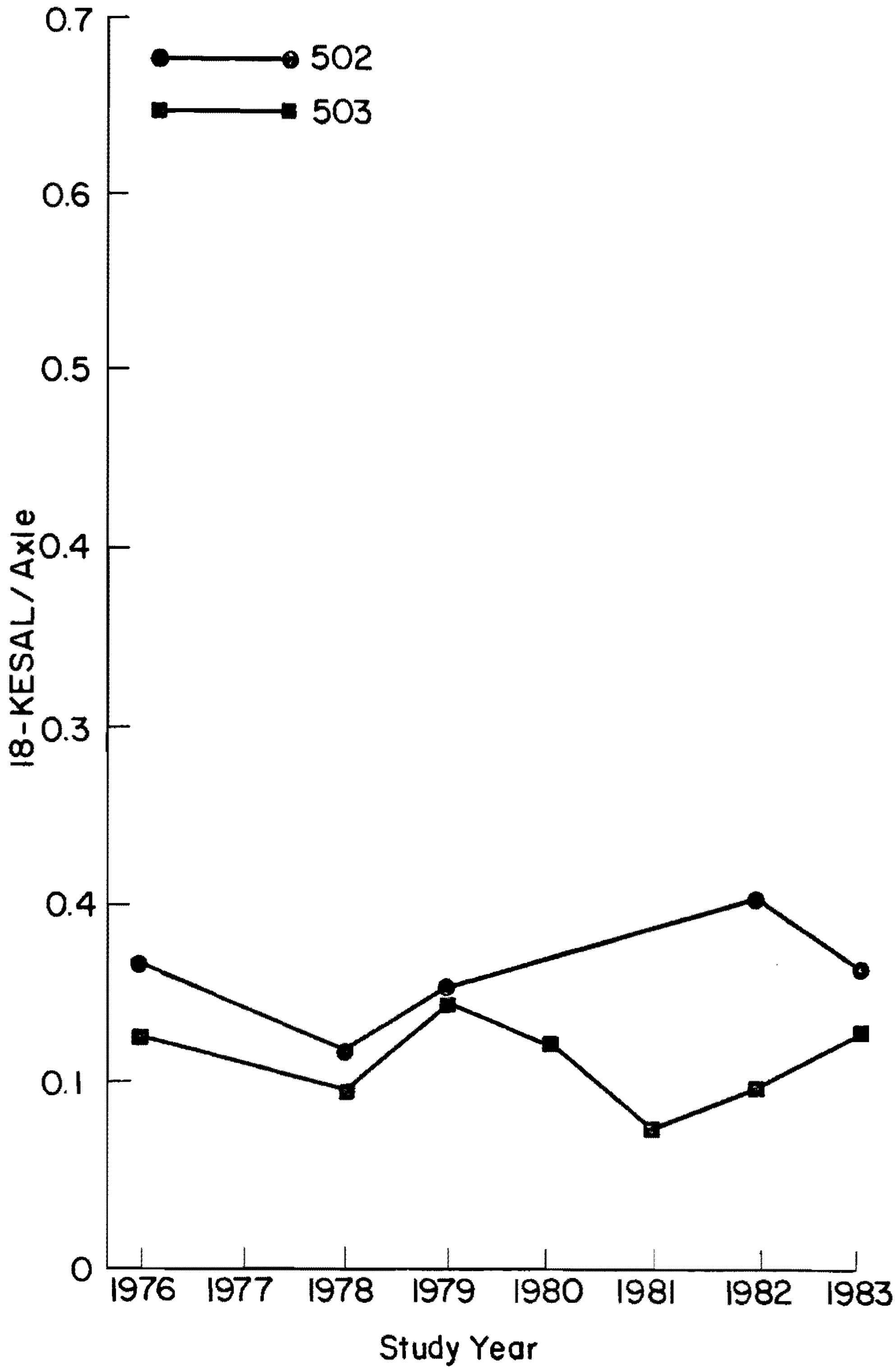

Fig D.12. Single-Unit Trucks: Stations 502 and 503, 1976-1983

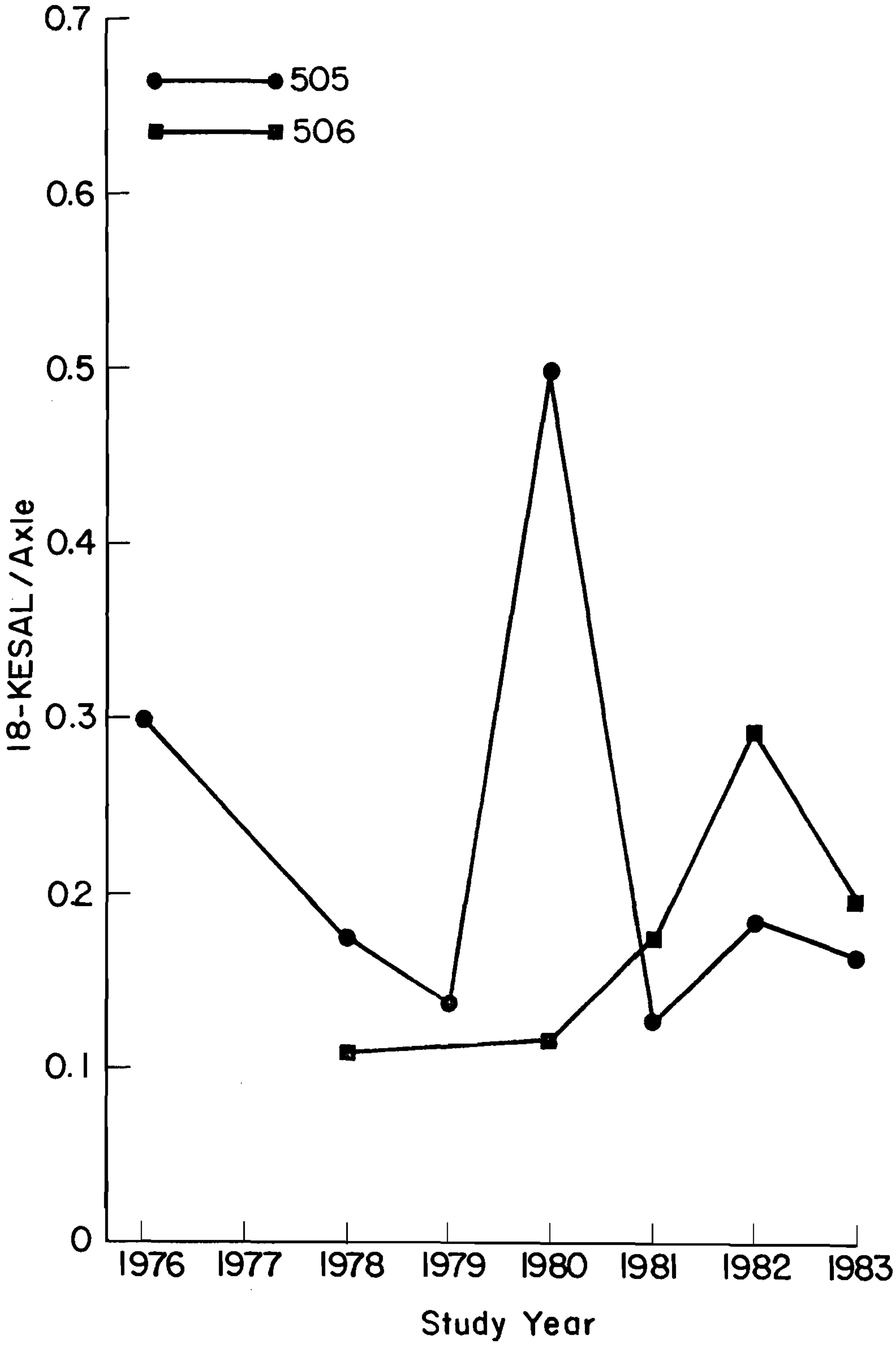

Fig D.13. Single-Unit Trucks: Stations 505 and 506, 1976-1983

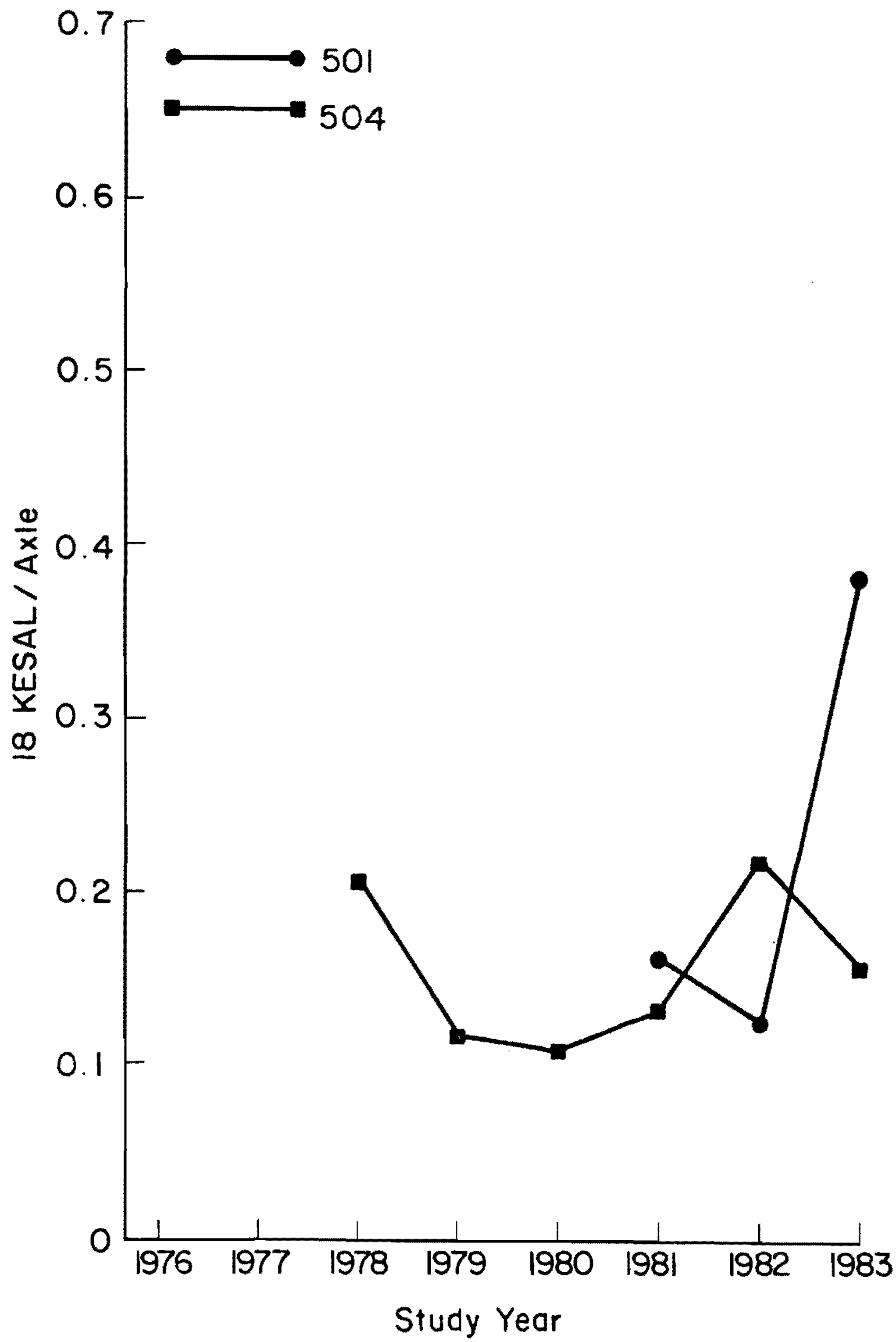

Fig D.14. 2-Axle Single-Unit Trucks: Stations 501 and 504, 1978-1983

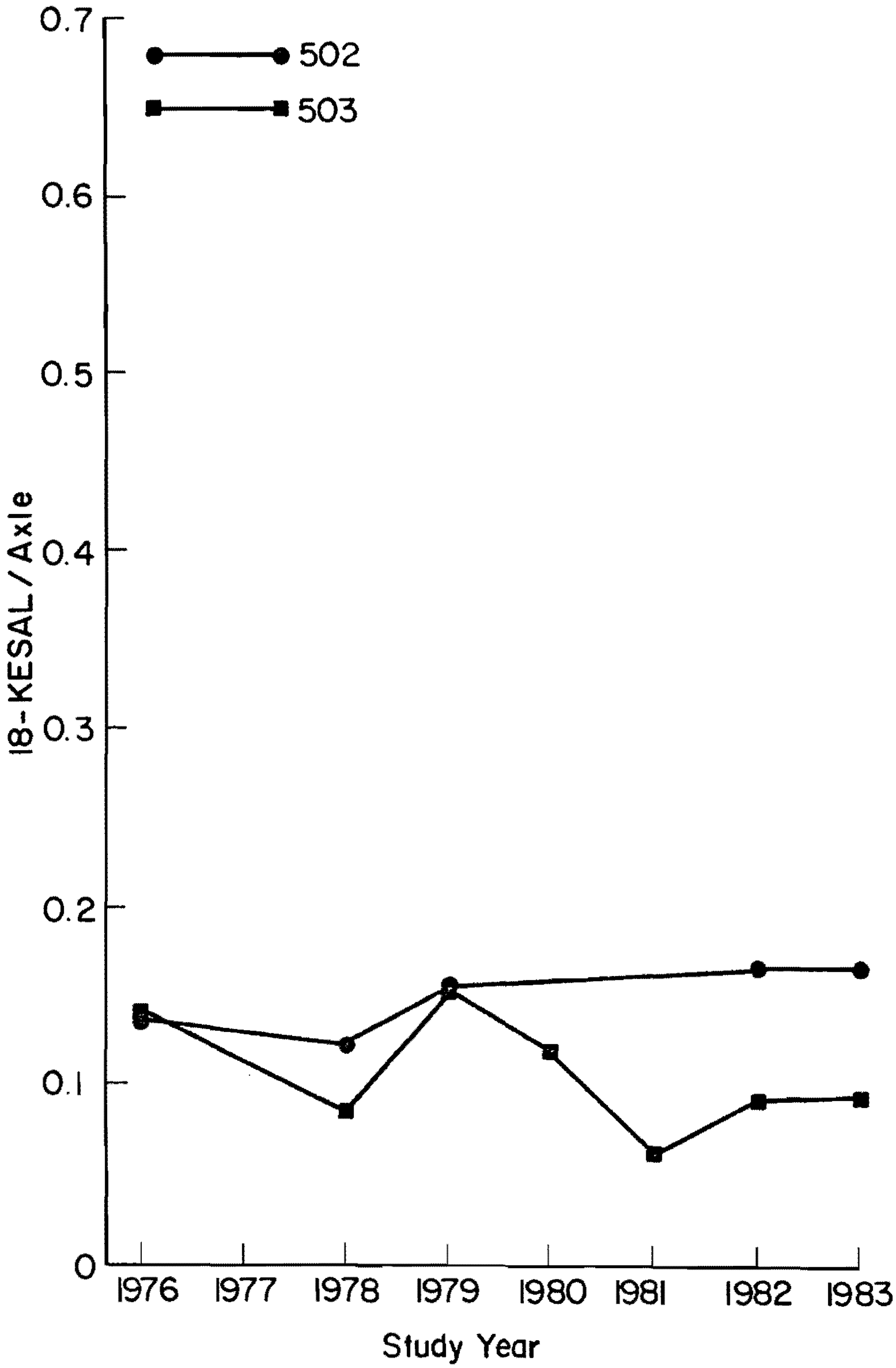

Fig D.15. 2-Axle Single-Unit Trucks: Stations 502 and 503, 1976-1983

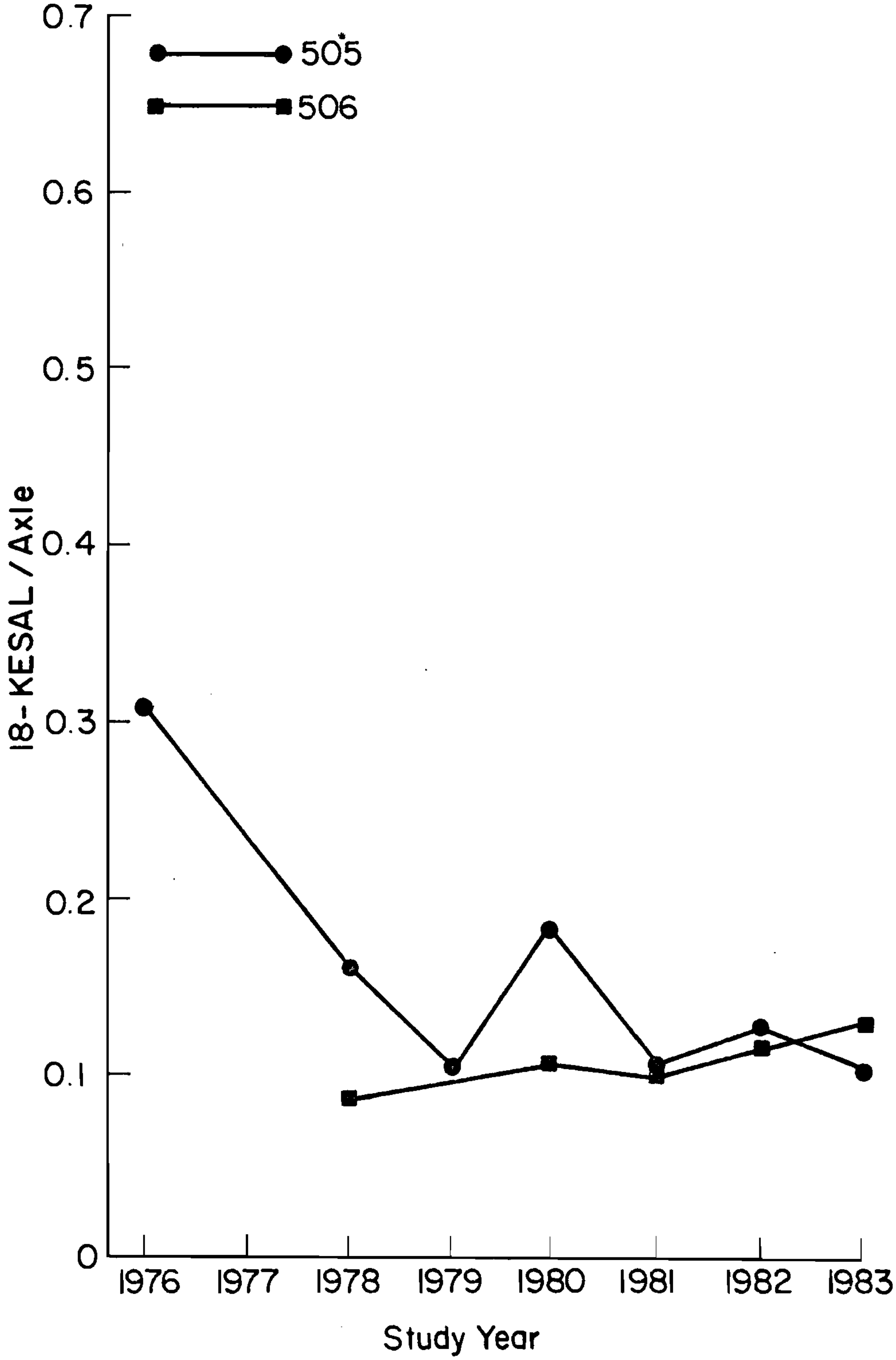

Fig D.16. 2-Axle Single-Unit Trucks: Stations 505 and 506, 1976-1983

