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Two objectives are addressed in this study: (1) to develop a practical technique for estimating the patterns of cumulative traffic loading in each lane of multilane highways, and (2) to define representative frequency distributions of truck wheel placement within highway traffic lanes. The feasibility of a portable vehicle classifier instrument with lanewise classifying capabilities was demonstrated. Sensors for the classifier consist of an inductance loop detector and a pair of newly-designed axle detectors which utilize an array of inexpensive piezoelectric elements. A procedure for combining vehicle classification information with axle weight frequency data for various classes of vehicles, as determined by in-motion weighing techniques, to estimate cumulative traffic loading on multilane highways is presented. Frequency distributions of truck wheel placements for single-unit and tractor-trailer trucks as well as for straight and curved roadway sections are presented. These data were determined by video taping the rear view of trucks traveling in the normal traffic stream from a chase vehicle.

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LATERAL PLACEMENT OF TRUCKS IN HIGHWAY LANES

by

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Bahman Izadmehr

Research Report Number 310-1F

Lateral Placement of Truck Traffic in Highway Lanes

Research Project 3-8-81-310

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

November 1983

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

There was no invention or discovery conveived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

In recognition of the important role which traffic loading plays in pavement design and performance, the Area III (Pavements) Technical Advisory Committee, chaired by William V. Ward, initiated this research study. Gerald B. Peck was the study contact individual for the SDHPT and Ted L. Miller represented the FHWA. District 14 (Austin; Robert A. Brown, District Engineer), primarily through Tom E. Word, participated in the field work associated with the installation and evaluation of the axle detectors and the vehicle classifier system that were developed. District 8 (Abilene; Roger G. Welsch, District Engineer) and through Bobby R. Lindley, Assistant District Engineer and Phillips Petroleum Company furnished samples of Petrotac for installing the detectors. Radian Corporation contributed generously of its resources in developing instrumentation and computer software needed for evaluating the vehicle classifier. The Transportation Planning Division, D-10, of the SDHPT made their WIM system available for use in the research study as needed. Leon Snider, Research Engineer Associate IV, in the Center for Transportation Research technical staff made valuable contributions in testing electronic equipment and in implementing the video data collection. Bassam Touma, Undergraduate Research Assistant, made many of the wheel placement measurements from the video recordings and assisted in the field work. Dr. Hani S. Mahmassani and Dr. Randy B. Machemehl made valuable suggestions concerning the analysis, interpretation, and presentation of data. Mrs. Candace Gloyd very ably handled the word processing and other aspects of preparing the final report.

SUMMARY

Two objectives are addressed in this study: (1) to develop a practical technique for estimating the patterns of cumulative traffic loading in each lane of multilane highways and (2) to define representative frequency distributions of truck wheel placement within highway traffic lanes. The feasibility of a portable vehicle classifier instrument with lanewise classifying capabilities was demonstrated. Sensors for the classifier consist of an inductance loop detector and a pair of newly-designed axle detectors which utilize an array of inexpensive piezoelectric elements. A procedure for combining vehicle classification information with axle weight frequency data for various classes of vehicles, as determined by in-motion weighing techniques, to estimate cumulative traffic loading on multilane highways is presented. Frequency distributions of truck wheel placements for single-unit and tractor-trailer trucks as well as for straight and curved roadway sections are presented. These data were determined by video taping the rear view of trucks traveling in the normal traffic stream from a chase vehicle.

Key Words: traffic loading, lateral wheel placement, lane distribution, truck traffic, pavement design, axle loads, wheel loads, vehicle classifier, axle detector

IMPLEMENTATION STATEMENT

A practicable technique for obtaining and analyzing data concerning the lanewise frequency distribution of vehicles and their corresponding wheel loads among the lanes of multilane highways has been developed. The upgraded weigh-in-motion (WIM) system with its four-lane weighing and classifying capabilities should be deployed and the lanewise data should be analyzed to obtain axle weight frequency distributions for various classes of trucks that operate in Texas. These data should be used directly with the procedure that is presented for estimating the cumulative traffic loading on highway sections over a period of time in terms of equivalent 18-kip single axle loads. Portable vehicle classifiers of the type developed under this study should be obtained and used to extend the coverage of axle weight estimates by correlation of vehicle class with a representative axle weight frequency distribution based on WIM system samples. Finally, the frequency distributions for lateral wheel placements that were developed should be used to evaluate the relative effects of traffic loading on stresses in pavement structures.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

Highway pavements must be designed to withstand the total stress which will be produced (1) by volume changes in the subgrade and in the pavement materials and (2) by traffic loading. Furthermore, the cumulative damaging effects of stress variations over extended periods of time must be recognized. Quantitative data, which serve as the basis for calculating the anticipated magnitude of stress and its time rate of change, are essential elements in the pavement design and performance evaluation process.

Volume change is an internal change in the subgrade or pavement material that is generally associated with a change in moisture content, a change in temperature, curing of portland cement, or aging of asphalt. Climatic conditions strongly influence these relatively slow changes; therefore, local meteorological data are needed to evaluate effects of moisture and temperature on pavements. These data have been observed for many years and are readily available in the written records. Pavement design procedures relate various patterns of meteorological conditions and inherent changes in the mechanical properties of roadbuilding materials to the resulting stresses in specified configurations of these materials on a quantitative basis and attempt to identify limiting stress conditions.

Stresses caused by external traffic loading combine with the volume change stresses to produce critical conditions for pavement design and performance evaluation. Vehicular traffic applies loads to the pavement surface through the tires of moving vehicles. These tire loads vary in magnitude, duration, frequency and number of applications, and location. Representative statistical data concerning tire contact areas and pressures, load frequency distributions for single axles and axle groups with respect to time and traffic lane, lateral placement of truck wheels within the traffic lane, and vehicle speed are needed to quantify the patterns of traffic loading that might be applied to a pavement section under consideration. Routine traffic surveys do not provide sufficient traffic loading information for pavement design and analysis, particularly with respect to the distribution of wheel or axle loads among the lanes on multilane highways and to wheel placement within the traffic lane.

This study was therefore undertaken to address two basic objectives:

(1) to develop a practical technique for estimating the patterns of traffic loading in each lane of multilane highways, and

(2) to define representative frequency distributions of wheel placement within the highway traffic lane.

In order to attain these objectives, practicable techniques for obtaining the required statistical data had to be developed.

With regard to the first objective, it was recognized that the existing weigh-in-motion (WIM) equipment could be upgraded to multilane capabilities for sampling wheel and axle weights in each lane of multilane highways but that deployment of such a system would probably be limited to a few locations. A means of extrapolating these samples of weight data through correlation with traffic characteristics which can be measured more economically was envisioned. Frequency distributions of axle weights for each axle on each class of vehicle can be developed from the WIM system data. These distributions can then serve as a basis for estimating the wheel loads that will be produced by the passage of a vehicle in any given class. The cumulative value of the wheel loads from all vehicles passing in a lane over a period of time is the statistic of interest. An economical, portable automatic vehicle classifier which will classify vehicles according to axle arrangement and count the number of vehicles of each class in each lane with respect to time is thus needed. The concept for such an instrument was defined, a new axle detector configuration was developed, and the feasibility of obtaining the derived vehicle classification information was demonstrated under field operating conditions. This work is described in Chapter 3. Development of the portable vehicle classifier is continuing under other related research studies, and pilot models will be available for use late in 1984.

A procedure for converting lanewise vehicle classification data into 18-kip equivalent single axle applications on multilane highways is also described in Chapter 3. Equations and tables of equivalency factors for single, tandem, and tridem axles are included. The step-by-step procedure is outlined and then illustrated with a numerical example.

In addressing the second study object, which was to define representative patterns of wheel placement within the traffic lane, it was necessary to obtain and analyze samples of field data. A video camera and recorder mounted in a chase vehicle were used to observe truck placement in the lanes of multilane highways at sites near Austin and Houston. Measurements from these recorded observations were analyzed to identify the factors which might influence the lateral lane position of truck wheels, and representative frequency distributions of wheel placement were derived for two general classes of trucks and for two categories of horizontal highway alignment. This information, which is presented in Chapter 4, will be useful in evaluating the potentially critical stress conditions which might exist in a pavement structure due to the combined effects of volume change and traffic loading, particularly in rigid pavements.

CHAPTER 2. TRAFFIC LOADING DATA IN TEXAS

Truck weighing programs have been in operation in Texas since 1936, and over the years, have undergone substantial changes both in weighing methodology and in schedules of operation. For the first 30 years of the program, weight samples were taken several times per year at each of 21 sites using a portable wheel-load weigher to weigh the wheels on the right-hand side of the trucks. From about 1967 until 1971, all 21 sites were occupied annually, but only during the summer months. In 1971, the weight survey program was further reduced to ten sites which were sampled only in the summer months. Static weighing operations were discontinued in Texas in 1975 and the new weigh-in-motion (WIM) technique was adopted.

Based on recommendations in a report by Machemehl, et al, (Ref 24) six of the 21 original weighing sites were selected as WIM survey sites. Each of the selected WIM stations exhibited wheel weight patterns that were similar to those at other stations in the original group and could therefore be used to obtain data that would be representative for more than one of the original sites. Recommendations were also made that WIM operations be conducted for both directions and scheduled at each site for seven days continuously, four times per year. These recommendations have not been implemented. Fewer than 8,000 trucks per year have been weighed in Texas in recent years by the WIM system.

WEIGHT DATA RECORDING

Static truck weight data collected from weighing stations were recorded in the field in a standard format and subsequently transferred to computer cards to permit analysis and storage by digital computer. In later years, magnetic tapes replaced the punched cards as the standard storage device for more efficient storage, faster access, and easier portability.

After the adoption of the weigh-in-motion (WIM) system in 1975, advanced electronic technology made it possible to record truck weight data on computer-compatible magnetic tape automatically at the site. In an improved instrument system which is now operational, data are recorded on floppy discs in a digital format in such a way that all records can be transmitted directly from the instrument van to the Department's computer in Austin over telephone lines.

WEIGHT DATA PROCESSING AND PUBLICATION

Until 1970, processing and publishing of all vehicle weight data collected from the surveys was performed by the Planning and Research Division (in concert with the Division of Automation) of the then Texas Highway Department in cooperation with the Bureau of Public Roads (Federal Highway Administration). The summary tabulation of these data was printed in an annual report. The report presented a series of data tables in a standard format specified by the Bureau of Public Roads. Copies of the annual report were distributed routinely to the Bureau, to the Districts and Divisions of the Texas Highway Department, and to others interested in this information (Ref 24).

In 1970, truck weight data processing and publishing was altered due to changes in Federal Highway Administration (FHWA) requirements; since then, printed reports have not been prepared. Instead, the Federal Highway

Administration has taken the responsibility of analyzing and publishing truck weight survey results. The raw data are forwarded on magnetic tapes to FHWA where it is processed, summarized, and sent back to the SDHPT as requested. The FHWA uses these data to estimate transportation system utilization, commodity flows, and a number of other related items for all the states (Ref 24). Since 1970, the truck weight data have been available to interested users on magnetic tapes and in printed format. Compilation and processing programs for analyzing the data are made available to users by the FHWA. In Texas, the data are generally furnished by FHWA to the State Department of Highways and Public Transportation in the form of a table which shows the percentage of all axles and wheels occurring in each of 50 one-kip (4.45 kN) weight classes at a station.

The yearly processed data may be furnished to the user in the form of six or seven standard weight tables in the annual truck weight survey study report. For example, the information obtained from a W-4 table includes (Ref 36):

(1) the number of axle loads of various magnitudes of each type weighed,

(2) the probable number of such loads,

(3) the 18-kip (80 kN) axle equivalents of each general type and of all types,

(4) summary of 18-kip (80 kN) rates and equivalents for rigid and for flexible pavement designs, and

(5) average daily load for each highway system compared to corresponding data for the previous year.

Other tables present the data in convenient formats for various other purposes.

VEHICLE CLASSIFICATION DATA

Vehicle classification surveys have been conducted by the SDHPT on a continuing basis for many years to collect information that is needed for highway design and planning and for use by the Environmental Protection Agency. Historically, classification surveys have been conducted at 284 designated vehicle classification stations located throughout Texas. The stations are generally near permanent traffic volume counting locations and are designed to provide representative classification samples for all portions of the highway network (Ref 23).

All classification counts are currently made manually whereby each vehicle is classed into one of 29 vehicle types. Classification surveys are conducted at each control station once each season for 24 non-consecutive hours while surveys at the coverage stations are conducted for a 16-hour period only once every other year. The recorded classification data are used as the basis for estimating an annual volume for each type of vehicle at each station.

Documents are generated annually for reporting vehicle classification data. The printed document includes a listing and description of the locations for all classification survey stations and a summary of the annual average counts by class of vehicle for each station.

CHAPTER 3. LANE DISTRIBUTION OF TRAFFIC LOADING ON MULTILANE HIGHWAYS

Traffic forecasting procedures usually project average daily vehicular traffic volumes for all lanes for both directions of travel on a highway. For pavement design and evaluation purposes, this traffic must be distributed by direction and by lanes. Directional distribution factors are developed from directional traffic volume counts on various types or classes of highways and are used to estimate the directional flows which must be accommodated at specific sites. Some policies suggest assigning half the total traffic to each direction unless conditions justify another directional split. Adequate estimates of directional traffic volumes are essential to the proper geometric and structural design of multilane highways.

With regard to lane distribution, the objective is to further divide each directional flow and define the design traffic loading for each lane on a multilane highway. Design traffic loading needs to be described in terms of the cumulative number of wheel loads of given magnitude which can be expected in the lane during the design life of the pavement. Heavier wheel loads require stronger pavements, and each repetition of a heavy load causes relatively more damage than a lighter load; therefore, consideration must be given to the practicability of designing and constructing a different pavement structure for each lane. To do this, the lane distribution of anticipated wheel loads is required along with the frequency distribution of wheel loads of various magnitudes in each lane.

In arriving at a descriptive lane distribution pattern for traffic on a section of roadway, it must be recognized that the lane placement which occurs at a given time and location results from each driver choosing to operate in a particular lane in response to a set of individual desires and to the constraints of the surrounding static and dynamic conditions. The basic tendency of most drivers seems to be toward driving in the right-hand lane while attempting to achieve and maintain comfortably a desired speed which is judged by them to be suitable for the roadway, terrain, and other prevailing conditions. When these desires can be realized more easily by traveling in another lane, an available lane to the left will be chosen. The decision by each individual driver to use a particular lane at any given time appears to be based on the momentary evaluation of a complex set of influencing factors - some tangible (e.g. rough pavement surface, slower vehicles, large vehicles, roadside obstructions) and some intangible (e.g. attitude, anxiety, frustration). The resulting pattern of lane distribution of vehicles on any selected highway section changes considerably with time. Both short term and long term fluctuations in this pattern must be recognized in estimating cumulative traffic loading in a lane over several years.