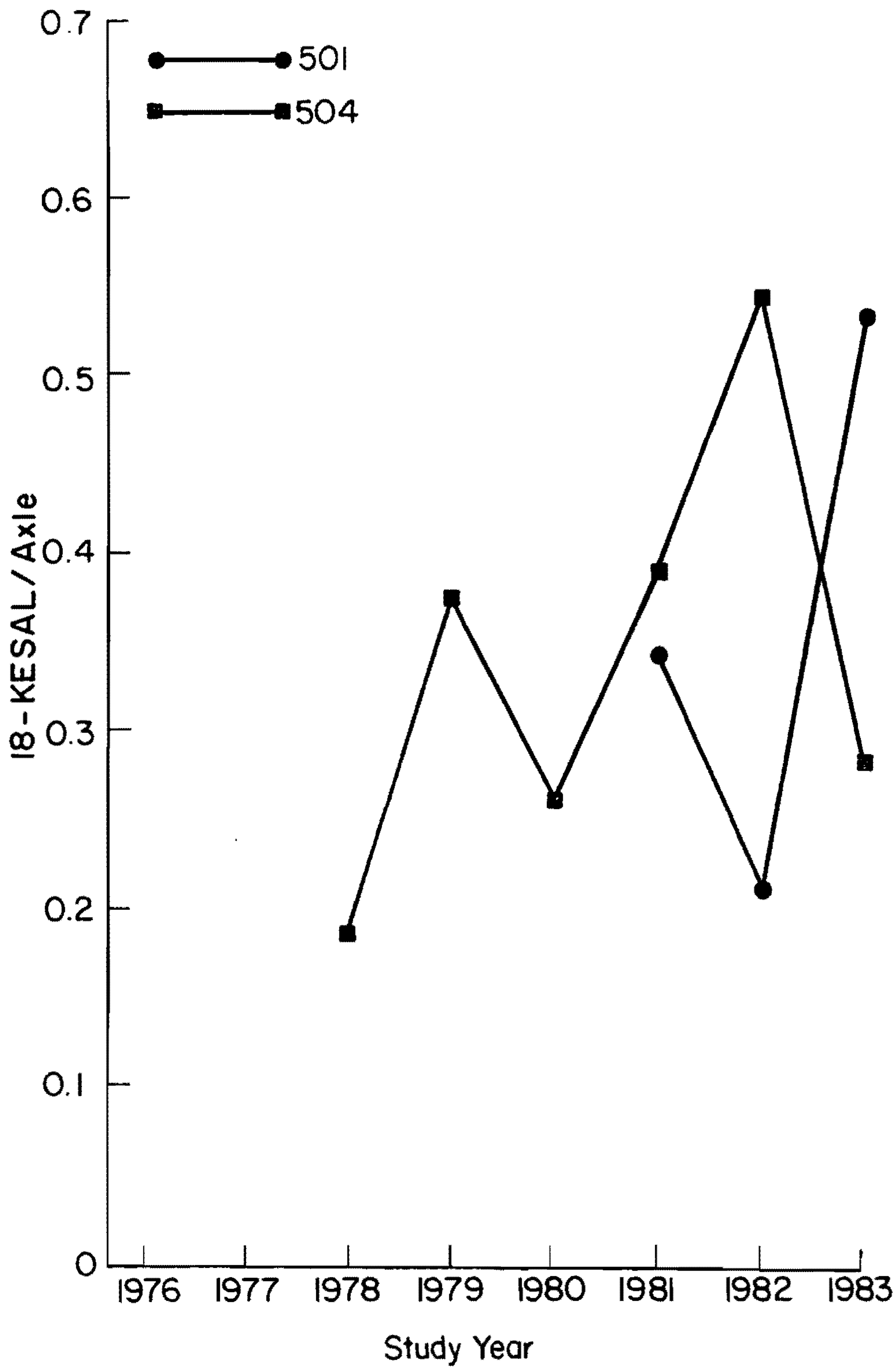

Fig D.17. 3-Axle Single-Unit Trucks: Stations 501 and 504, 1978-1983

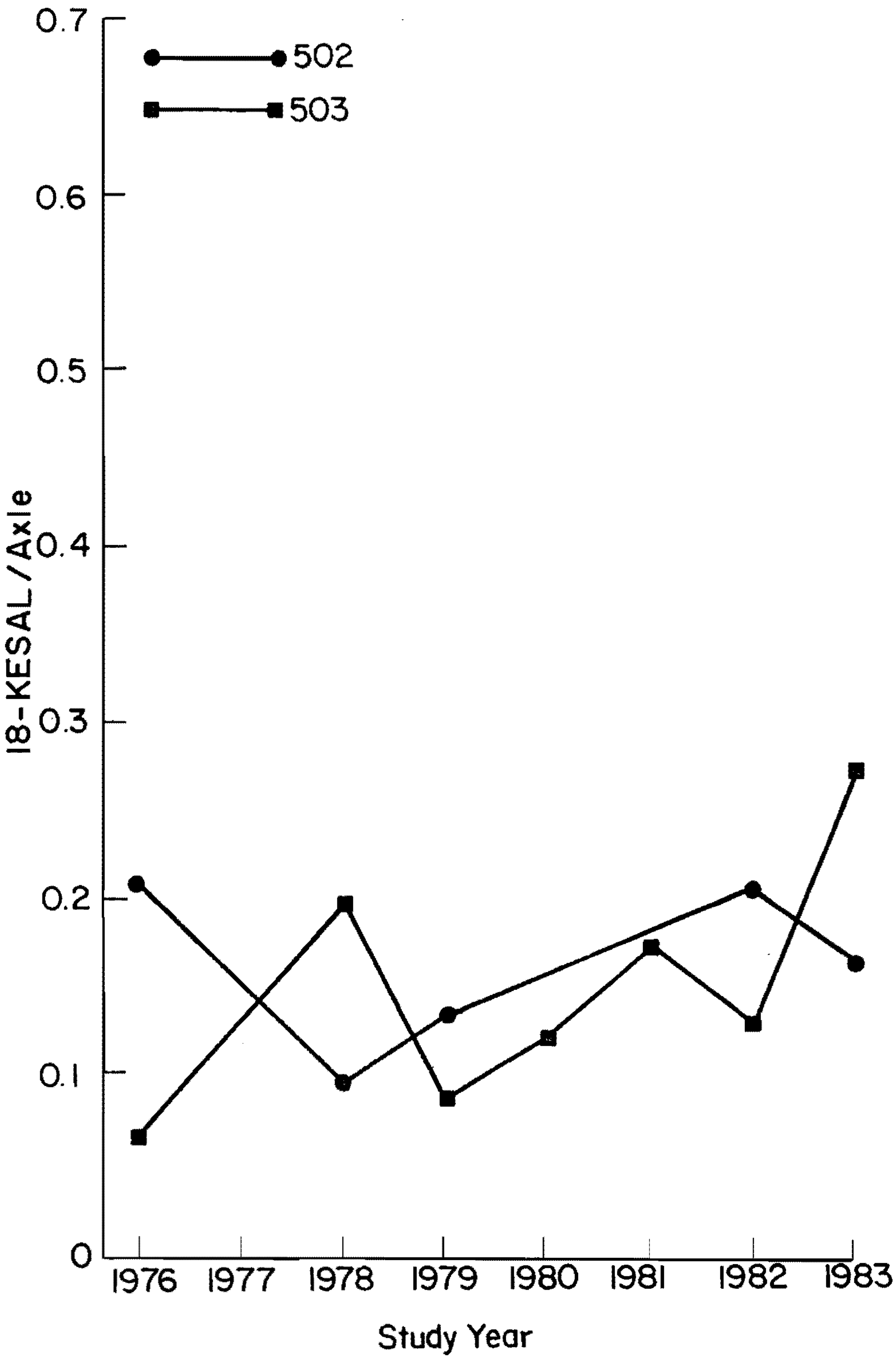

Fig D.18. 3-Axle Single-Unit Trucks: Stations 502 and 503, 1976-1983

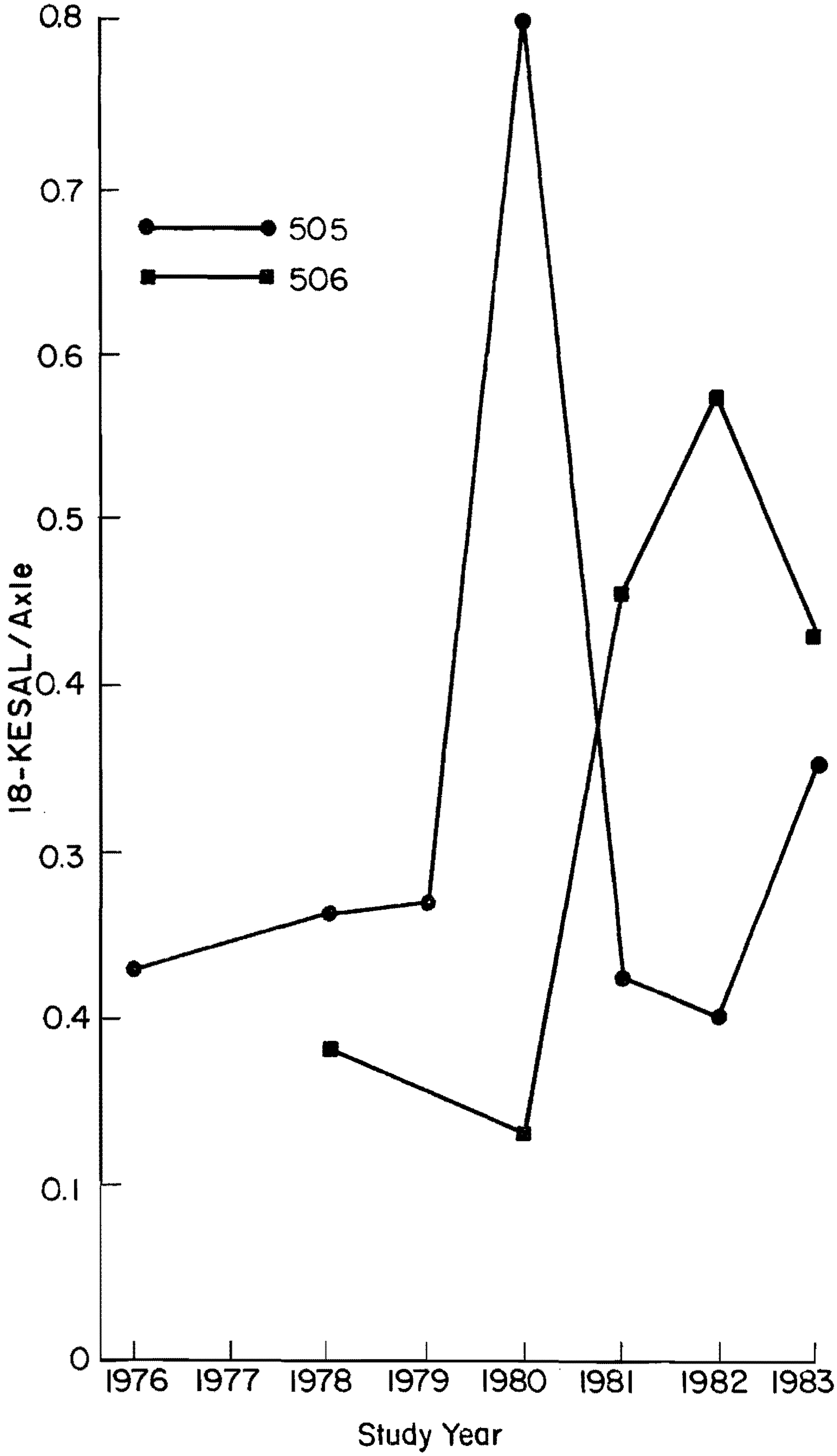

Fig D.19. 3-Axle Single-Unit Trucks: Stations 505 and 506, 1976-1983

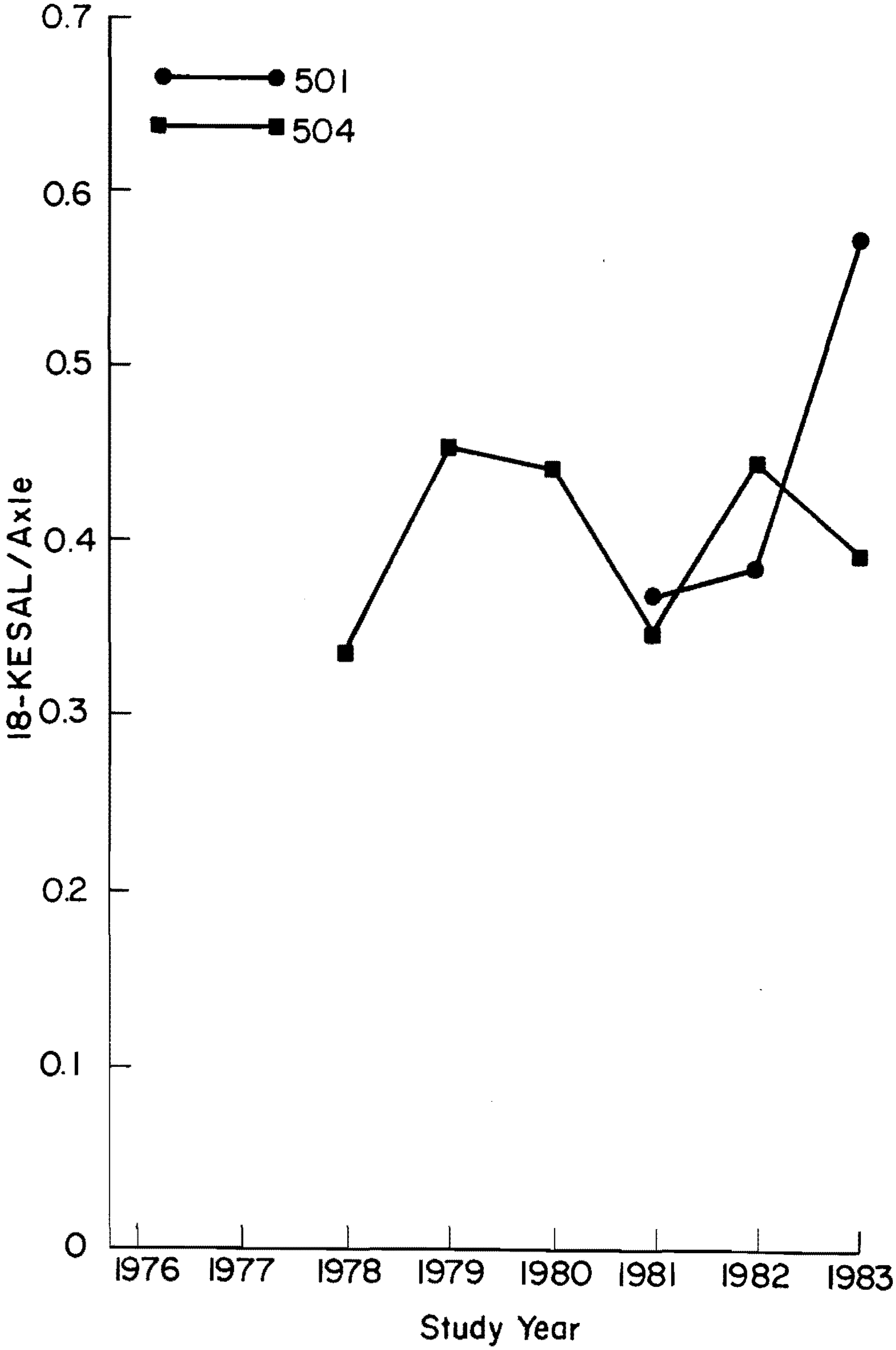

Fig D.20. Multiple-Unit Trucks: Stations 501 and 504, 1978-1983

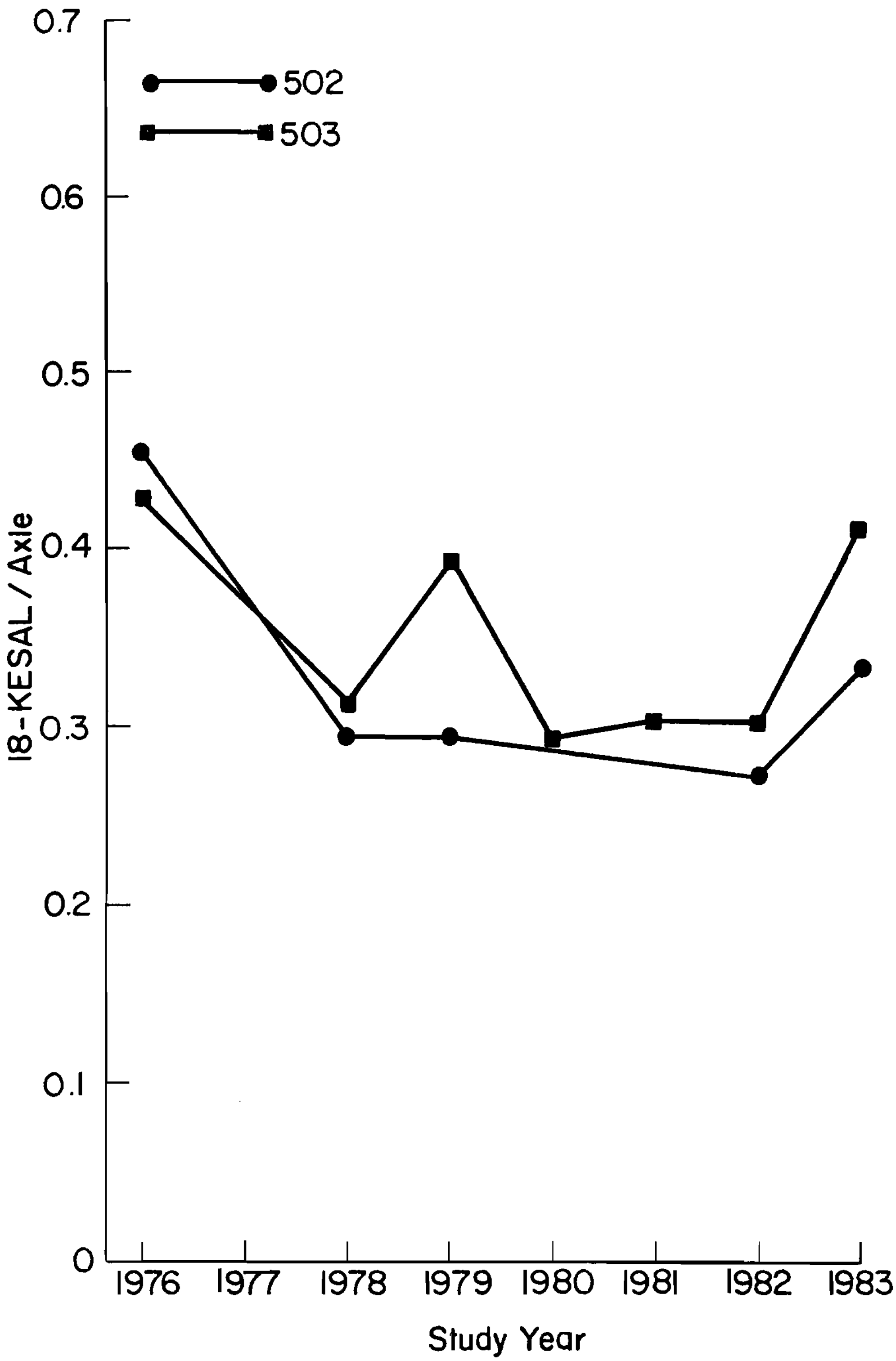

Fig D.21. Multi-Unit Trucks: Stations 502 and 503, 1976-1983