The number of vehicles in each lane can be determined with conventional inductance loop detectors and recording traffic counters. While this provides valuable information, it is not sufficient for predicting the cumulative number of wheel loads of various magnitudes in a highway lane. The number of wheels or axles must be sampled, and the magnitude of the load imposed on the pavement by each wheel or axle must be defined. Ideally, the sampling would measure the wheel forces for each axle on every vehicle in each lane of a multilane highway.

Weigh-in-motion (WIM) technology which has been developed during the past two decades now makes such sampling feasible. A brief description of the Texas WIM system is given in a subsequent section of this chapter. The system started with one-lane weighing, dimensioning, and classifying (according to axle arrangement) capabilities about 1971 and was upgraded to two-lane capabilities about ten years later. A new system with four-lane weighing, dimensioning, and classifying capabilities was delivered to the State Department of Highways and Public Transportation in June 1984. This new WIM system, for the first time, provides a practical means for obtaining directly the type of data that are needed for predicting the design traffic loading on multilane highways.

Even though the WIM system instrumentation is mounted in a vehicle and is easily transportable between weighing sites, a pair of wheel force transducers and two loop detectors must be installed in the pavement in each lane. Installation of the in-road hardware takes several hours for pavement sawing and for placing and curing of materials, but subsequent occupancy of a site requires only about twenty minutes of work in the traffic lane to replace inactive load cells with active load cells. The transportable instrument system is normally attended by technicians during sampling periods, primarily for security reasons. The cost of the in-road hardware is approximately $7,000 per lane, and the vehicle-mounted instrument system with software currently costs about $70,000. This system is capable of sampling in four lanes simultaneously at ten to twenty sites per year when it is in full-time field operation. The type of information that is produced by this system is unique and is essential to designing and evaluating the performance of pavements. Representative frequency distributions can be obtained at appropriate locations for wheel and axle loads of selected classes of vehicles with respect to lane of operation and to direction of travel.

With this information, lanewise vehicle counts and classification (according to axle arrangement) counts can then be extrapolated to estimate the probable frequency of occurrence of wheel loads of given magnitudes in a lane over a period of time without actually measuring the loads. No easily installed portable vehicle counting and classifying equipment which will function in a lane-by-lane mode on multilane highways is commercially available; therefore, a considerable portion of this research study was directed toward such a development. This work is described later in the report.

Portable vehicle counter/classifiers that can be installed in a few minutes in each lane of a multilane highway and operated unattended for a few days at a time will extend the coverage of the WIM survey system extensively and guide the selection of WIM sites where weight data are needed. This concept, when implemented for a sufficient time to identify trends, will provide a substantial data base upon which to base projections of design traffic loading for multilane highways at specific locations.

A case study of the lanewise distribution of various classes of vehicles is presented later in this chapter. The manual survey method that was used to obtain data in this study was prohibitively manpower intensive for extensive use across the state, but it serves to illustrate the need for factual, representative data of this type.

Finally in this chapter, a step-by-step procedure for converting sample classification counts and WIM weight survey data into cumulative equivalent single-axle loads in each lane of a multilane highway is outlined and illustrated. A unique set of tables of equivalency factors for tridem axles is also presented.

TEXAS WEIGH-IN-MOTION SYSTEM

Texas began developing a weigh-in-motion (WIM) system in 1963, and a suitable wheel-load transducer had been designed and field-tested by 1968. By 1971, a transportable instrumentation system had been developed, and the

Texas Highway Department (now the State Department of Highways and Public Transportation) had begun using this newly designed in-motion vehicle weighing system on a limited basis for sampling representative statistical truck weight data (Refs 22 and 24). The WIM system was capable of obtaining and recording dynamic wheel forces in each wheel path of one traffic lane, time between successive wheels, vehicle presence over the loop detectors, and time of day. From these data, summary statistics including gross weight, axle weights, vehicle length, axle count, axle spacing, speed, and vehicle classification were automatically computed.

The current Texas WIM system consists of two wheel-load transducers (weighing scales) per lane; two inductance loop-type vehicle detectors per lane; an operator's console with CRT display, a keyboard and flexible disc recorder; and a printer. The transducers, each about 18 x 52 x 3.5 inches in size and embedded in the pavement, measure only the wheel forces that are applied normal to the pavement surface by a passing vehicle. The loop detectors placed beneath the pavement surface are used for both detecting the vehicle presence and providing data needed for the computation of vehicle speed and axle spacing.

Electronic instruments are mounted in a vehicle which is parked well away from the roadway and near an electric power source. Analog electrical signals that come from the sensors in the road are converted immediately to digital form, stored, interpreted, displayed on a CRT screen, and recorded on a magnetic disc. The recorded data may be transmitted over telephone lines from the van. The system may be operated in a fully automatic mode while recording data for all traffic in two lanes, or the operator can manually select certain vehicles in the stream by setting a weight threshold to determine which vehicles are weighed by the WIM system. The present system can handle two lanes of traffic simultaneously.

VEHICLE CLASSIFIER

As mentioned earlier, there is a continuing need for data on the number and type of vehicles travelling in each lane on a given section of road with respect to time. For pavement design purposes, it is important to know not only the load on each wheel or axle, of a vehicle in a lane, but also the spacing between adjacent axles. It is therefore desirable to classify vehicles according to the total number of axles on the vehicle as well as according to the arrangement or spacing of these axles. A portable vehicle classifier with these basic capabilities is needed. The concept for one such classifier configuration is shown in Figure 3-1.

Three detectors are used in each lane. A rectangular-shaped inductance loop detector which is approximately nine feet wide and twelve feet long senses the presence of a metal mass over the area bounded by the insulated loop wire and closes an electrical switch during the entire time that any metallic part of the vehicle is within the area. This information is used to identify the axles which are on each vehicle. Two axle detectors are spaced eight feet apart and approximately centered inside the loop detector. Each axle detector closes a separate electrical switch whenever a tire applies pressure to it.

Knowing the distance between the axle detectors and the time needed for the front axle to go from the upstream axle detector, A_1, to the downstream axle detector, A_2, the speed of the vehicle can be computed. Then, knowing the times t_2, t_3, t_4, etc between successive axles passing over A_1 (or A_2) the spacings between successive axles can be computed as the product of speed and time. This assumes a constant speed of the vehicle as all the axles on

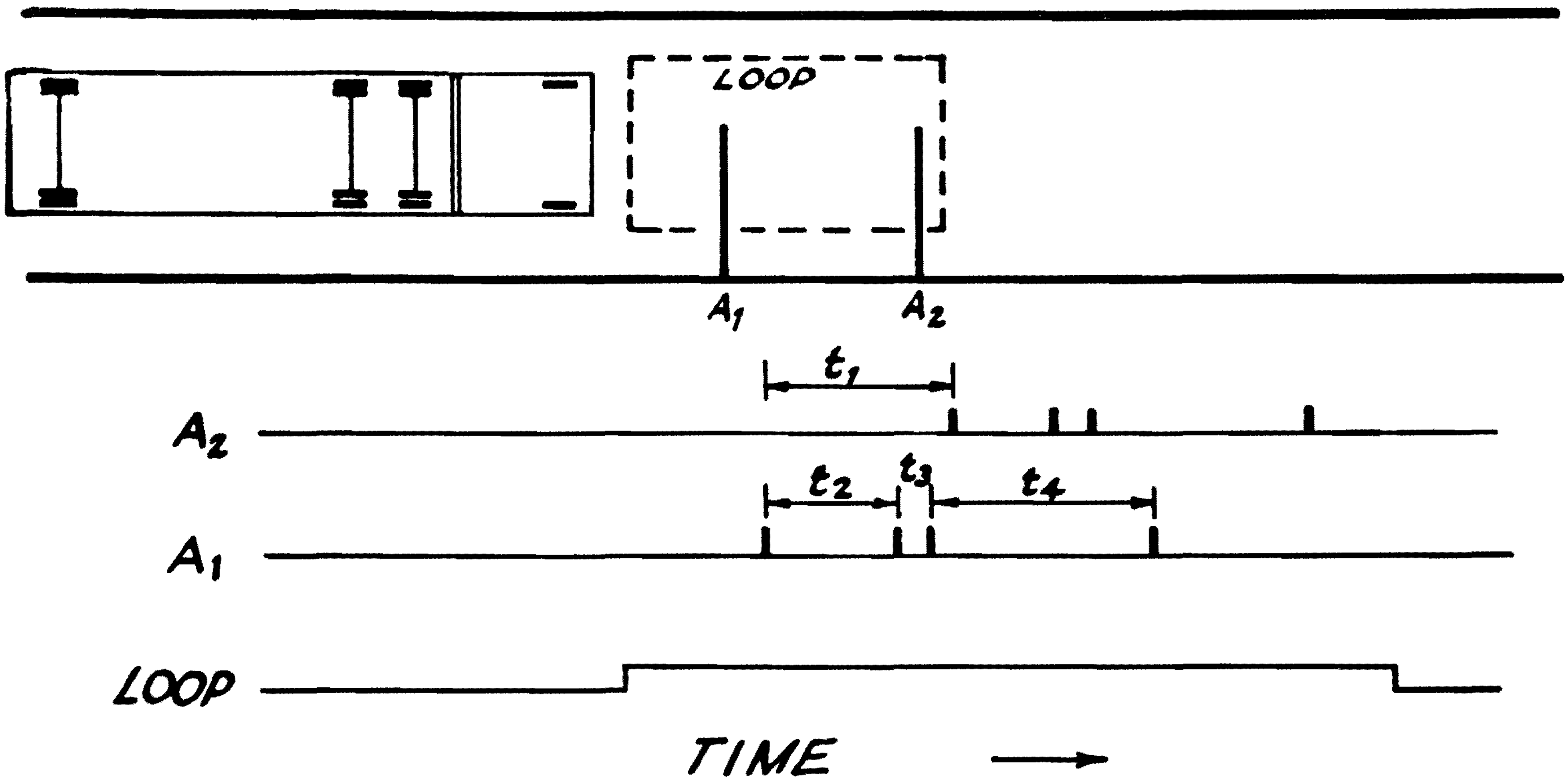

Figure 3-1. Detector array and sequence of signals for a vehicle classifier.

the vehicle pass over the axle detector. By comparing the number of axles and the computed axle spacings of the observed vehicle with previously-defined axle arrangements for selected classes of vehicles, the class of the observed vehicle can be identified.

Successful performance of this classifier obviously depends upon consistent detection of vehicles and axles. Several years of experience with using inductance loop detectors has indicated that reliable detection of vehicle presence in a lane can be achieved, but at the time this study began there was no known axle detector in existence which (1) could be used for detection in each lane, (2) could be installed in the lane in a few minutes, (3) was reliable, (4) was durable, at least for a few days, and (5) was inexpensive. Experimental work was therefore undertaken to develop such an axle detector.

DEVELOPMENT OF AN AXLE DETECTOR

The first attempt at designing a new axle detector configuration involved placing a miniature microphone at the end of an eight-feet long section of stainless steel tubing with 1/8 inch inside diameter and 1/4 inch outside diameter and measuring the audio-frequency signals induced into the tube by tire impact. Laboratory tests quickly indicated that the signal level was not adequate for practical use.

The next design evolved from the familiar rubber hose/diaphragm axle detector. In order to improve the durability, an eight-feet long section of the 1/2 inch outside diameter flexible hose was partially buried in the pavement while being protected by a metal tube with the upper 1/5 cut away and set in epoxy in a saw cut. Approximately 0.1 inch of the hose diameter protruded above the surrounding pavement for contact with the tires of a crossing vehicle. A brass diaphragm, to which a piezoceramic element was cemented, was used to sense the pressure variations in the hose as it was deformed by vehicle tires. An electrical voltage was produced by the bending of the piezoceramic material. This diaphragm was housed in a hollowed-out lane marker button cemented to the pavement surface on the lane line. Surging of the column of air in the hose produced a voltage signal from the piezoceramic element that had a damped sine wave form. An electronic circuit which would trigger on the initial voltage change and remain activated for approximately 20 milliseconds was devised to detect a wheel passage. This design had a number of desirable features, but it was not deemed suitable for use in the study as it took approximately three hours to saw the pavement and cement the tube into place. Traffic on heavily-traveled multilane highways would not permit this type of installation.

A surface-mounted version of this detector was tried whereby the hose was protected on the pavement surface by a formed-in-place epoxy ramp that was reinforced with a preformed cage of 1/4 inch mesh hardware cloth. Again, the detector worked well for several weeks, but the installation time was considered to be prohibitive. The 1/2 inch high rigid bumps were also objectionable for high speed traffic.

The most successful axle detector design that was developed during the study utilizes a series of one inch diameter brass diaphragms with 1/2-inch square piezoceramic bender elements, that are about 0.010-inch thick, cemented to one surface. These units are commercially available and are normally used as audio-frequency speakers or beepers when excited by a varying voltage.

For the axle detector, approximately twenty piezo elements are arranged in a linear array with four-inch spacing and connected in parallel electrically. This eight-feet long array is placed on top of a 1 1/2-inch wide strip of Petrotac. Petrotac is a product of the Phillips Petroleum Company and consists of a polypropylene fabric on a rubberized asphalt adhesive backing. The 1/16-inch thick strip of Petrotac supports the brass diaphragm/piezo element and allows it to bend slightly under load from a crossing tire and spring back; thereby generating a voltage signal. A 1/2-inch square pad of Petrotac is also placed directly on top of the piezo element to transfer tire contact forces to the unit and cause concave bending. When one or more of the piezo elements is bent by truck tires crossing over at high speed, signals up to 10 volts or more are produced. This voltage change is used to trigger an electronic circuit and produce a switch-closure pulse of a fixed duration to indicate passage of an axle over the detector.

An important feature of this piezo electric axle detector is that it has a low profile (about 1/8-inch) and can be mounted on the pavement surface. A number of cements and tapes were used in attempts to hold the detector in place in the traffic lane and protect the electrical wires needed to take signals across adjacent traffic lanes to the roadside classifier instrument. The only successful technique of surface mounting the detector involved covering it with eight-inch wide strips of ordinary asphalt-impregnated fiber roofing shingles with the usual sand aggregate surfacing. These shingle strips are held in place on the pavement by stripes of asphalt cement applied along the bottom edges. Initially, stripes of AC-20 asphalt cement were hot-applied in the laboratory and protected by waxed paper for transport to the road, but RC-2 cutback asphalt applied from a plastic squeeze bottle in the field proved to be a more practical means of applying the asphalt cement. Strips of three-inch wide cloth-backed duct tape are used along each edge of the shingles and across the end joints between the one-meter long sections of shingle to hold the shingles in place until traffic can roll the asphalt into place. Sections of shingles have been in place under arterial street traffic in Austin for over two years and are still intact. Axle detectors have been installed under traffic in about 15 seconds in the right-hand traffic lane by pre-preparing the shingles with tape on the roadside. Some of the detectors have remained in place on IH-35 near Austin for over a year.

The entire three-detector classifier sensor array that is shown schematically in Figure 3-1 can be surface mounted in a lane in about 15 minutes, and electrical wires can be routed to the roadside or median across adjacent lanes under the protective shingles. The inductance loop is installed first by preparing a protective pad under the 14-gage insulated stranded wire with two-inch wide strips of Petrotac, sticky side to the pavement and fabric side up. Two hardened masonry nails at each corner of the rectangle aid in shaping the two turns of wire into a nine-by-twelve feet rectangle loop. The nine-feet width, centered in a normal twelve-feet wide traffic lane, places the longitudinal loop strands out of the passenger car wheel paths and reduces wear. A 1-1/2 inch wide of Petrotac over the loop wires holds them in place and distributes the tire force. All the loop wires are covered with strips of roofing shingles as are the axle detectors that are placed inside the loop rectangle. Petrotac pads are used where wires cross over each other.

The piezo electric axle detector (1) operates on a lane-by-lane basis, (2) can be installed quickly and easily, (3) is relatively inexpensive (about twenty dollars in materials), (4) senses all tires regardless of size, weight, or speed, and (5) is sufficiently durable for sampling purposes. Recent configurations have withstood interstate highway traffic for over three weeks without failure. Further improvements in protective packaging of the piezo elements and the electrical connections are underway.

Feasibility of a multilane vehicle classifier system was demonstrated by installing the three-detector array described above in each of the two northbound lanes of IH-35 near Austin and connecting them to the WIM instrument system. Electronic signal processing instruments for the piezo electric axle detectors were developed by Radian Corporation, as were the needed software changes to allow the WIM system to process signals from the axle detectors in lieu of the wheel force transducers that are normally used for weighing. Several hours of near-perfect vehicle classification was accomplished. Improvements in the durability of the axle detectors that are now being investigated will soon make it practicable to have a portable, relatively inexpensive vehicle classifier system that is usable for making lanewise classification surveys on multilane highways.

CASE STUDY

As mentioned earlier, an economical vehicle-classification system with the ability to classify traffic on a lane-by-lane basis, has not yet been developed. It was desirable to conduct a manual classification survey of trucks on a lane-by-lane basis at a representative site in order to gain insight into the patterns of lane distribution and the timewise variations in the pattern. Such a study was conducted on U.S. 59 north of Houston, Texas in the summer of 1981.

Location of Study

A fairly heavily travelled section of U.S. 59, just north of the Houston city limits (in Montogomery County) was chosen for the study. A permanent volume counting station was located near this site (station number 12-5-174) where manual classification surveys have been made at regular intervals of time, the latest of which was during 27 and 28 May 1981. It should be noted that these classification surveys did not provide lanewise distribution of traffic; only the total traffic volume by vehicle class in each direction. The site that was selected for the lane-by-lane classification study is located about 2 1/2 miles north of Loop 610 on U.S. 59.

Data Collection

Though a continuous 24-hour survey was desired, the available manpower made it possible to conduct only a 13-hour survey with the counting periods, distributed as shown below.

DATE	DAY	TIME
July 9, 1981	Thursday	12:30 PM - 5:30 PM
July 9-10, 1981	Thursday-Friday	11:15 PM - 2:15 AM
July 10, 1981	Friday	7:30 AM - 12:30 PM

Two observers were assigned to each direction of traffic. One observer classified passenger cars and pick-up trucks by lanes for the two lanes in one direction, and the other observer classified trucks and semi-trailers by type and lane. The observed data are summarized in Appendix A.

Data Analysis and Implementation

The total volumes and percentages of different types of vehicles travelling in the different lanes are shown in Tables 3-1 through 3-4.

Graphs showing the distributional variation by lanes of three different classes of vehicles - (1) cars and pick-up trucks, (2) single unit trucks, and (3) 3-S2 and other tractor-trailer combination trucks, at different volume levels are plotted in Figures 3-2 through 3-5.

TABLE 3-1. TOTAL VOLUME, NUMBER AND PERCENTAGE OF DIFFERENT CLASSES OF VEHICLES (NORTHBOUND)

DATE	TIME PERIOD	TOTAL VOLUME	CARS & PICKUPS		SINGLE UNITS		3-S2's		OTHERS	
			NO.	%	NO.	%	NO.	%	NO.	%
Thursday July 9, 1981	12:30- 1:30	1658	1503	90.7	62	3.7	72	4.3	21	1.3
	1:30- 2:30	1930	1721	89.2	80	4.1	94	4.9	35	1.8
	2:30- 3:30	2295	2125	92.6	61	2.6	82	3.6	27	1.2
	3:30- 4:30	3323	3142	94.6	60	1.8	80	2.4	41	1.2
	4:30- 5:30	3808	3684	96.7	57	1.5	50	1.3	17	0.5
	11:15-12:00	573	547	95.4	5	0.9	12	2.1	9	1.6
Friday July 10, 1981	12:00- 1:00	506	460	90.9	5	1.0	31	6.1	10	2.0
	1:00- 2:00	311	265	85.2	7	2.3	32	10.3	7	2.2
	2:00- 2:15	35	25	71.4	3	8.6	6	17.1	1	2.9
	7:30- 8:00	683	598	87.6	52	7.6	22	3.2	11	1.6
	8:00- 9:00	1425	1227	86.1	106	7.4	71	5.0	21	1.5
	9:00-10:00	1525	1323	86.8	75	4.9	101	6.6	26	1.7
	10:00-11:00	1741	1527	86.7	94	5.4	89	5.1	31	1.8
	11:00-12:00	2010	1777	88.4	91	4.5	111	5.5	31	1.6

TABLE 3-2. TOTAL VOLUME, NUMBER AND PERCENTAGE OF DIFFERENT CLASSES OF VEHICLES (SOUTHBOUND)

DATE	TIME PERIOD	TOTAL VOLUME	CARS & PICKUPS		SINGLE UNITS		3-S2's		OTHERS	
			NO.	%	NO.	%	NO.	%	NO.	%
Thursday July 9, 1981	12:30- 1:30	1546	1400	90.6	48	3.1	73	4.7	25	1.6
	1:30- 2:30	1855	1747	94.2	37	2.0	56	3.0	15	0.8
	2:30- 3:30	1766	1610	91.2	52	3.0	82	4.6	22	1.2
	3:30- 4:30	1708	1597	93.5	41	2.4	52	3.0	18	1.1
	4:30- 5:30	1732	1623	94.2	44	2.5	46	2.7	19	1.1
	11:15-12:00	344	315	91.5	3	0.9	24	7.0	2	0.6
Friday July 10, 1981	12:00- 1:00	294	255	86.7	2	1.4	32	10.9	3	1.0
	1:00- 2:00	276	230	83.3	0	0.0	45	16.3	1	0.4
	2:00- 2:15	60	54	90.0	0	0.0	6	10.0	0	0.0
	7:30- 8:00	1750	1679	95.9	24	1.4	42	2.4	5	0.3
	8:00- 9:00	2423	2232	92.1	63	2.6	115	4.8	13	0.5
	9:00-10:00	1791	1628	90.9	49	2.7	95	5.3	19	1.1
	10:00-11:00	1738	1583	91.1	56	3.2	93	5.4	6	0.3
	11:00-12:00	1791	1618	90.3	76	4.2	85	4.8	12	0.7

TABLE 3-3. TOTAL VOLUME AND PERCENTAGE OF VARIOUS CLASSES OF VEHICLES BY LANES (NORTHBOUND)

Date	Time Period	Cars & Pickups			Single Units			3-S2's			Total Volume
		L*	R**	L/R	L	R	L/R	L	R	L/R	
Thursday July 9, 1981	12:30- 1:30	44.0	56.0	0.79	38.7	61.3	0.63	54.2	45.8	1.18	1658
	1:30- 2:30	44.8	55.2	0.81	28.7	71.3	0.40	61.7	38.3	1.61	1930
	2:30- 3:30	48.5	51.5	0.94	26.4	75.4	0.33	57.3	42.7	1.34	2295
	3:30- 4:30	53.2	46.8	1.14	35.0	65.0	0.54	48.8	51.2	0.95	3323
	4:30- 5:30	53.3	46.7	1.14	21.1	78.9	0.27	50.0	50.0	1.00	3808
	11:15-12:00	38.8	61.2	0.63	40.0	60.0	0.67	33.3	66.7	0.50	573
Friday July 10, 1981	12:00- 1:00	34.1	65.9	0.52	40.0	60.0	0.67	22.6	77.4	0.29	506
	1:00- 2:00	34.3	65.7	0.52	28.6	71.4	0.40	31.2	68.8	0.45	311
	2:00- 2:15	24.0	76.0	0.32	33.3	66.7	0.50	-	-	-	35
	7:30- 8:00	44.6	55.4	0.81	25.0	75.0	0.33	45.4	54.6	0.83	683
	8:00- 9:00	45.8	54.2	0.85	32.1	67.9	0.47	39.4	60.6	0.65	1425
	9:00-10:00	43.2	56.8	0.76	28.0	72.0	0.39	48.5	51.5	0.94	1525
	10:00-11:00	45.5	54.5	0.83	30.9	69.1	0.45	44.9	55.1	0.81	1741
	11:00-12:00	47.5	52.5	0.90	27.5	72.5	0.38	67.6	32.4	2.08	2010

* L = left lane (inside lane), %

** R = right lane (outside lane), %

TABLE 3-4. TOTAL VOLUME AND PERCENTAGE OF VARIOUS CLASSES OF VEHICLES BY LANES (SOUTHBOUND)

Date	Time Period	Cars & Pickups			Single Units			3-S2's			Total Volume
		L*	R**	L/R	L	R	L/R	L	R	L/R	
Thursday July 9, 1981	12:30- 1:30	50.6	49.4	1.03	27.1	72.9	0.37	52.1	47.9	1.09	1546
	1:30- 2:30	49.1	50.9	0.96	18.9	81.1	0.23	67.9	32.1	2.12	1855
	2:30- 3:30	50.7	49.3	1.03	25.0	75.0	0.33	51.2	48.8	1.05	1766
	3:30- 4:30	51.2	48.8	1.05	22.0	78.0	0.28	32.7	67.3	0.49	1708
	4:30- 5:30	49.3	50.7	0.97	38.6	61.4	0.63	43.5	56.5	0.77	1732
	11:15-12:00	34.9	65.1	0.54	33.3	66.7	0.5	37.5	62.5	0.6	344
Friday July 10, 1981	12:00- 1:00	31.8	68.2	0.47	-	-	-	9.4	90.6	0.10	294
	1:00- 2:00	35.2	64.8	0.54	-	-	-	31.1	68.8	0.45	267
	2:00- 2:15	29.6	70.4	0.42	-	-	-	16.7	83.3	0.20	60
	7:30- 8:00	57.3	42.7	1.34	16.7	83.3	0.20	47.6	52.4	0.91	1750
	8:00- 9:00	57.2	42.8	1.34	30.2	69.8	0.43	33.0	67.0	0.49	2423
	9:00-10:00	56.6	43.4	1.30	16.3	83.7	0.19	31.6	68.4	0.46	1791
	10:00-11:00	53.1	46.9	1.13	19.6	80.4	0.24	33.3	66.7	0.5	1738
	11:00-12:00	52.9	47.1	1.12	35.5	64.5	0.55	32.9	67.1	0.49	1791

* L = left lane (inside lane), %

** R = right lane (outside lane), %

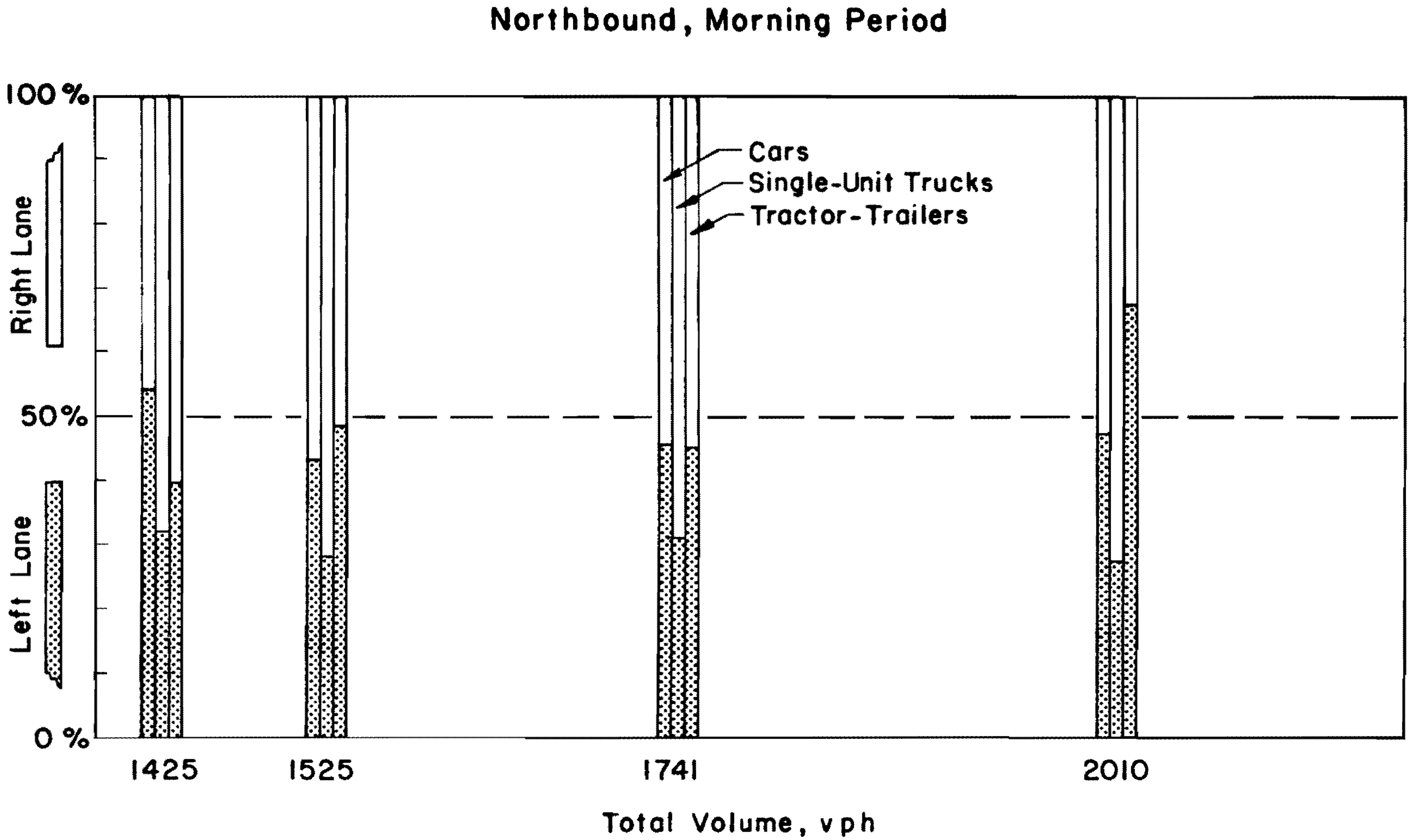

Figure 3-2. Distributional variation by volume.