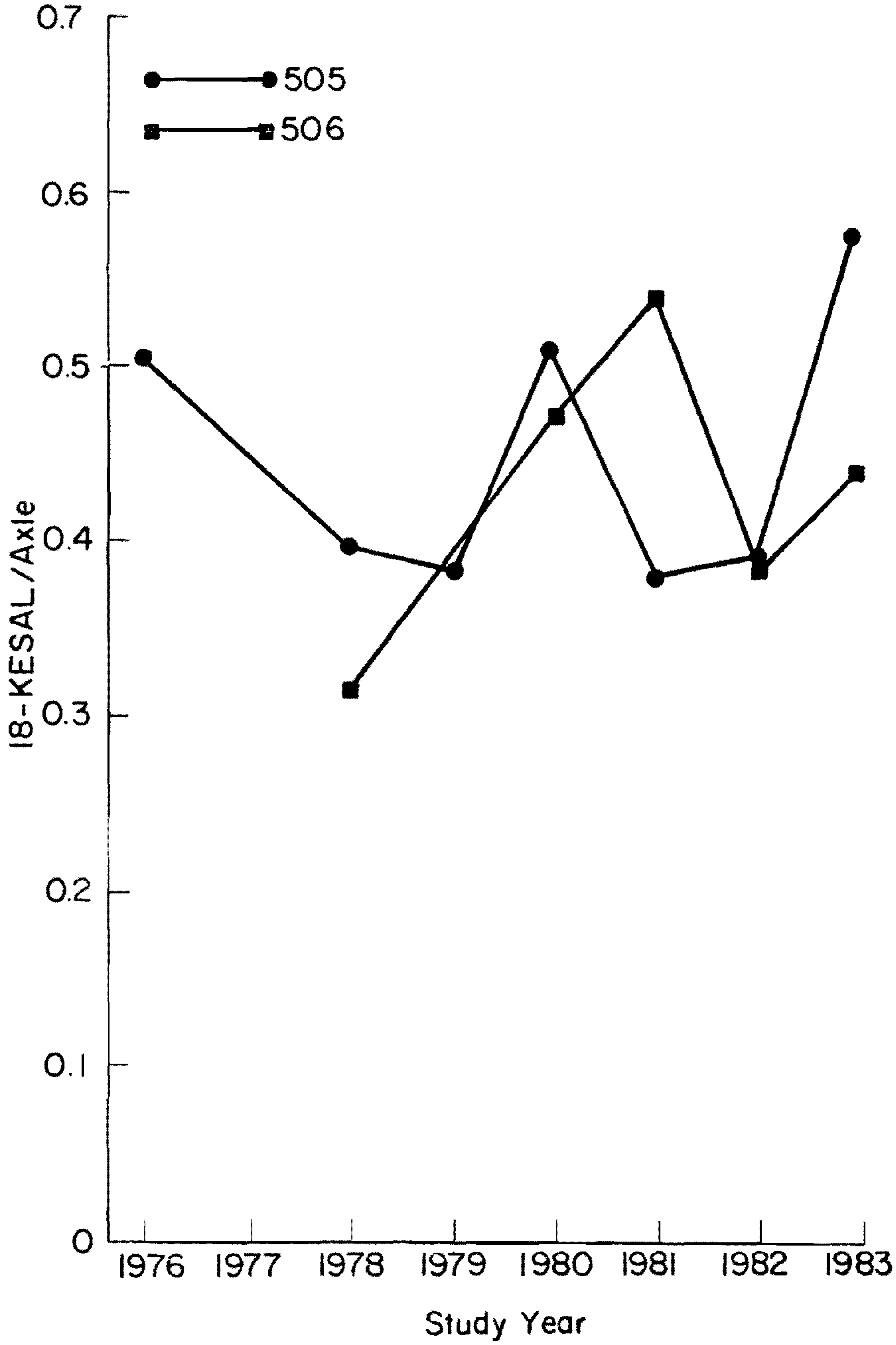

Fig D.22. Multi-Unit Trucks: Stations 505 and 506, 1976-1983

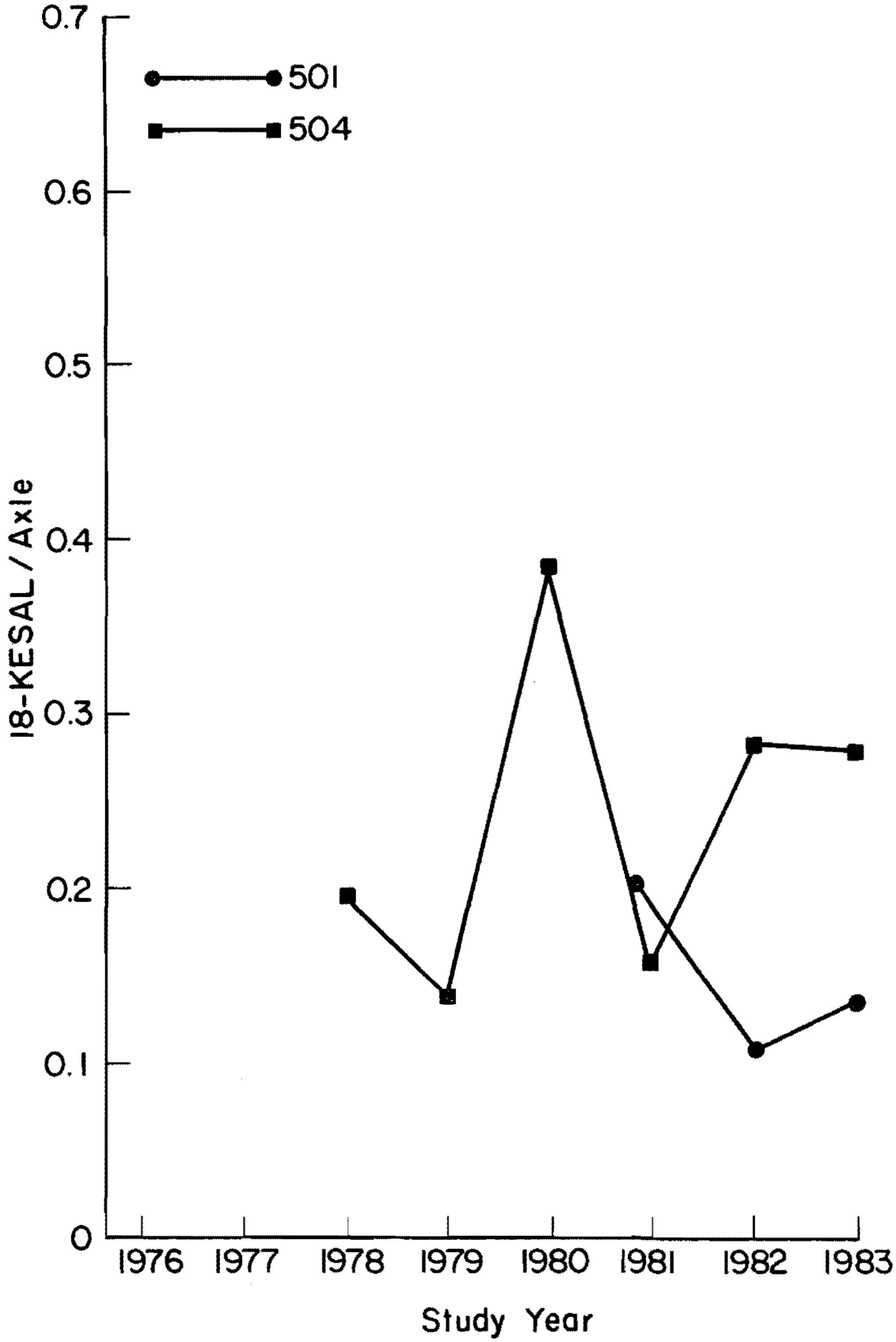

Fig D.23. 3-Axle Multiple-Unit Trucks: Stations 501 and 504, 1978-1983

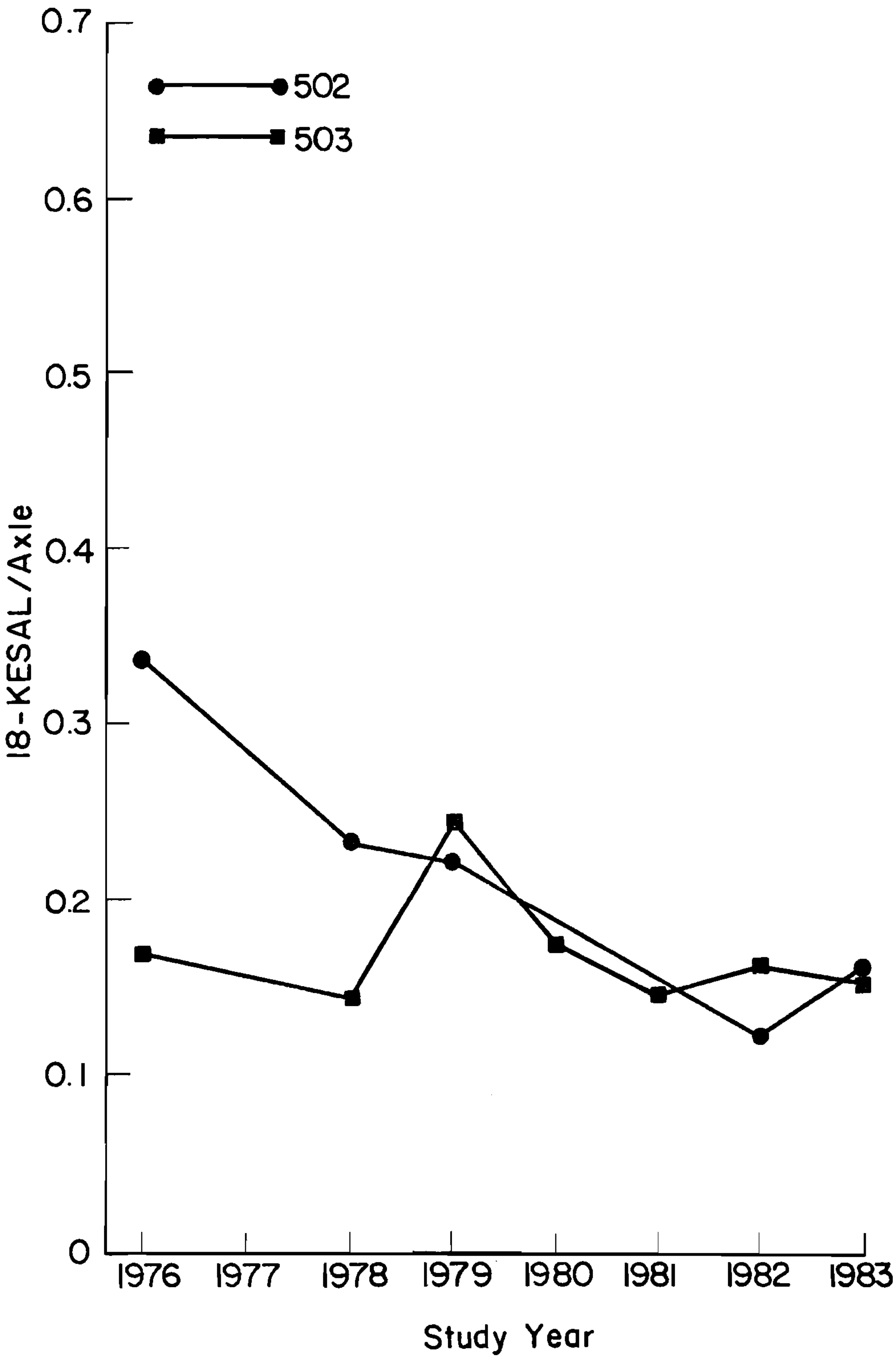

Fig D.24. 3-Axle Multi-Unit Trucks: Stations 502 and 503, 1976-1983

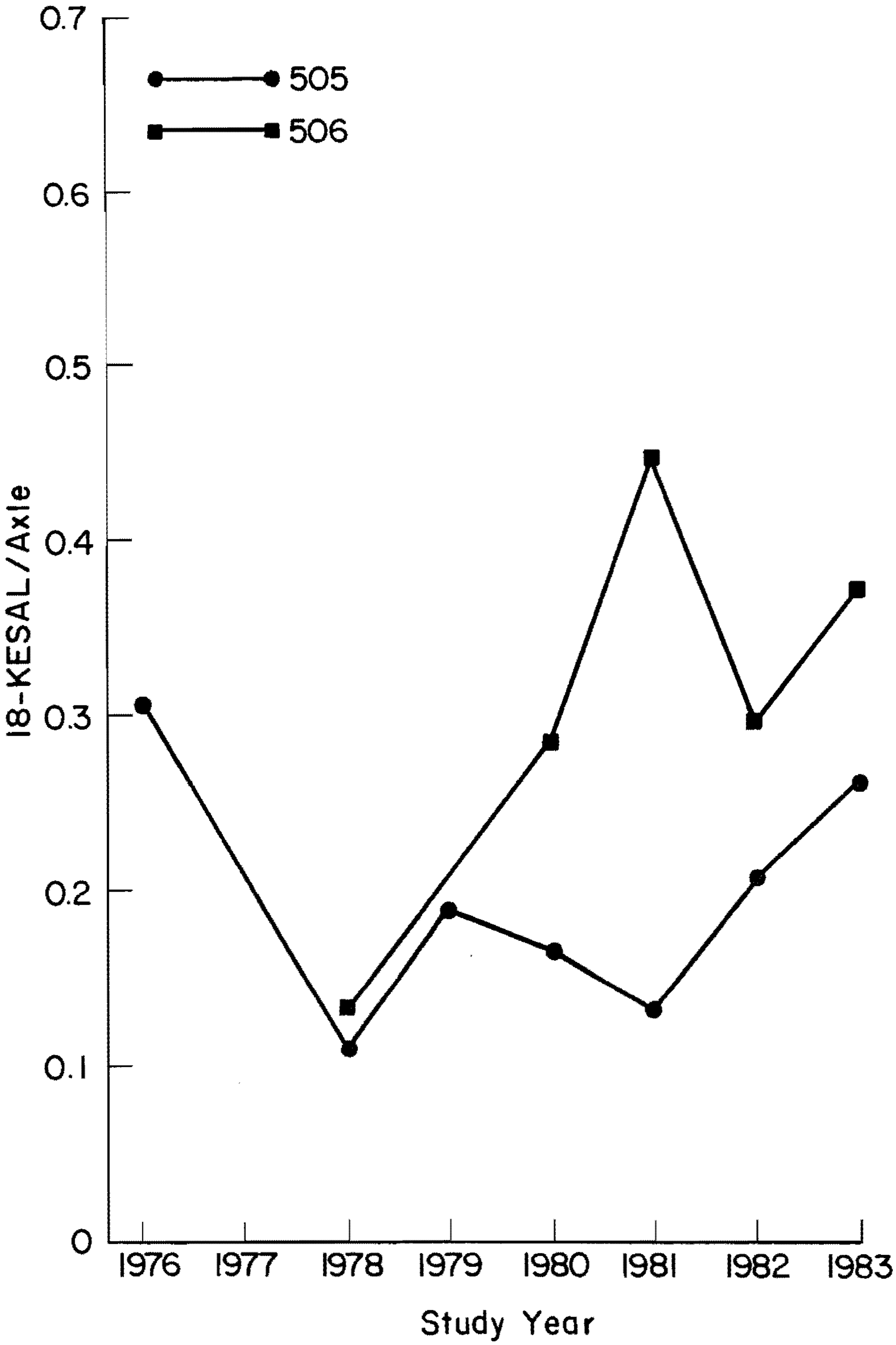

Fig D.25. 3-Axle Multi-Unit Trucks: Stations 505 and 506, 1976-1983

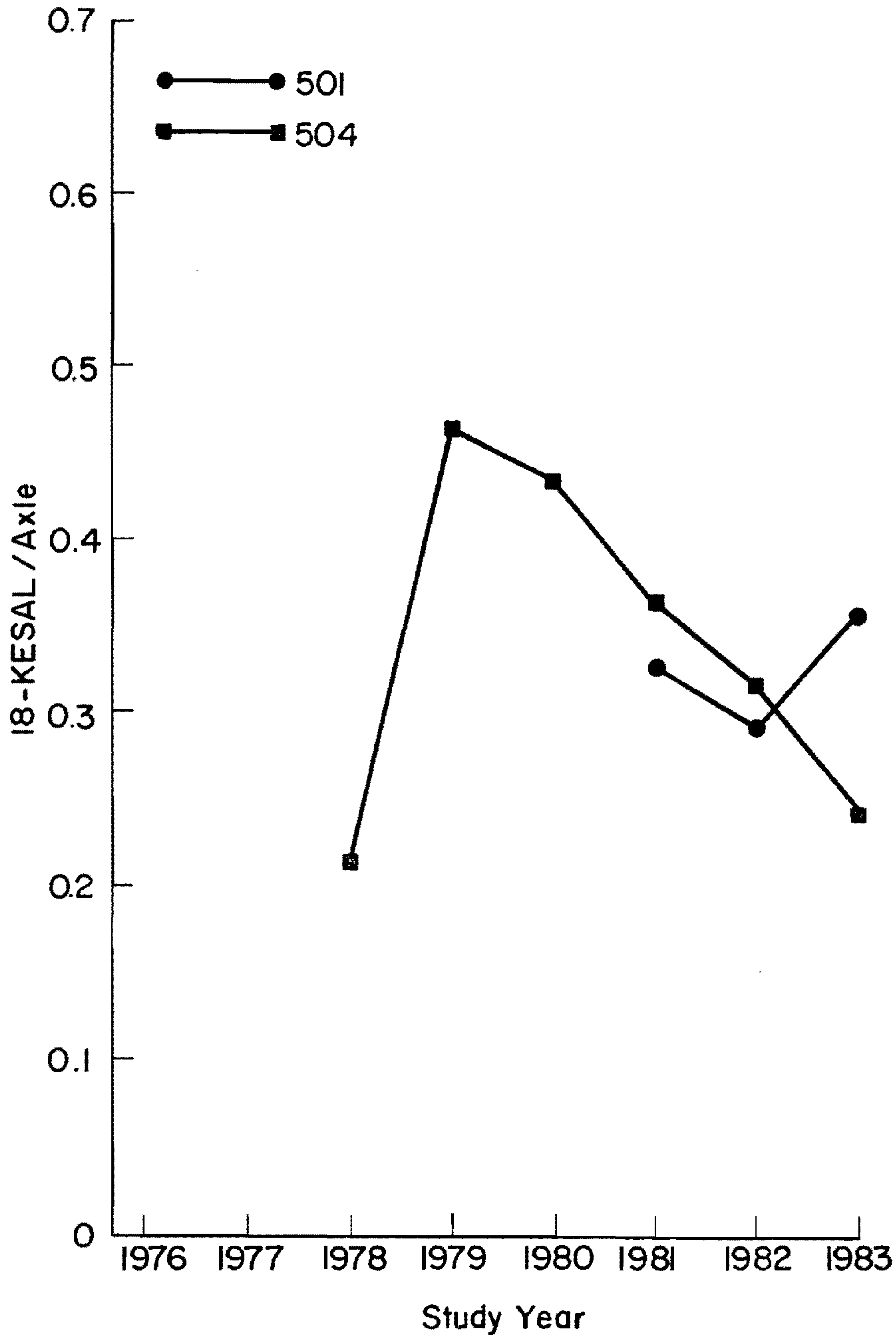

Fig D.26. 4-Axle Multiple-Unit Trucks: Stations 501 and 504, 1978-1983