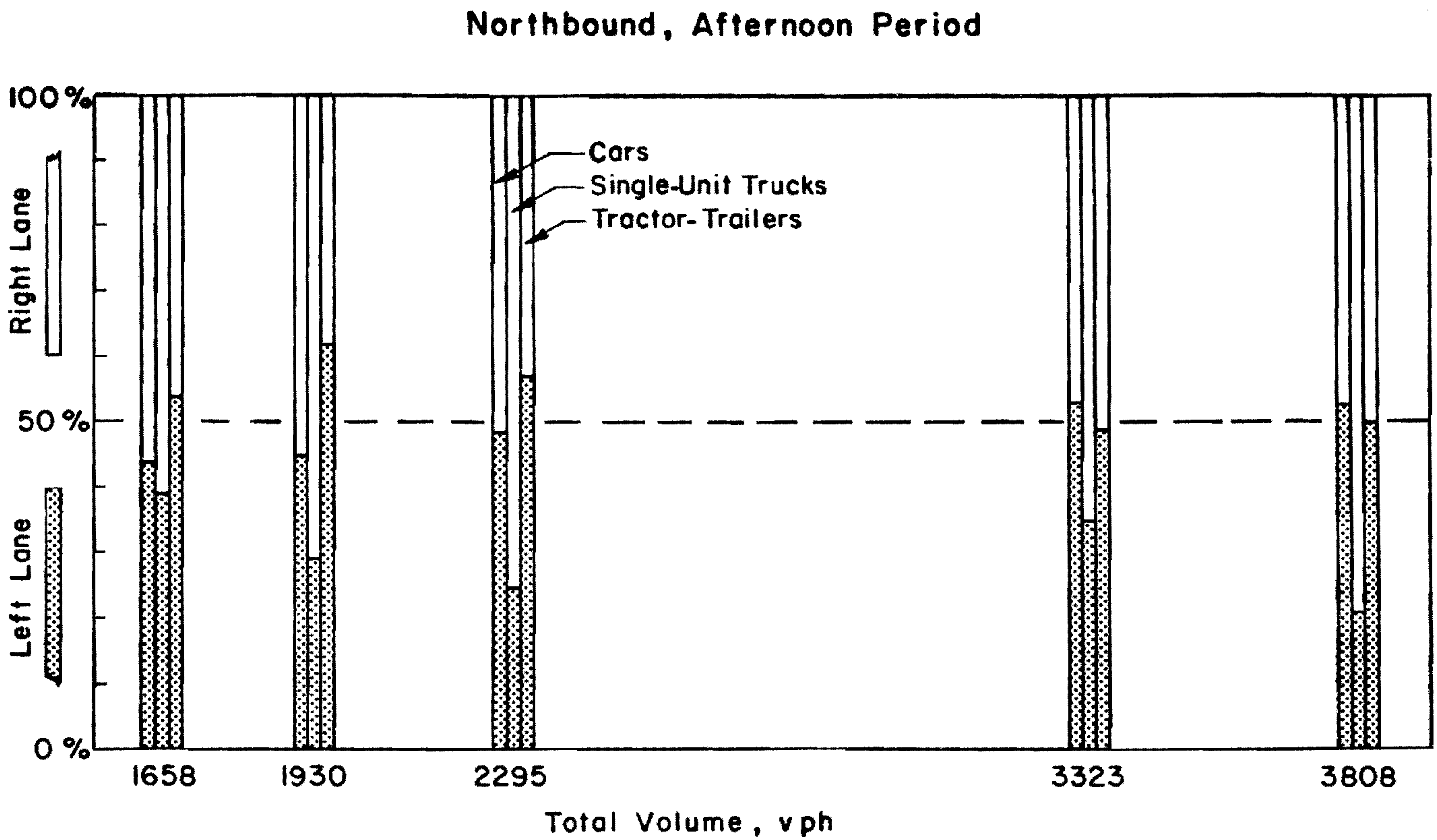

Figure 3-3. Distributional variation by volume.

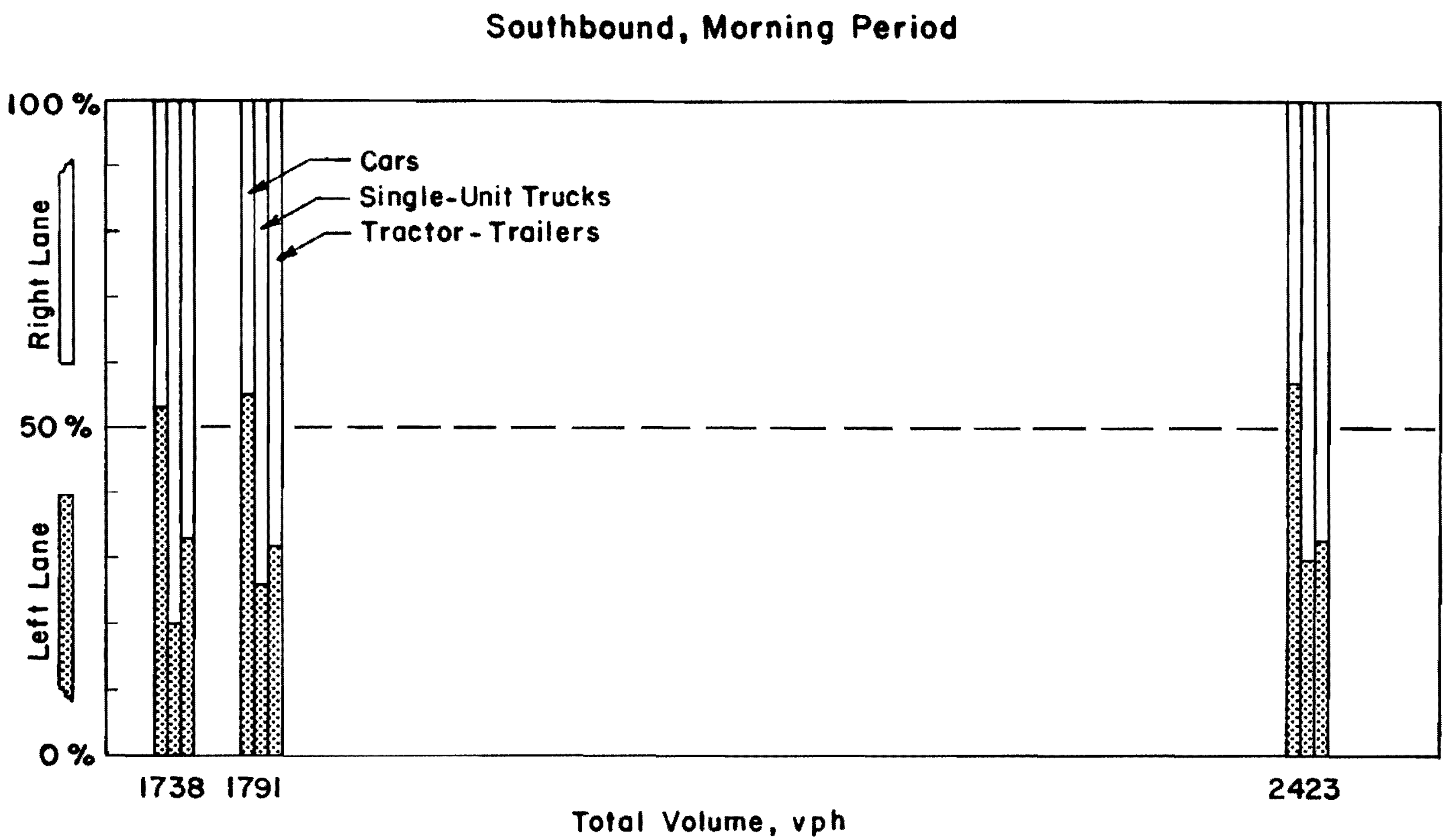

Figure 3-4. Distributional variation by volume.

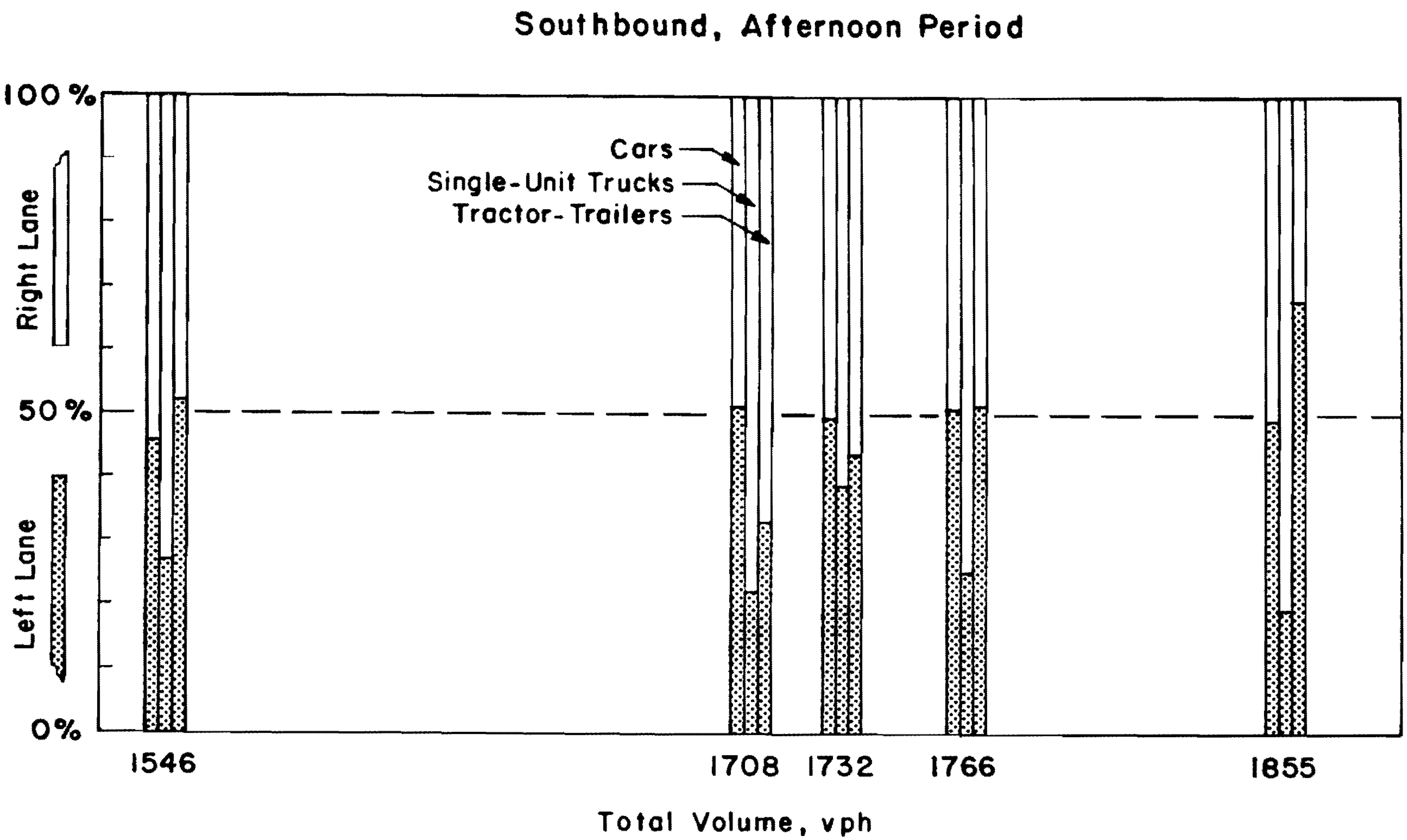

Figure 3-5. Distributional variation by volume.

The tractor-trailer combinations were observed to be driving mostly in the left lane, but a shift to the right lane was noticed as volume increased in the northbound direction. Cars were more or less equally distributed on the two lanes at fairly high volumes. As the total traffic volume increased, mostly due to increase in car volumes, the cars tended to shift to the left lanes displacing some of the tractor-trailer vehicles. Thus there appeared to be some interaction between cars and trucks as traffic volume changed.

Single-unit trucks tended to drive in the right lane. At high volumes more of the single-unit trucks drove in the right lane, showing an identifiable shift.

The above patterns were fairly evident during both morning and evening periods. Overall percentages for observed lane distribution are given in Table 3-5.

ESTIMATION OF TRAFFIC LOADING ON MULTILANE HIGHWAYS

Among the most important factors to be evaluated in the structural design of highway pavements is the cumulative effect of traffic loading. Traffic loading is made up of numerous passes of various vehicle types usually classified according to axle configuration, in a highway lane within a selected traffic analysis period (20 years is often used). Each particular vehicle class has a defined pattern of axle configuration, number of tires, axle spacing, axle load, and tire pressure. Furthermore, the lateral placement of the vehicle within the lane follows a stochastic pattern.

Historically, pavement design procedures have been based on an evaluation of cumulative traffic loading effects. Figure 3-6 illustrates conceptually a design approach that uses a standard axle load and expresses the design thickness of pavement as a function of the number of applications to failure of the standard axle load for various subgrade support values.

TABLE 3-5. OBSERVED LANE DISTRIBUTION OF THREE COMMON CLASSES OF VEHICLES

Vehicle Type	North Bound		South Bound		Both Directions	
	Left %	Right %	Left %	Right %	Left %	Right %
Cars & Pickups	43*	57	47	53	45	55
S.U. Trucks	31	69	26	74	29	71
3-S2 Trucks	47	53	37	63	42	58
ADT (Total Volume in Both Dierections) = 62,400 VPD (extrapolated)						

* All the numbers are averages over the study period

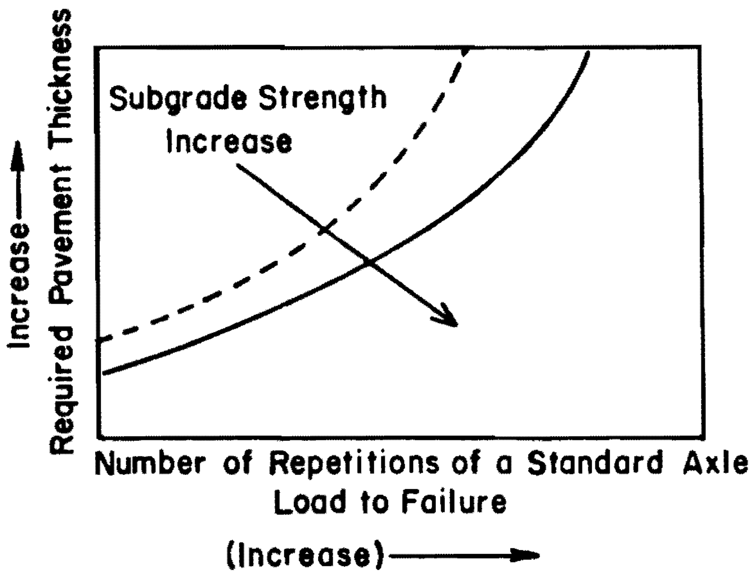

Figure 3-6. Basic pavement design approach (adapted from Ref 46).

To use this concept, the damaging effect of each axle load in a mixed traffic stream must be expressed in terms of the equivalent number of repetitions of the standard axle load. The numerical factors that relate the number of passes of a standard axle load that will cause pavement damage equivalent to that which will be caused by one pass of a particular axle load are called equivalent axle load factors (EALF) or traffic equivalence factors.

In many parts of the world, a legal axle load limit has been imposed for enforcement. Thus the maximum axle loads on highways have probably not increased as much with time as they would have if no such limits had existed. In the United States of America, the 18-kip (80-kN) single-axle load was the maximum legal load permitted in most states for many years; therefore, this axle load has been selected for general use as a standard axle load. Axle loads for mixed traffic are frequently converted to equivalent 18-kip (80 kN) single-axle loads (EAL) for use in structural design of highways. Since several procedures for evaluating the cumulative effects of traffic loading on pavement performance utilize the concept of traffic equivalence factors, for converting mixed traffic weight data to equivalent 18-kip (80 kN) single-axle load applications for the design of structural subsystems of highway pavements, the AASHTO equivalency factors are reviewed briefly. Finally, a procedure for converting truck weight and classification survey data to equivalent 18-kip (80 kN) single-axle load repetitions on a lane-by-lane basis is presented.

AASHO Equivalency Factors

Perhaps the most commonly used equivalency factors for pavement design and analysis are those derived from a statistical analysis of the AASHO (now AASHTO) road test data (Ref 18). As stated earlier, these factors are used to convert various axle loads to a common denominator by expressing the cumulative effect of axle loads applied by mixed traffic as the sum of the effects that would be caused by a computed number of applications of a standard axle load. The standard axle load used by AASHTO is an 18-kip (80 kN) single-axle load. Analysis of the AASHO road test (Ref 17) design equations permits the determination of equivalency factors for both flexible and rigid pavements.

Traffic Equivalence Factors for Flexible Pavements. The design equations for flexible pavements presented in the AASHTO Interim Guides (Ref 3) are

$$\log W_t = 5.93 + 9.36 \log(\overline{SN} + 1) - 4.79 \log (L_1 + L_2) + 4.331 \log L_2 + G_t / \beta \qquad (3\text{-}1)$$

$$\beta = 0.40 + \frac{0.081 \, (L_1 + L_2)^{3.23}}{(\overline{SN} + 1)^{5.19} L_2^{3.23}} \qquad (3\text{-}2)$$

where W_t = number of axle load applications at the end of time t for axle sets with dual tires

$\overline{SN}$ = structural number, an index number derived from an analysis of traffic, roadbed conditions, and regional factor which may be converted to a thickness of flexible pavement layer coefficient that is related to the type of material being used in each layer of the pavement structure

L_1 = load on one single axle, or on one tandem axle set for dual tires, kips

L_2 = axle code (one for single axle, and two for tandem axle sets

G_t = a function (the logarithm) of the ratio of loss in serviceability at time t to the potential loss taken to a point where

$P_t = 1.5$, $G_t = \log[(4.2-P_t)/(4.2-1.5)]$

β = a function of design and load variables that influences the shape of the p-versus-W serviceability curve

P_t = serviceability at the end of time t (serviceability is the ability of a pavement at the time of observation to serve high speed, high volume automobile and truck traffic)

As indicated above, for this design method the number of axle load repetitions to failure are expressed in terms of a pavement "stiffness" or "rigidity" value which is represented by Structural Number ($\overline{SN}$), load characteristics denoted by L_1 and L_2, and the terminal level of serviceability selected as the pavement "failure" point. Values commonly used to define terminal serviceability, P_t, are 2.0 and 2.5.

The relationship between the number of applications of an 18-kip (80 kN) single-axle load (standard axle), W_{t18} and the number of applications of any axle load, i, single or tandem, W_{ti}, to cause the same potential damage can be found from the following equation:

$$E_i = \frac{W_{t18}}{W_{ti}} \left[\frac{(L_i + L_2)^{4.79}}{(18 + 1)^{4.79}} \right] \left[\frac{10^{G_t/\beta_{18}}}{(10^{G_t/\beta_i}) L_2^{4.331}} \right] \qquad (3\text{-}3)$$

The ratio shown above is defined as an equivalence factor, and is evaluated by solving Equation 3-3 for any value i. Because the term β is a function of $\overline{SN}$ as well as L_i, the equivalence factor varies with $\overline{SN}$. A summary of E_i values for a wide range of axle loads (single and tandem) are given in Appendix B for Structural Numbers from one to six and P_t values of 1.5 through 3.0. As can be seen from these tables, the E_i values are only slightly affected by either the P_t value or the $\overline{SN}$ value within the range normally used in practice.

<u>Traffic Equivalence Factors for Rigid Pavements</u>. The basic equations for rigid pavements developed from the AASHO road test (Ref 3) are

$$\log W_t = 5.85 + 7.35(\log D + 1) - 4.62 \log(L_1 + L_2) + 3.28 \log L_2 + G_t/\beta \qquad (3\text{-}4)$$

and

$$\beta = 1.0 + \frac{3.63(L_1 + L_2)^{5.20}}{(D + 1)^{8.46} L_2^{3.52}} \qquad (3\text{-}5)$$

where D = thickness of rigid pavement slab, inches

G_t = $\log[(4.5 - P_t)/(4.5-1.5)]$

and all other terms are defined above.

As can be seen from analyzing the two equations above, pavement "rigidity" or "stiffness" value is expressed by the pavement thickness, D.

The relationship between the number of passes of an 18-kip (80 - kN) single-axle load and the number of passes of any axle, i, single or tandem, to cause equivalent damage to a rigid pavement can be found from the following equation:

$$E_i = \frac{W_{t18}}{W_{ti}} \left[\frac{(L_i + L_2)^{4.62}}{(18 + 1)^{4.62}} \right] \left[\frac{10^{G_t/\beta_{18}}}{(10^{G_t/\beta_i})L_2^{3.28}} \right] \qquad (3\text{-}6)$$

The ratio is defined as an equivalent factor, and is evaluated by solving Eq 3-6 for any value, i. Because the term β is a function of D as well as L_i, the equivalence factor varies with D. A summary of E_i values for a wide range of axle loads (single and tandem) are given in Appendix B for D ranging from six to eleven inches (152 to 279 mm) and P_t values of 1.5 through 3.0. As can be seen from these tables, the E_i values are only slightly affected by either the P_t value or the D value.

A Procedure for Estimating Traffic Loading on Multilane Highways

The procedure for using traffic equivalence factors is quite direct. Most states have accumulated samples of truck weight survey information and summarized it in the standard format of the Federal Highway Administration (FHWA) W-4 weight tables. These tabulations give the number of observed axle (single and tandem) loads within each of a series of load groups; each load group is usually a 2000-lb (8.9-kN) increment. Historically, W-4 table data have been the basis for estimating equivalent 18-kip (80-kN) single-axle load repetitions for pavement design.

The prediction of traffic for design purposes generally relies on information about past traffic patterns, and the use of adjustment factors which account for growth or other expected changes such as weight limit changes (trend analysis). Because it is often considered to be impractical to forecast future traffic on each existing route or proposed road by each axle group that is included in the W-4 tables, many states have developed approximate methods to be used to determine the equivalent 18-kip (80- kN) single-axle load applications based on various assumed load frequency distributions, correlations to average daily traffic (ADT), and other simplifying factors. These methods usually appear in an easy-to-work form for conversion. For example, the number of axles in each load interval is multiplied by an appropriate factor for conversion to equivalent 18-kip (80-kN) single-axle load repetitions for the load interval; these then are summed for all load groups to yield the total estimated number of equivalent 18-kip (80- kN) single-axle load repetitions that will be produced by mixed traffic for the time period.

In the following sections, a detailed procedure for using traffic survey data to estimate traffic loading in terms of the number of 18-kip (80 - kN) single-axle load applications that will occur in each lane of a multilane highway in each direction is developed. It utilizes the following sets of information:

(1) frequency distributions for the weight of each axle on each class of truck from weight survey data,

(2) truck volume and classification (according to axle arrangement) data from vehicle classification surveys, and

(3) modified and extended AASHO axle-load equivalency factors.

Representative frequency distributions for the weight of each axle on each class (according to axle arrangement) of truck in each direction can be developed from WIM data or any other weight survey data which are obtained at representative weighing sites.

Statistical data related to the frequency with which various classes of vehicles operate in each lane of multilane highways can be obtained by sampling the operational patterns of various types of trucks. Manual observation can be used to collect these data, or the technique for automatically classifying trucks described earlier can be utilized. Appropriate equivalency factors can then be used to estimate the cumulative number of equivalent 18-kip (80-kN) single-axle loads in each lane, in each direction on multilane facilities for a selected period of time.

With regard to suitable equivalence factors, the procedure for calculating AASHO equivalency factors for single axle and tandem axle sets is summarized above. The values that will be used in the proposed procedure are given for 1,000-lb (4.45- kN) axle load increments. A separate set of equivalency factors for steering axles that was developed recently (Ref 5) will also be used. For tridem axles, AASHO equations have been used to develop another set of axle load equivalency factors. The procedure is described in detail in the following sections of this report, and an example of its application is presented.

Axle Weight Frequency Distribution. Annually, most states, including Texas, submit truck weight survey data to the Federal Highway Administration (FHWA). As mentioned previously, the axle weight data are processed and summarized by FHWA into a convenient format and presented in W-4 tables. These W-4 tables contain the most comprehensive information available for estimating the truck traffic loading carried by highways. This loading needs to be defined in terms of the magnitude of axle loads, the number of repetitions of various magnitudes of load with respect to time, and distribution of load by lane. Full benefits from a pavement design procedure cannot be realized unless very good forecasts of expected traffic loading can be made available to the design engineers.

For structural design of pavements, an adequate sample of truck weights is needed. To ensure a sufficiently large sample, it may be necessary in some cases to combine data from several years for all or certain truck types. Table 3-6 shows the number of trucks weighed at WIM stations in Texas, in 1978-1980. These data were observed from FHWA files. Table 3-7 illustrates the weight sample size of each truck type at station number 502 for years 1978-1980. The weight survey data from this station are used in the example problem that is presented later.

The adequacy of a sample taken from a larger population is judged according to whether it is representative and whether it is reliable. In theory, a data collection system which gives every vehicle passing a weight sampling station an equal opportunity to be weighed is one that may obtain a representative or random sample. In order to determine whether the samples are reasonably representative of the population, collections obtained

TABLE 3-6. NUMBER OF TRUCKS WEIGHED AT THE WIM STATIONS IN TEXAS

Station	Year			Total
	1978	1979	1980	
502	1,493	975	1,112	3,580
503	1,275	408	477	2,160
504	673	1,203	1,461	3,337
505	956	524	359	1,839
506	1,245	976	421	2,642
507	-	119	-	119
508	-	-	238	238
Total	5,642	4,205	4,086	13,915

TABLE 3-7. NUMBER OF TRUCKS BY TYPE WEIGHED AT THE WIM STATION 502 IN YEARS 1978-1980

Truck Type	Year			Total
	1978	1979	1980	
2-Axle, 6-Tire	176	120	146	442
3-Axle	51	29	48	128
2-S1	24	10	8	42
2-S2	81	76	49	206
3-S2	1,100	706	822	2,628
Other	61	34	39	134

according to the time of day, day of the week, week of the month, month of the year, and year of the planning should be studied. If a representative sample has been collected at each station, then the next step is to generate estimates of the population parameters. The intermediate step to this is that of obtaining a sample large enough to overcome large chance sampling errors (unbiased sample). The sample size depends on the accuracy needed in the estimates, the extent of variation in the sample observations, and the stated probability level. To estimate the size of random sample that is needed, the following relationship can be used (Ref 14):

$$N = K^2 V^2 / E^2 \tag{3-7}$$

where N = sample size needed to obtain some specific precision in the estimate of a desired characteristic

K = number of standard deviations which implies the degree of certainty that the sample estimate is in error by no more than E

V = population value of the coefficient of variation of the characteristic being estimated

E = allowable relative error expressed as a fraction of the true mean

Using the above relationship Machemehl et al (Ref 24) obtained estimates of the number of vehicles which must be weighed at survey sites in Texas in order to attain a specified level of sampling accuracy. The estimate was based on the need to attain data of a quality at least equal to that taken during 1968, 1969, and 1970.

In view of the relatively small amount of annual truck weight data now available in Texas, data for the three most recent years are recommended for use in developing axle weight frequency distributions of various classes of trucks. This technique tends to smooth the effects of recent changes in truck types or axle configurations on trend analysis. Missing data for truck types not included in the sample but known to be operating on the highway system may be supplied from the data files of other states or estimated from special samples. Frequency distributions for the weight of each axle on each class (according to axle arrangement) of truck can be developed from these data. Two sequential steps are involved in the development and analysis.

Step 1. Tabulate the sample data by steering axles (single tire, single axle), single axles (dual tire, single axle), tandem axle sets, and tridem (triple) axle sets by truck type and weight, at least by direction, and preferably by highway lane. Determine an axle weight frequency distribution for axles in each of the four groups for weight classes of one kip (4.45 - kN) or two kip (8.9-kN) increments.

Step 2. Compute the mean and variance of axle weights for each axle type on each truck type for each year in which data are available and plot both versus time. Once these curves have been plotted, specific trends of axle weight means and variance by axle and truck type may be recognized. If the plots show possible trends with respect to time, specific regression or time series analysis can be performed for the trend analysis.

Classification Counts. Samples of the number of trucks of each type operating in each lane of a highway can be taken in truck classification surveys. Data can be collected by manual observation over short periods of time or, by using the automatic vehicle classifier system now under development for longer periods at carefully selected locations. Trend information on percentage or number of trucks of each type can be developed from the existing vehicle classification data that are routinely obtained by SDHPT at selected sites. The projected percentages or number of each truck type for each year of the design period can be estimated from extrapolations of these trends. For example, Figure 3-7 shows that since 1965 the percent of 2-S2 trucks has declined by approximately one-half. On the other hand, Figure 3-8 shows that the trend in the percentage of 3-S2 trucks with time has been increasing since 1965 and by 1976 had reached an apparent plateau value. Such extrapolations are usually based on standard statistical data analysis procedures such as least squares linear regression or time series analysis. Engineering judgement and experience will also be required in many practical situations.