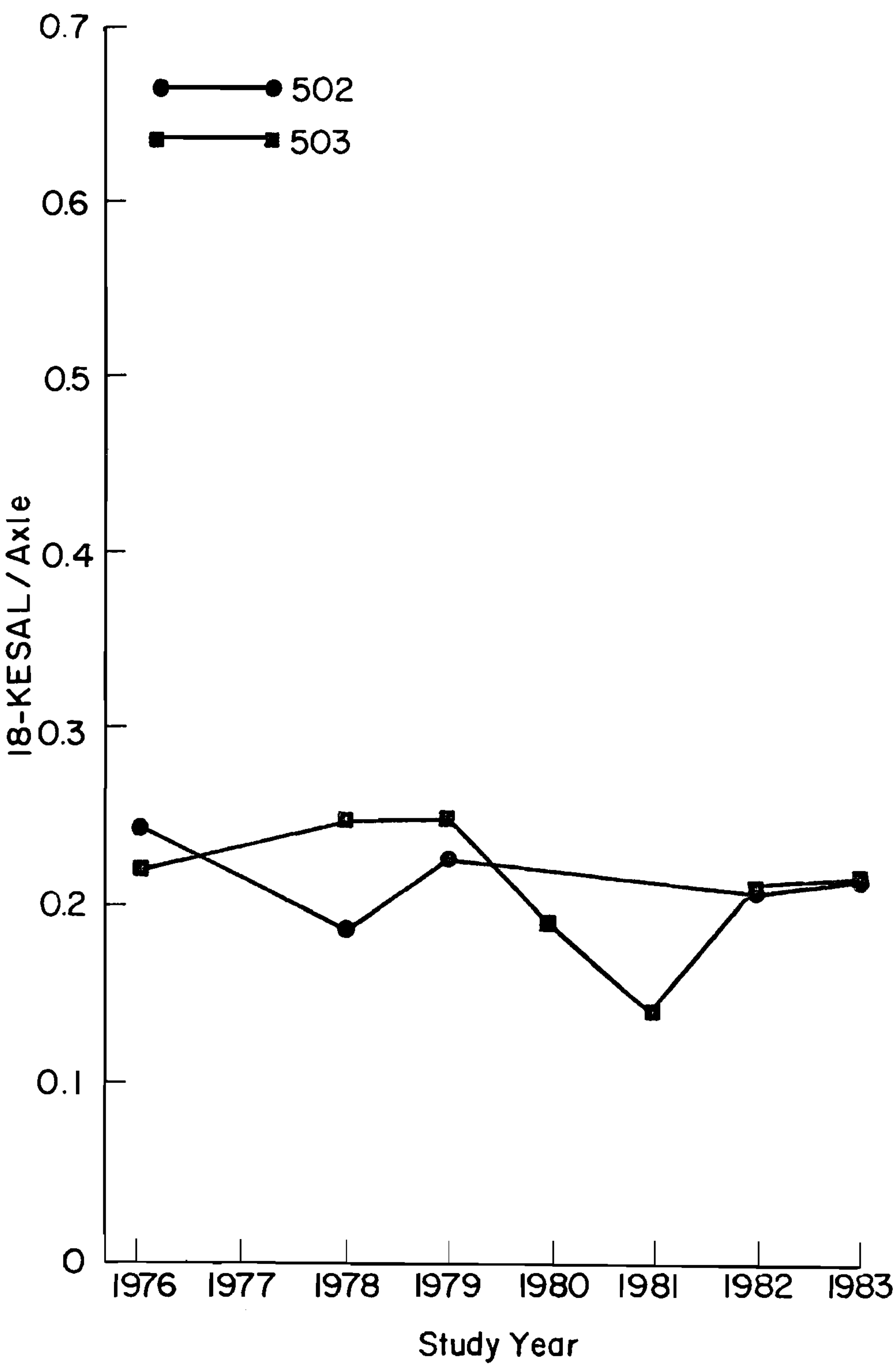

Fig D.27. 4-Axle Multi-Unit-Trucks: Stations 502 and 503, 1976-1983

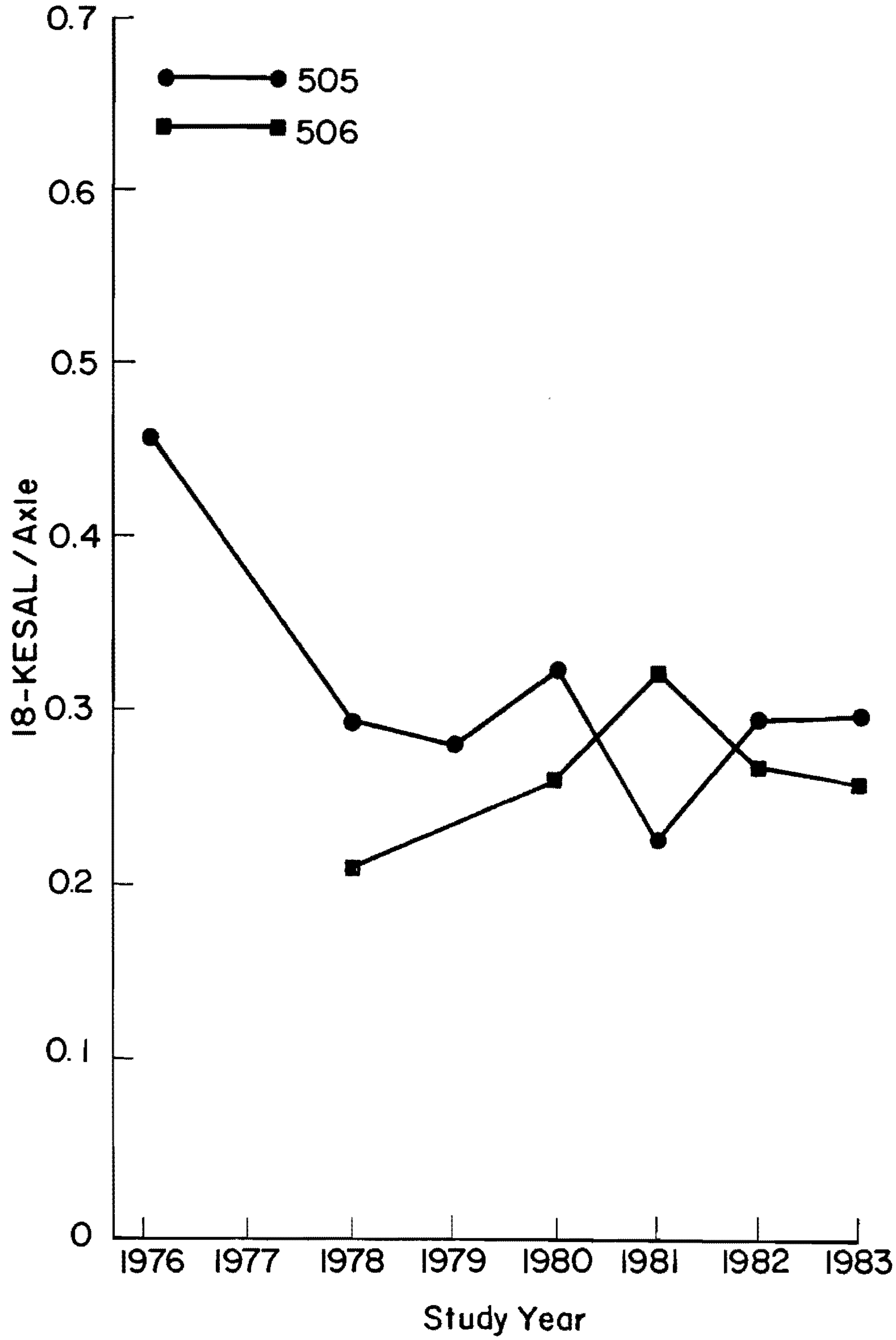

Fig D.28. 4-Axle Multi-Unit Trucks: Stations 505 and 506, 1976-1983

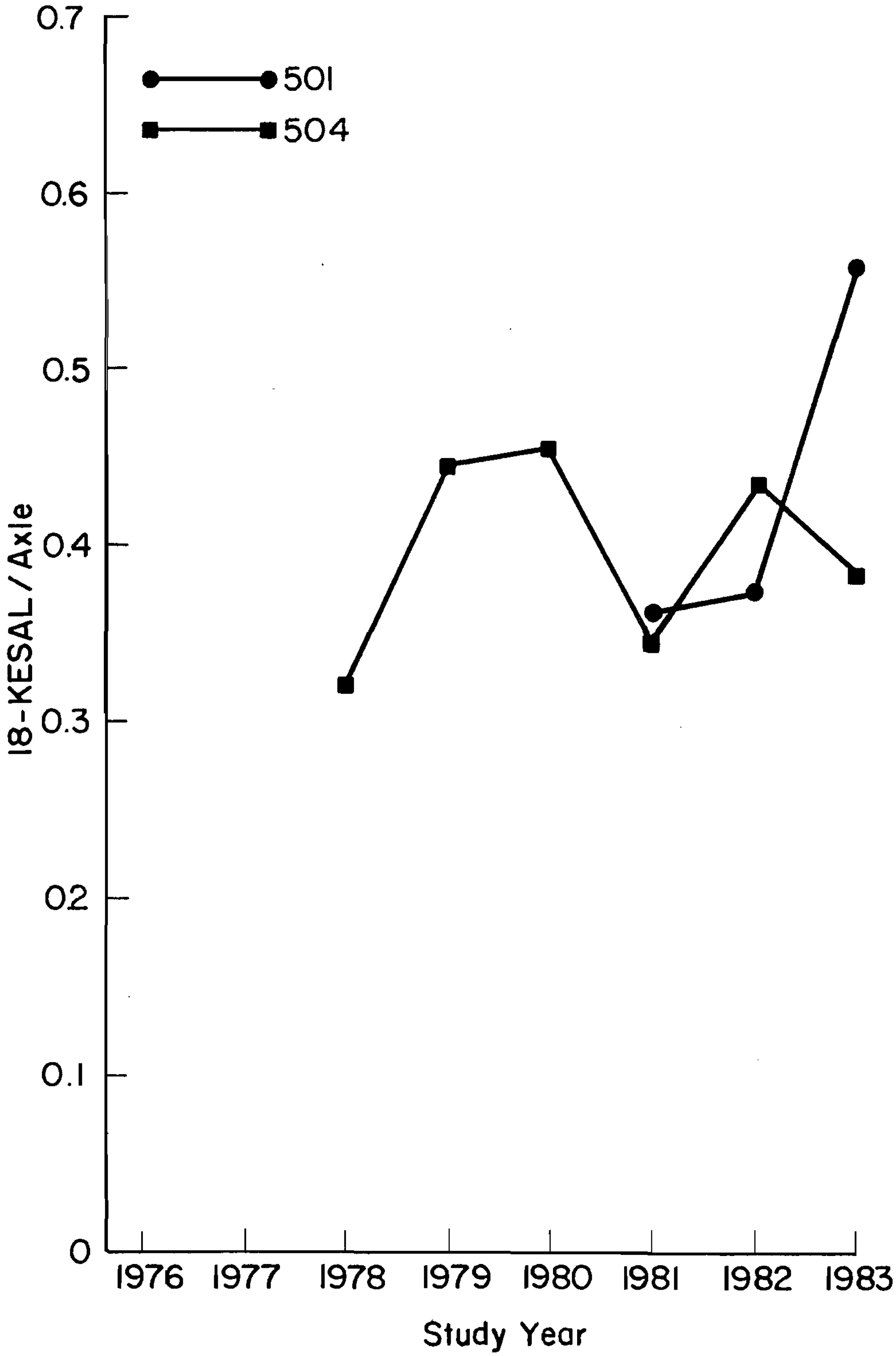

Fig D.29. 5-Axle Multiple-Unit Trucks: Stations 501 and 504, 1978-1983

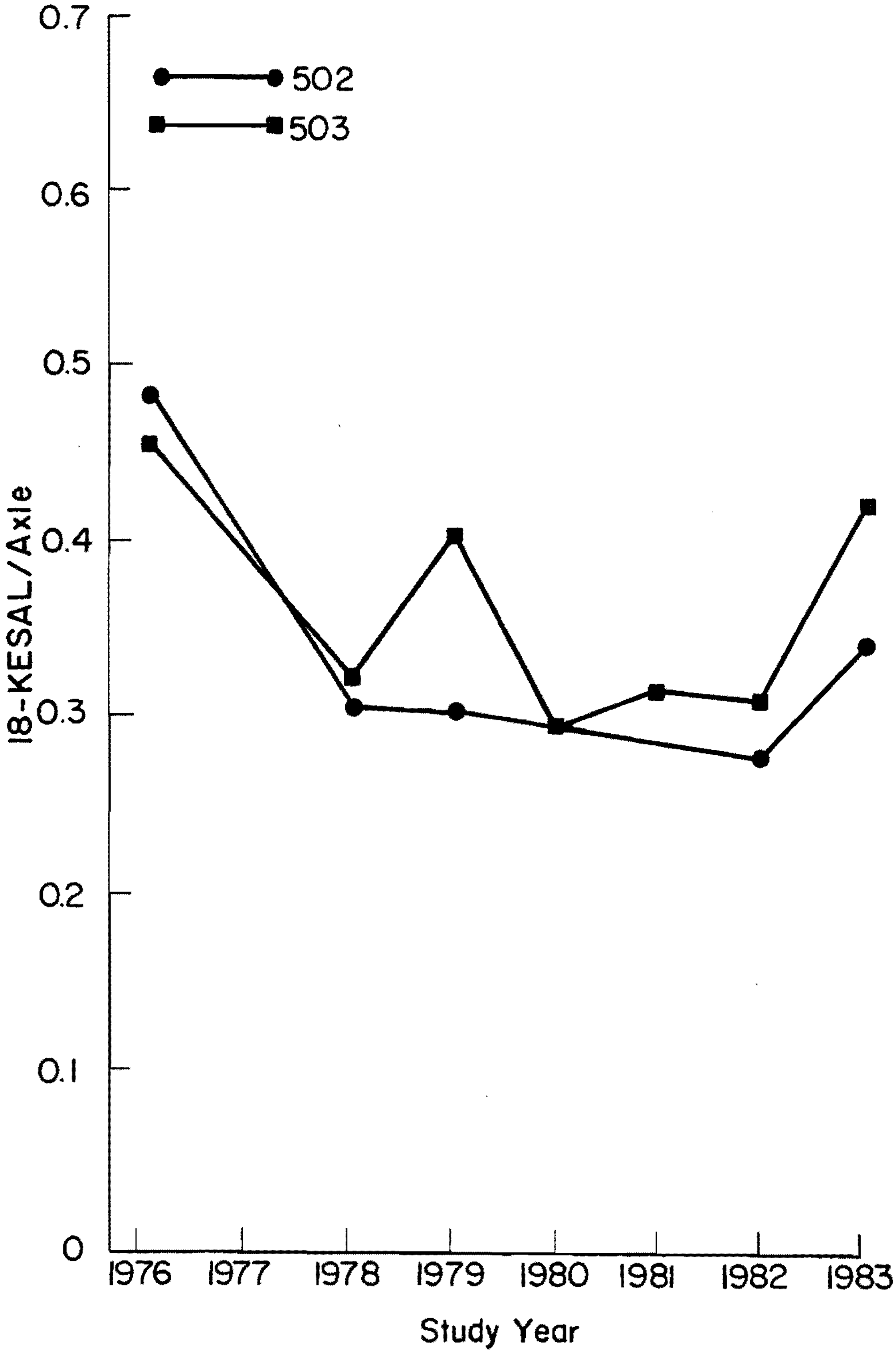

Fig D.30. 5-Axle Multi-Unit Trucks: Stations 502 and 503, 1976-1983

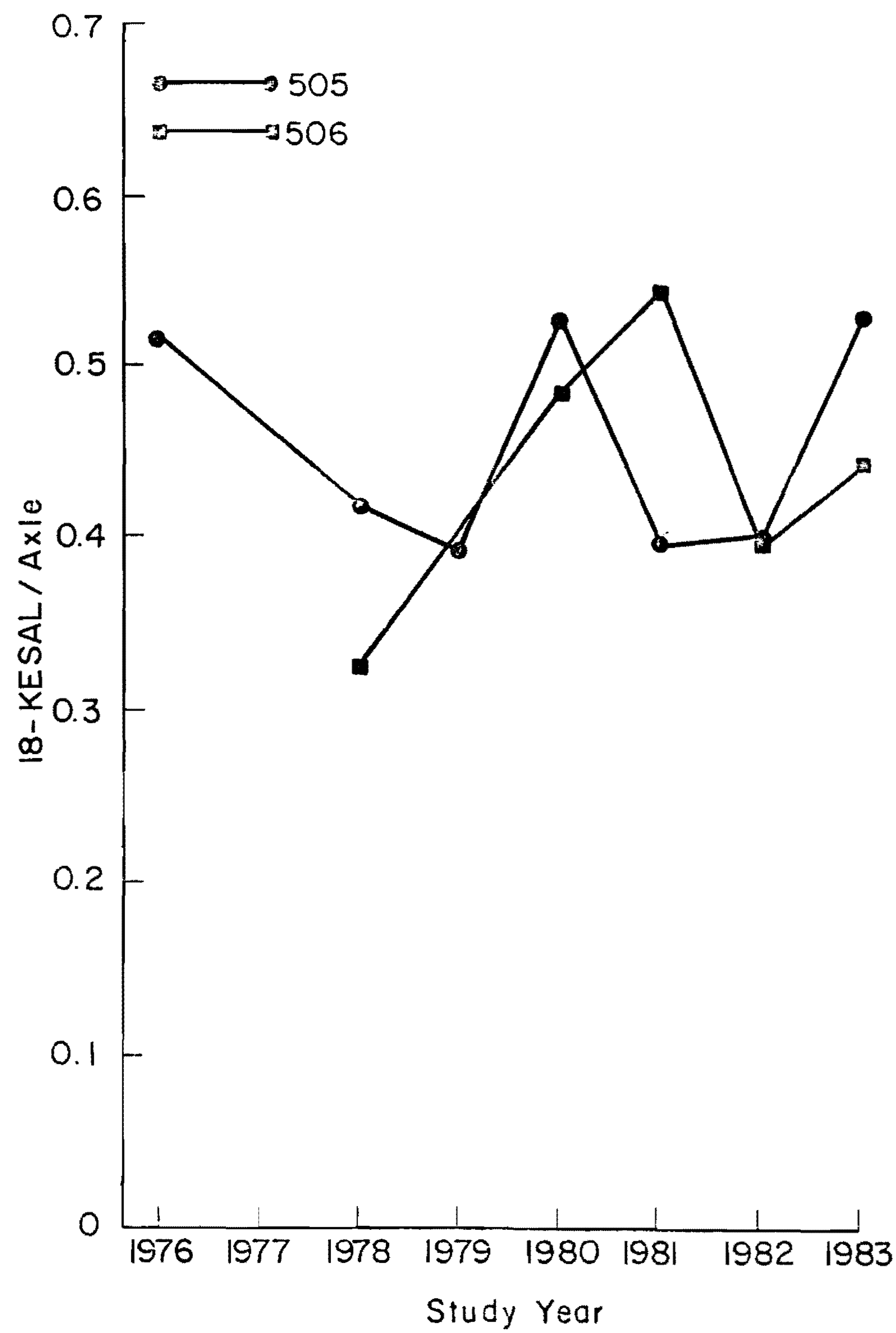