The procedure proposed herein, requires an adequate number of sample 24-hour volume counts to arrive at the base year Average Annual Daily Truck Traffic (AADTT) count of each truck type in each lane and the need for obtaining the sample still exists. Moreover, the effect of using varying numbers of 24-hour volume counts within years and across years in estimating a base year AADTT count for each truck type in each lane of a highway has to be studied, if the data is not uniform in nature. It is recommended that at least four 24-hour counts per year per station (to show the seasonal effects) be undertaken henceforth to estimate the base year AADTT of each truck type in each lane of a highway to overcome this later difficulty. Two sequential steps are involved in the development and analysis.

Step 1. Use the most recent years' count, or use the most recent years' trend line count, to be determined from at least three years of data obtained by automatic vehicle classifier system.

Step 2. Project AADTT of each truck type for each year of the design period for each lane.

Equivalence Factors. As discussed briefly before, one of the most widely used sets of equivalency factors for pavement design is that developed

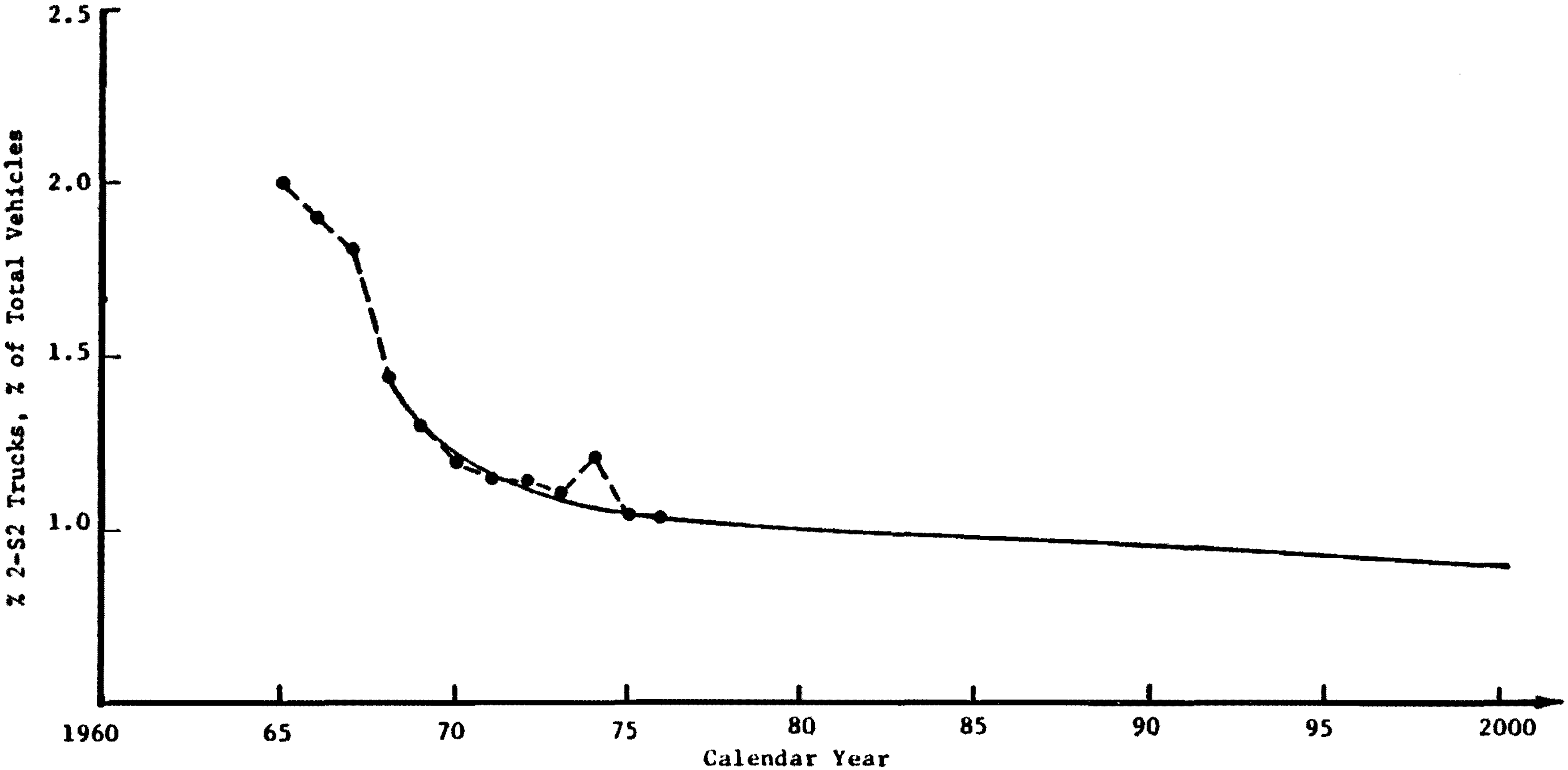

Figure 3-7. Projected percentage of 2-S2 trucks on the interstzte system for a 20-year analysis period, 1977-1997 (Ref 5).

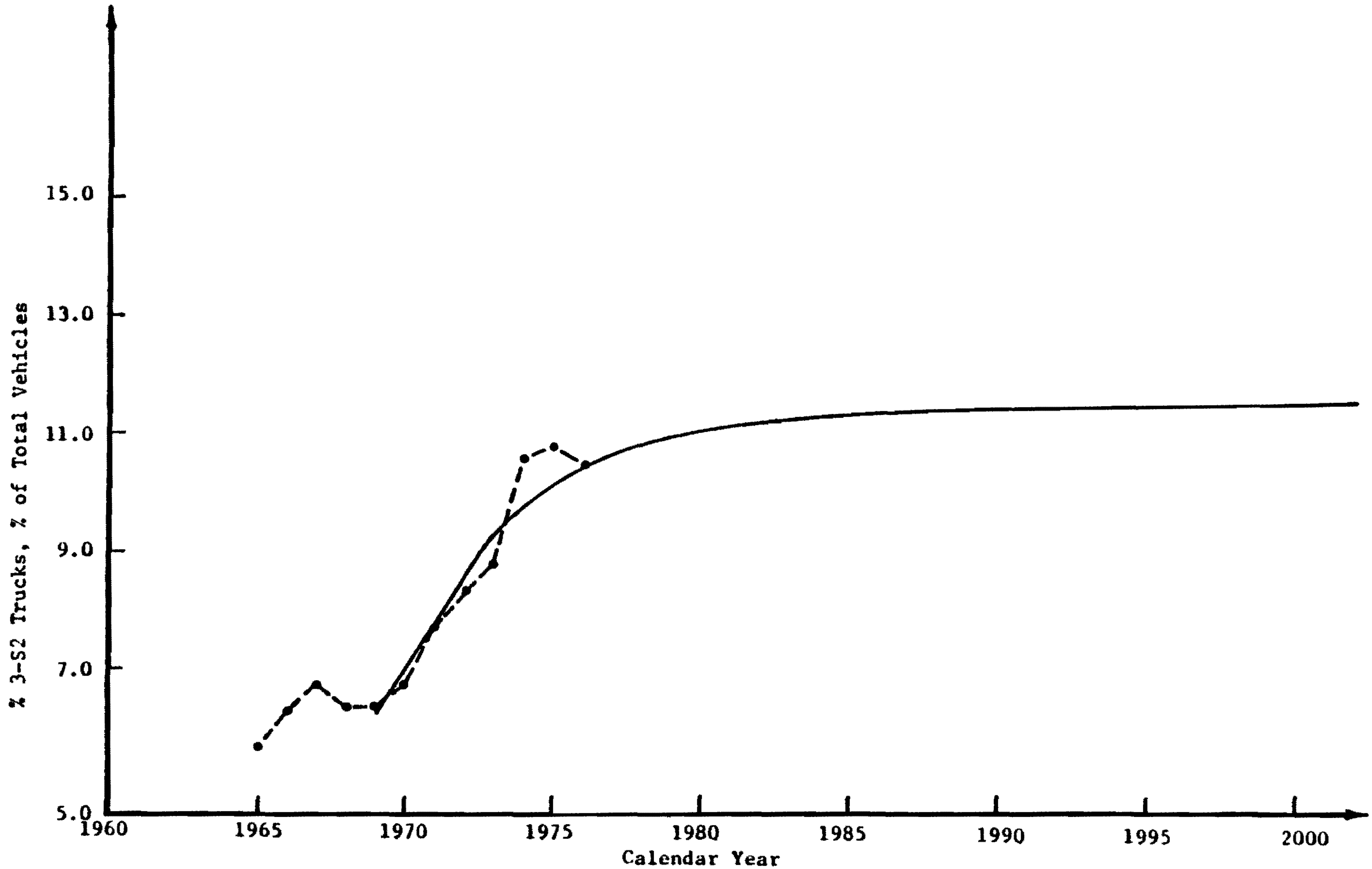

Figure 3-8. Projected percentage of 3-S2 trucks on the interstate system for a 20-year analysis period, 1977-1997 (Ref 5).

from the AASHO road test equations. These are given in terms of two standard axle configurations, single and tandem axles with dual tires and with loads less than 30 and 48 kips (134 and 215- kN), respectively. As axle loads increase and/or exceed current weight limits, and as axle configurations change (see Peterson (Ref 26), and Groves (Ref 13)) a problem arises when the AASHO equivalency factors have to be extrapolated outside the range of conditions under which they are developed. Also, because of the data collection techniques employed at the road tests (Ref 18), the present AASHO equivalency factors incorporate the damage caused by the single-tired steering axle loadings of the test trucks with the dual-tire axles. Equivalency factors for the single-tire axles can be derived by using analytical techniques to separate the damage caused by single and dual tires at the AASHO road test (Ref 18). Using Minor's hypothesis, Carmichael III et al (Ref 5) developed equations which provide for the separation of damage. The comparable equivalency factors for AASHTO traffic conditions for flexible pavements are shown in Table 3-8. There are only small differences between the equivalency factors developed with and without considering separately the effects of the steering axle. It is also shown that the single tire loadings generally produce somewhat more damage than does a comparable loading of dual tires. This was also supported by Deacon's theoretical work (Ref 7). He reported that axles with single tires are three times more damaging than dual tires with the same load.

The above load separation procedure was also used by Carmichael III et al (Ref 5) to compute rigid pavement load equivalency factors in an attempt to separate the damage caused by single and dual tires. The calculated damages due to the single-tire loads were negative; therefore, the authors concluded that, "The damage produced by single tire loads could not be

TABLE 3-8. COMPARISON OF EQUIVALENCY FACTORS WITH AND WITHOUT THE EFFECT OF STEERING AXLES BASED ON PERFORMANCE CRITERIA FOR A STRUCTURAL NUMBER EQUAL TO 4.0, P_t = 2.0 AND FOR A FLEXIBLE PAVEMENT (adapted from Ref 5)

Axle Load		Single Axle Loads		Tandem Axle Loads		Steering Axles
Kips	KN	Predicted Without Single Tires	AASHO With Single Tires	Predicted Without Single Tires	AASHO With Single Tires	
2	8.9	.00009	.0002	-	-	-
4	17.8	.002	.002	-	-	.009
6	26.7	.009	.01	-	-	.05
8	35.6	.03	.03	.006	.01	.25*
10	44.5	.08	.08	.006	.01	
12	53.4	.18	.18	.01	.01	.46
14	62.3	.34	.35	.02	.03	-
16	71.2	.61	.61	.04	.05	-
18	80.1	1.00	1.00	.07	.08	-
20	89.1	1.56	1.55	.11	.12	-
22	97.9	2.34	2.31	.16	.17	-
24	106.8	3.39	3.33	.23	.25	-
26	115.7	4.77	4.68	.33	.35	-
28	124.6	6.53	6.42	.45	.48	-
30	133.4	8.75	8.65	.61	.64	-
32	142.3	11.51	11.46	.80	.84	-
34	151.2	14.89	14.97	1.03	1.08	-
36	160.1	18.98	19.28	1.32	1.38	-
38	169.0	23.87	24.55	1.66	1.72	-
40	177.9	29.68	30.92	2.06	2.13	-
42	186.8	-	-	2.53	2.62	-
44	195.7	-	-	3.09	3.18	-
46	204.6	-	-	3.73	3.83	-
48	213.5	-	-	4.47	4.58	-

* Equivalency factor for the 9 Kip Steering Axle Load

separated from the total damage included in the rigid equivalency factors by the techniques used and information available."

Theoretical techniques have been applied by different authors to compute equivalency factors for axle configurations not actually used at the AASHO road test and for axle loadings outside the range that was used. Carmichael III et al (Ref 5) used a "Curvature Method" (Eq 3-8) to produce equivalence factors for flexible pavement that corresponded to those based on AASHO performance:

$$F(X_n) = \left[\frac{\varepsilon_1(X_n)}{\varepsilon(18_s)}\right]^{\beta} + \sum_{i=1}^{n}\left[\frac{\varepsilon_{i+1}(X_n) - \varepsilon_{i-i+1}(X_n)}{\varepsilon(18_s)}\right]^{\beta} \qquad (3\text{-}8)$$

where β = $\log F(X_s)/[\log \varepsilon(X_s)/\varepsilon(18_s)]$

$F_i(X_n)$ = predicted equivalency factor for axle configuration n of load X

$\varepsilon(18_s)$ = maximum asphalt tensile strain or subgrade vertical strain for the 18-kip (80 kN) ESAL, inch/inch

$\varepsilon_1(X_n)$ = maximum tensile strain or subgrade vertical strain under the leading axle of axle configuration n of load X, inch/inch

$\varepsilon_{i+1}(X_n)$ = maximum asphalt tensile strain or subgrade vertical strain under axle i + 1 of axle configuration of load X, inch/inch

$\varepsilon_{i-i+1}(X_n)$ = asphalt tensile strain or subgrade vertical strain, in critical direction, between axles i and i + 1 of axle configuration n of load X, inch/inch

$F(X_s)$ = AASHO performance equivalency factor for an X-kip single axle load

$(X)_s$ = maximum asphalt tensile strain or subgrade vertical strain for an X-kip single axle load, inch/inch.

Equivalency factors, using this procedure, are shown in Table 3-9 for a wide range of steering axle loads. A summary of developed equivalency factors for flexible pavements for numerous axle loads and axle configurations are included in Appendix B of Refs 5 and 20.

The magnitude of load on the steering axle at the road test ranged from 2 to 12 kips (9 to 53-kN) with 6, 9, or 12 kips (27, 40, or 53-kN) being used on the 3-S2 vehicles and 4, 6, or 9 kips (18, 27, or 40- kN) on the 2-S1 vehicles (Ref 18). Because it is possible for steering axle loads to exceed those included in the empirically based load equivalency factors developed at the road test, those in Table 3-9 are recommended for use in accounting for steering loads larger than those which were utilized at the road test.

For calculating tridem load equivalence factors, the term L_2 in the AASHO equation for flexible pavements (Eq 3-3) was set equal to three. This resulted in a set of tridem equivalency factors that are in very close agreement with those presented in Ref 5 from using the "Curvature Method" based on asphalt tensile strain. A summary of flexible pavement E_i values computed with Equation 3-3 for a wide range of tridem axle loads are shown in Table B-17 through B-21 in Appendix B for SN's from one to six and P_t values of 1.5 through 3.0.

Carmichael III et al (Ref 5) also used the type of relationship described in Equation 3-8 in developing rigid pavement equivalency factors. The resulting equivalency factors were different from those developed at the AASHO road test by a factor of two or greater. The AASHO equations are

TABLE 3-9. STEERING AXLE EQUIVALENCIES BY AXLE LOAD AND TERMINAL PSI FOR FLEXIBLE PAVEMENT (adapted from Ref 5)

Axle Load		Pt			
Kips	KN	1.5	2.0	2.5	3.0
2	8.9	0.0005	0.0009	0.002	0.004
4	17.8	0.008	0.01	0.02	0.03
6	26.7	0.04	0.05	0.06	0.09
8	35.6	0.13	0.14	0.18	0.23
10	44.5	0.28	0.31	0.36	0.41
12	53.4	0.52	0.54	0.62	0.66
14	62.3	0.92	0.86	0.93	0.94
16	71.2	1.42	1.31	1.33	1.28
18	80.1	2.12	1.94	1.90	1.74
20	89.1	2.95	2.52	2.44	2.16
22	97.9	4.02	3.35	3.15	2.70
24	106.8	5.29	4.40	3.95	3.28
26	115.7	6.73	5.49	4.82	3.89
28	124.6	8.31	6.67	5.83	4.59
30	133.4	10.19	8.05	6.80	5.23

probably the best basis for generating equivalency factors for other than standard axle configurations (see Eq 3-6). A summary of rigid pavement E_i values for various tridem axle loads are shown in Tables B-21 through B-24 in Appendix B for D ranging from 6 to 11 inches (152 to 279 mm) and P_t values of 1.5 through 3.0.

If pavement structures that are being designed vary significantly from the AASHO road test material properties and thicknesses, appropriate equivalence factors should be developed for site specific conditions. Care in using load equivalency factors derived from AASHTO equations must also be exercised if the actual longitudinal spacing between axles or the transverse spacing between dual ties varies significantly from those used at the road test.

<u>Summary of Procedure</u>. With the above discussion in mind, a proposed procedure for estimating the traffic loading on multilane highways is outlined below in a sequential order. The flowchart in Figure 3-9 represents the procedure schematically and shows the order in which the traffic analysis proceeds. An illustrative example based on available data is also presented to demonstrate application of procedure. The following steps are used in calculating estimates of the number of equivalent 18-kip (80-kN) single-axle loads in each lane of a multilane highway for a selected period of time.

(1) Obtain the latest three year's truck weight survey data from selected weigh stations at which truck traffic patterns are similar to those at the location being designed.

(2) Arrange the data by steering, single, tandem, and tridem axles for each class of truck by direction, and preferably by lane if such data are available, and by weight group (one-kip (4.45-kN) or two-kip (8.9-kN) interval). Develop a frequency distribution of axle weight by axle type on each class of truck.

(3) Predict a frequency distribution for each year of the analysis period. Use available prediction models, i.e., trend analysis, time series analysis, etc., or engineering judgement as appropriate.

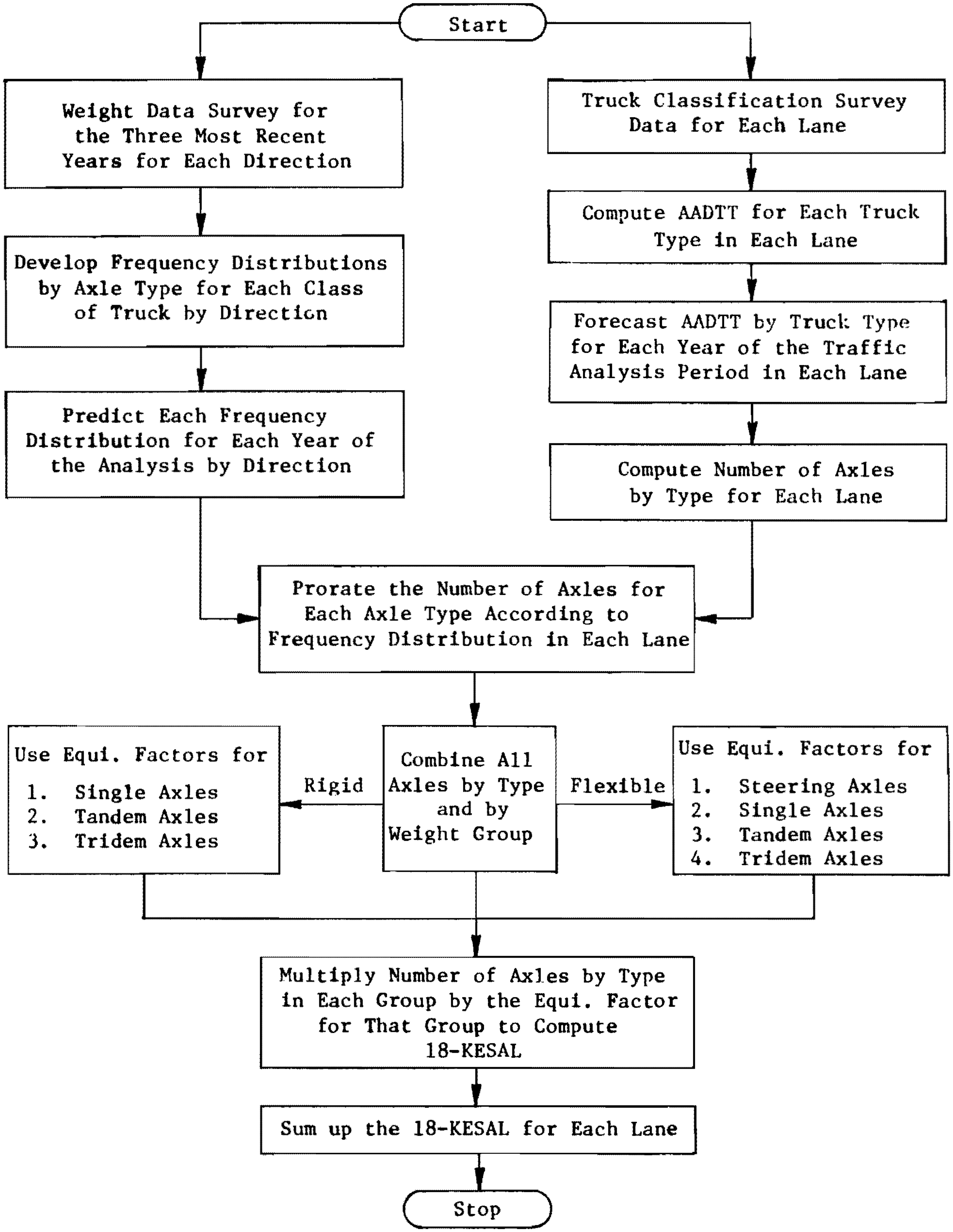

Figure 3-9. Schematic flow chart of the traffic load estimating procedure.

(4) Estimate Average Annual Daily Truck Traffic (AADTT) count of each truck type in each lane from truck classification survey data. Surveys must include lanewise sample counts.

(5) Forecast AADTT of each truck type for each year of the design period for each lane.

(6) Compute the number of steering, single, tandem, and tridem axles which will result from each truck type in each lane for the expected AADTT.

(7) Prorate, or distribute the number of axles of each type according to the frequency distributions of weight developed in step two.

(8) Sum the number of steering, single, tandem, and tridem axles by weight group in each lane.

(9) Multiply the total number of axles in each load group by the appropriate traffic equivalence factor to give equivalent 18-kip (80-kN) single-axle loads for each load group for each lane.

(10) Sum the number of equivalent 18-kip single-axle loads over all axle groups in each lane.

Mathematically, the computation of the number of 18-kip (80 - kN) single-axle load applications, W_{t18}, for an axle type in a lane can be shown as follows:

$$
\begin{aligned}
N_1 &= n_1 * P_{11} + n_2 * P_{21} \; ... + N_i * P_{i1} \; ... + n_m * P_{m1} \\
N_2 &= n_1 * P_{12} + n_2 * P_{22} \; ... + n_i * P_{i2} \; ... + n_m * P_{m2} \\
&\;\vdots \\
N_k &= n_1 * P_{1k} + n_2 * P_{2k} \; ... + n_i * P_{ik} \; ... + n_m * P_{mk}
\end{aligned}
\qquad (3\text{-}9)
$$

$$
\begin{aligned}
W_1 &= N_1 * E_1 \\
W_2 &= N_2 * E_2
\end{aligned}
\qquad (3\text{-}10)
$$

.
.
.

$$W_k = N_k * E_k$$

$$W_{jt18} = \qquad (3\text{-}11)$$

where N_k = number of axles expected for load group k

n_i = total number of axles on truck type i

P_{ik} = percent of axles on truck i in load group k

E_k = axle-load equivalence factor for load group k

W_k = equivalent 18-kip (80-kN) single-axle loads for load group k

W_{jt18} = number of 18-kip (80-kN) single-axle load applications in time t for jth axle type where j=1 denotes steering axle, j=2 denotes single axle, j=3 denotes tandem axle, and j=4 denotes tridem axle

The number of equivalent 18-kip (80-kN) single-axle loads for all axle groups is then summed to give one number that is representative of the traffic loading effects of mixed traffic in a lane:

$$W_{t18} = \sum_{1}^{4} \sum_{k=1}^{K} W_k \qquad (3\text{-}12)$$

Example of Equivalent 18-kip (80-kN) Single Axle Load Computation

Assume that the truck traffic volume shown in Table 3-10 is representative of traffic on a design section of flexible pavement. Calculation is for a 20-year design period.

The axle weight frequency distributions for the design section are as shown in Tables 3-11 through 3-16. Equivalency factors for P_t = 2.5 and SN = 3.0 are used in estimating the number of equivalent 18-kip (80 - kN) single-axle loads for a flexible pavement.

Table 3-17 illustrates the computation of total EAL for a flexible pavement. Data in the left-hand column are representative axle loads of the axle load groups shown in Tables 3-11 through 3-16. The summation of the number of loads times its appropriate factor yields the number of equivalent 18-kip (80-kN) single-axle loads (ESAL) per 1278 trucks on the left lane and 1787 trucks on the right lane.

The 18-kip (80-kN) equivalent single axle loading would be:

for average day in 20-year design
Left Lane = 976.46
Right Lane = 1131.61

for total load during design period
Left Lane = 976.46 * 365 * 20 = 7128158
Right Lane = 1131.61 * 365 * 20 = 8260753

This example illustrates a simplified procedure for the calculation of 18-kip (80- kN) equivalent single-axle loads on a lane-by-lane basis for design. This example assumes the axle weight distribution remains constant over the design period (i.e., step three is not carried out in this example).

TABLE 3-10. AVERAGE ANNUAL DAILY TRUCK TRAFFIC (AADTT) FOR A 20-YEAR DESIGN PFRIOD IN EACH LANF ON A HIGHWAY

Lane	Type of Truck						Total
	2-A	3-A	2-S1	2-S2	3-S2	3-S3	
Left	258	78	16	50	862	14	1278
Right	600	195	54	86	844	22	1787

TABLE 3-11. WEIGHT DATA FREQUENCY DISTRIBUTIONS AND AVERAGE DAILY AXLE APPLICATIONS BY 2A TRUCKS IN EACH LANE OF A FOUR-LANE HIGHWAY

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tandem Axle	Steering Axle		Single Axle		Tandem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
1.5 - 2.5	106	35		61.9	145.3	20.4	48.0		
2.5 - 3.5	-	-		-	-	-	-		
3.5 - 4.5	131	37		76.5	179.6	21.6	50.7		
4.5 - 5.5	72	40		42.0	98.7	23.3	54.8		
5.5 - 6.5	86	71		50.2	117.9	41.4	97.3		
6.5 - 7.5	33	58		19.3	45.2	33.9	79.5		
7.5 - 8.5	6	41		3.5	8.2	23.9	56.2		
8.5 - 9.5	4	33		2.3	5.5	19.3	45.2		
9.5 - 10.5	3	25		1.8	4.1	14.6	34.3		
10.5 - 11.5	1	7		.6	1.4	4.1	9.6		
11.5 - 12.5		8				4.7	11.0		
12.5 - 13.5		8				4.7	11.0		
13.5 - 14.5		5				2.9	6.9		
14.5 - 15.5		13				7.6	17.8		
15.5 - 16.5		5				2.9	6.9		
16.5 - 17.5		11				6.4	15.1		
17.5 - 18.5		13				7.6	17.8		
18.5 - 19.5		7				4.1	9.6		
19.5 - 20.5		20				11.7	27.4		
20.5 - 21.5		3				1.8	4.1		
21.5 - 22.5		2				1.2	2.7		

TABLE 3-12. WEIGHT DATA FREQUENCY DISTRIBUTIONS AND AVERAGE DAILY AXLE APPLICATIONS BY 3A TRUCKS ON EACH LANE OF A FOUR-LANF HIGHWAY

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tandem Axle	Steering Axle		Single Axle		Tandem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
3.5 - 4.5	2		-	1.2	3.0			-	-
4.5 - 5.5	10		-	6.1	15.0			-	-
5.5 - 6.5	10		-	6.1	15.0			-	-
6.5 - 7.5	18		-	11.0	27.4			-	-
7.5 - 8.5	15		6	9.1	22.9			3.7	9.1
8.5 - 9.5	33		10	20.1	50.3			6.1	15.0
9.5 - 10.5	17		14	10.4	25.9			8.5	21.3
10.5 - 11.5	8		9	4.9	12.2			5.5	13.7
11.5 - 12.5	8		14	4.9	12.2			8.5	21.3
12.5 - 13.5	3		5	1.8	4.6			3.0	7.6
13.5 - 14.5	2		5	1.2	3.0			3.0	7.6
14.5 - 15.5	1		5	0.6	1.5			3.0	7.6
15.5 - 16.5	-		4	-	-			2.4	6.1
16.5 - 17.5	1		3	0.6	1.5			1.8	4.6
17.5 - 18.5			2	-	-			1.2	3.0
18.5 - 19.5			1					0.6	1.5
19.5 - 20.5			2					1.2	3.0
20.5 - 21.5			1					0.6	1.5
21.5 - 22.5			4					2.4	6.1
22.5 - 23.5			2					1.2	3.0
23.5 - 24.5			5					3.0	7.6
24.5 - 25.5			6					3.7	9.1
25.5 - 26.5			9					5.5	13.7
26.5 - 27.5			1					0.6	1.5
27.5 - 28.5			1					0.6	1.5
28.5 - 29.5			1					0.6	1.5

(continued)

TABLE 3-12. (CONTINUED)