Fig D.31. 5-Axle Multi-Unit Trucks: Stations 505 and 506, 1976-1983

APPENDIX E

ALTERNATIVE FORECASTING PROCEDURES

APPENDIX E. ALTERNATIVE FORECASTING PROCEDURE

As the quantity (and quality) of vehicle weight and classification data increases over the next few years, SDHPT may want to consider an alternative traffic load forecasting procedure. One possible alternative, which makes better use of vehicle classification data than the current procedure, is described in this appendix.

Calculations Performed Once a Year

With SDHPT's current procedure, six axle weight distribution tables are created each year. Each table is based on the weight data collected at a WIM station over the latest three-year period.

An alternative approach would be to use the weight data calculated, by WIM station, to determine the average annual 18-KESAL/truck factor for each of five truck types:

1. single-unit 2-axle, 6-tire,
2. single-unit 3-axle +,
3. multiple-unit 3-axle,
4. multiple-unit 4-axle, and
5. multiple-unit 5-axle +.

Two sets of 18-KESAL/truck factors would be developed, one for flexible pavements (structural number = 3, terminal serviceability index = 2.5) and one for rigid pavements (slab thickness = 8 inches, terminal serviceability index = 2.5). Based on the available historical data, trend-line analyses could be made for each truck type -- by WIM station -- in order to predict future 18-KESAL/truck values. An average 18-KESAL/vehicle factor could also be estimated for all other vehicles not normally weighed (passenger cars and pickups).

Individual Forecasts

When an 18-KESAL forecast is needed for a particular highway segment, two steps would be undertaken:

1. selection of the appropriate 18-KESAL/vehicle factor (by vehicle type) for the mid-year of the design period, and
2. estimation of total one-way traffic volumes, by vehicle type, over the design period.

The factors in step one are then multiplied by the appropriate volumes in step two and summed in order to estimate total one-way 18-KESAL volumes. Appropriate lane distribution factors can then be used to assign a certain percentage of the one-way traffic loadings to the design lane.