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tandem Axle	Steering Axle		Single Axle		Tandem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
29.5 - 30.5			5					3.0	7.6
30.5 - 31.5			1					0.6	1.5
31.5 - 32.5			1					0.6	1.5
35.5 - 36.5			9					5.5	13.7
37.5 - 38.5			2					1.2	3.0

TABLE 3-13. WEIGHT DATA FREQUENCY DISTRIBUTIONS AND AVERAGE DAILY APPLICATIONS BY 2S-1 TRUCKS IN EACH LANE OF A FOUR-LANE HIGHWAY

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tandem Axle	Steering Axle		Single Axle		Tandem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
5.5 - 6.5	1	13		0.4	0.8	5.0	10.5		
6.5 - 7.5	2	5		0.8	1.6	1.9	4.0		
7.5 - 8.5	2	19		0.8	1.6	7.2	15.4		
8.5 - 9.5	10	16		3.8	8.1	6.1	13.0		
9.5 - 10.5	3	5		1.1	2.4	1.9	4.0		
10.5 - 11.5	2	4		0.8	1.6	1.5	3.2		
11.5 - 12.5	7	7		2.7	5.7	2.7	5.7		
12.5 - 13.5	6	5		2.3	4.9	1.9	4.0		
13.5 - 14.5	4	1		1.5	3.2	0.4	0.8		
14.5 - 15.5	-	3		-	-	1.1	2.4		
15.5 - 16.5	1	1		0.4	0.8	0.4	0.8		
16.5 - 17.5	1	2		0.4	0.8	0.8	1.6		
17.5 - 18.5	1	-		0.4	0.8	-	-		
18.5 - 19.5	1	-		0.4	0.8	-	-		
19.5 - 20.5	-	-		-	-	-	-		
20.5 - 21.5	1	-		0.4	0.8	-	-		
22.5 - 23.5	-	2		-	-	0.8	1.6		
25.5 - 26.5	-	1		-	-	0.4	0.8		

TABLE 3-14. WEIGHT DATA FREQUENCY DISTRIBUTIONS AND AVERAGE DAILY APPLICATIONS BY 2-S2 TRUCKS ON EACH LANE OF A FOUR-LANF HIGHWAY

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tandem Axle	Steering Axle		Single Axle		Tandem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
1.5 - 2.5	4	1	-	1.0	1.7	.2	0.4	-	-
3.5 - 4.5	3	1	-	0.7	1.3	.2	0.4	-	-
4.5 - 5.5	10	1	-	2.4	4.2	.2	0.4	-	-
5.5 - 6.5	17	4	2	4.1	7.1	1.0	1.7	0.5	0.8
6.5 - 7.5	21	6	2	5.1	8.8	1.5	2.5	0.5	0.8
7.5 - 8.5	51	17	9	12.4	21.3	4.1	7.1	2.2	3.8
8.5 - 9.5	69	14	10	16.7	28.8	3.4	5.8	2.4	4.2
9.5 - 10.5	24	19	12	5.8	10.0	4.6	7.9	2.9	5.0
10.5 - 11.5	7	20	17	1.7	2.9	4.9	8.3	4.1	7.1
11.5 - 12.5	-	20	11	-	-	4.9	8.3	2.7	4.6
12.5 - 13.5		12	10			2.9	5.0	2.4	4.2
13.5 - 14.5		12	18			2.9	5.0	4.4	7.5
14.5 - 15.5		14	16			3.4	5.8	3.9	6.7
15.5 - 16.5		17	16			4.1	7.1	3.9	6.7
16.5 - 17.5		13	13			3.2	5.4	3.2	5.4
17.5 - 18.5		15	11			3.6	6.3	2.7	4.6
18.5 - 19.5		10	10			2.4	4.2	2.4	4.2
19.5 - 20.5		6	7			1.5	2.5	1.7	2.9
20.5 - 21.5		2	16			0.5	0.8	3.9	6.7
21.5 - 22.5		1	2			0.2	0.4	0.5	0.8
22.5 - 23.5		-	5			-	-	1.2	2.1
23.5 - 24.5		1	4			0.2	0.4	1.0	1.7
24.5 - 25.5			5					1.2	2.1
25.5 - 26.5			4					1.0	1.7
26.5 - 27.5			1					0.2	0.4
27.5 - 28.5			1					0.2	0.4

(Continued)

TABLE 3-14. (CONTINUED)

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tandem Axle	Steering Axle		Single Axle		Tandem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
28.5 - 29.5			1					0.2	0.4
30.5 - 31.5			1					0.2	0.4
34.5 - 35.5			1					0.2	0.4
41.5 - 42.5			1					0.2	0.4

TABLE 3-15. WEIGHT DATA FREQUENCY DISTRIBUTIONS AND AVERAGE DAILY AXLE APPLICATIONS BY 3-S2 TRUCKS ON EACH LANE OF A FOUR-LANE HIGHWAY

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tandem Axle	Steering Axle		Single Axle		Tandem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
4.5 - 5.5	1		-	0.3	0.3			-	-
5.5 - 6.5	22		8	7.2	7.1			2.6	2.6
6.5 - 7.5	192		37	63.0	61.7			12.1	11.9
7.5 - 8.5	609		140	199.8	195.6			45.9	45.0
8.5 - 9.5	996		251	326.7	319.9			82.3	80.6
9.5 - 10.5	544		271	178.4	174.7			88.9	87.0
10.5 - 11.5	196		268	64.3	62.9			87.9	86.1
11.5 - 12.5	54		241	17.7	17.3			79.0	77.4
12.5 - 13.5	12		205	3.9	3.9			67.2	65.8
13.5 - 14.5	3		207	1.0	1.0			67.9	66.5
14.5 - 15.5	-		154	-	-			50.5	49.5
15.5 - 16.5	-		102	-	-			33.5	32.8
16.5 - 17.5			112					36.7	36.0
17.5 - 18.5			98					32.1	31.5
18.5 - 19.5			86					28.2	27.6
19.5 - 20.5			117					28.4	37.6
20.5 - 21.5			103					33.4	33.1
21.5 - 22.5			124					40.7	39.8
22.5 - 23.5			158					51.8	50.7
23.5 - 24.5			136					44.6	43.7
24.5 - 25.5			139					45.6	44.6
25.5 - 26.5			136					44.6	43.7
26.5 - 27.5			156					51.2	50.1
27.5 - 28.5			196					64.3	62.9
28.5 - 29.5			188					61.7	60.4
29.5 - 30.5			224					73.5	71.9
30.5 - 31.5			218					71.5	70.0

(Continued)

TABLE 3-15. (CONTINUED)

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tandem Axle	Steering Axle		Single Axle		Tandem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
31.5 - 32.5			208					68.2	66.8
32.5 - 33.5			222					72.8	71.3
33.5 - 34.5			178					58.4	57.2
34.5 - 35.5			139					45.6	44.6
35.5 - 36.5			130					42.6	41.8
36.5 - 37.5			81					26.6	26.0
37.5 - 38.5			68					22.3	21.8
38.5 - 39.5			41					13.4	13.2
39.5 - 40.5			47					15.4	15.1
40.5 - 41.5			24					7.9	7.7
41.5 - 42.5			12					3.9	3.9
42.5 - 43.5			10					3.3	3.2
43.5 - 44.5			8					2.6	2.6
44.5 - 45.5			5					1.6	1.6
45.5 - 46.5			1					0.3	0.3
46.5 - 47.5			4					1.3	1.3
47.5 - 48.5			-					-	-
48.5 - 49.5			1					0.3	0.3
49.5 - 50.5			2					0.7	0.6

TABLE 3-16. WEIGHT DATA FREQUENCY DISTRIBUTIONS AND AVERAGE DAILY AXLE APPLICATIONS BY 3-S3 TRUCKS ON EACH LANE OF A FOUR-LANE HIGHWAY

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tridem Axle	Steering Axle		Single Axle		Tridem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
5.5 - 6.5	1			0.7	1.1				
6.5 - 7.5	2			1.4	2.2				
7.5 - 8.5	3			2.1	3.3				
8.5 - 9.5	5			3.5	5.5				
9.5 - 10.5	6			4.2	6.6				
10.5 - 11.5	1			0.7	1.1				
11.5 - 12.5	1	1		0.7	1.1	0.7	1.1		
12.5 - 13.5	-	-		-	-	-	-		
13.5 - 14.5	-	-	1	-	-	-	-	0.7	1.1
14.5 - 15.5	1	1	-	0.7	1.1	0.7	1.1	-	-
15.5 - 16.5	-	1	1			0.7	1.1	0.7	1.1
16.5 - 17.5		1	-			0.7	1.1	-	-
17.5 - 18.5		1	-			0.7	1.1	-	-
18.5 - 19.5		2	1			1.4	2.2	0.7	1.1
19.5 - 20.5		2	2			1.4	2.2	1.4	2.2
20.5 - 21.5		-	2			-	-	1.4	2.2
21.5 - 22.5		-	-			-	-	-	-
22.5 - 23.5		-	2			1.4	2.2	1.4	2.2
23.5 - 24.5		1	1			0.7	1.1	0.7	1.1
24.5 - 25.5		2	-			1.4	2.2	-	-
25.5 - 26.5		1	1			0.7	1.1	0.7	1.1
26.5 - 27.5		1	1			0.7	1.1	0.7	1.1
27.5 - 28.5		1	-			0.7	1.1	-	-
28.5 - 29.5		1	1			0.7	1.1	0.7	1.1
33.5 - 34.5		-	1			-	-	0.7	1.1
34.5 - 35.5		-	-			-	-	-	-
35.5 - 36.5		1	-			0.7	1.1	-	-

(Continued)

TABLE 3-16. (CONTINUED)

Axle Load Groups (Kips)	Number of Axles			Average Daily Axle Applications					
	Steering Axle	Single Axle	Tandem Axle	Steering Axle		Single Axle		Tandem Axle	
				Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
37.5 - 38.5		-	1			-	-	0.7	1.1
44.5 - 45.5		1	-			0.7	1.1	-	-
46.5 - 47.5		-	1			-	-	0.7	1.1
47.5 - 48.5		-	1			-	-	0.7	1.1
48.5 - 49.5		1	1			0.7	1.1	0.7	1.1
51.5 - 52.5		-	1			-	-	0.7	1.1
52.5 - 53.5		1	1			0.7	1.1	0.7	1.1

TABLE 3-17. DETERMINATION OF EQUIVALENT 18-kip (80-kN) SINGLE AXLE LOADS

	Representative Axle Load, kips	Equiv. Factor	Number of Axles		Equivalent 18-kip Single Axles	
			L*	R*	L	R
Steering Axles	2	0.002	62.9	147.0		
	4	0.02	78.4	183.9		
	6	0.06	119.5	267.2		
	8	0.18	338.3	399.8		
	10	0.36	574.8	641.8		
	12	0.62	99.0	118.4		
	14	0.93	11.7	20.6	10.88	19.16
	16	1.33	1.7	3.4	2.26	7.92
	18	1.90	1.4	3.1	2.66	5.89
	20	2.44	0.4	0.8	0.98	1.95
	22	3.15	0.4	0.8	1.26	2.52
				Subtotal	18.04	37.44
Single Axles	2	0.0003	20.6	48.4	0.01	0.01
	3	0.0012	—	—	—	—
	4	0.0035	21.8	51.1	0.08	0.18
	5	0.0082	23.5	55.2	0.19	0.45
	6	0.0167	47.4	109.5	0.79	1.83
	7	0.0304	37.3	86.0	1.13	2.61
	8	0.0507	35.2	78.7	1.78	4.00
	9	0.0793	28.8	64.0	2.28	5.08
	10	0.12	21.1	46.2	2.53	5.54
	11	0.17	10.5	21.1	1.78	3.59
	12	0.23	12.3	25.0	2.83	5.75
	13	0.31	9.5	20.0	2.95	6.20
	14	0.40	6.2	12.7	2.48	5.08
	15	0.51	12.1	26.0	6.17	13.26
	16	0.65	7.4	14.8	4.81	9.62
	17	0.81	10.4	22.1	8.42	17.90
	18	1.00	11.2	24.1	11.20	24.10
	19	1.23	6.5	13.8	8.00	16.97
	20	1.49	13.2	29.9	19.67	44.55
	21	1.81	2.3	7.2	4.16	13.03
	22	2.17	1.4	3.1	3.04	6.73
	23	2.60	0.8	1.6	2.08	4.16
	24	3.09	0.2	0.4	0.62	1.24
	26	4.31	0.4	0.8	1.72	3.45
				Subtotal	88.72	195.23

L = Left Lane
R = Right Lane

(continued)

TABLE 3-17. (Continued)

	Representative Axle Load, kips	Equiv. Factor	Number of Axles L	Number of Axles R	Equivalent 18-kip Single Axles L	Equivalent 18-kip Single Axles R
Tandem Axles	6	0.0017	3.1	3.4	0.005	0.006
	7	0.0030	12.6	12.7	0.038	0.038
	8	0.005	51.8	57.9	0.259	0.290
	9	0.008	90.8	99.8	0.726	0.798
	10	0.011	100.3	113.3	1.10	1.25
	11	0.016	97.5	106.9	1.56	1.71
	12	0.02	90.9	104.4	1.82	2.09
	13	0.03	72.6	77.6	2.18	2.33
	14	0.04	75.3	81.6	3.01	3.26
	15	0.05	58.1	64.9	2.91	3.25
	16	0.07	40.5	46.7	2.84	3.27
	17	0.09	42.4	47.1	3.82	4.24
	18	0.11	36.7	40.2	4.04	4.42
	19	0.13	32.6	35.5	4.24	4.62
	20	0.16	42.7	45.7	6.83	7.31
	21	0.19	37.9	41.3	7.20	7.85
	22	0.23	43.6	46.0	10.03	10.58
	23	0.27	55.6	58.0	15.01	15.66
	24	0.31	49.3	54.1	15.28	16.77
	25	0.36	51.9	58.0	18.68	20.88
	26	0.42	51.8	60.2	21.76	25.28
	27	0.48	52.7	53.1	25.30	25.49
	28	0.55	65.8	65.9	36.19	36.25
	29	0.62	63.2	63.4	39.18	39.31
	30	0.70	76.5	79.5	53.55	55.65
	31	0.79	72.3	71.9	57.12	56.80
	32	0.89	68.8	68.3	61.23	60.79
	33	1.00	72.8	71.3	72.80	71.30
	34	1.11	58.4	57.2	64.82	63.49
	35	1.24	45.8	45.0	56.79	55.80
	36	1.38	48.8	56.6	67.34	78.11
	37	1.53	26.6	26.0	40.70	39.78
	38	1.69	23.5	24.8	39.72	41.91
	39	1.86	13.4	13.2	24.92	24.55
	40	2.06	15.4	15.1	31.72	31.12
	41	2.26	7.9	7.7	17.85	17.40
	42	2.49	4.1	4.3	10.21	10.71
	43	2.73	3.3	3.2	9.01	8.74
	44	2.99	2.6	2.6	7.77	7.77
	45	3.27	2.3	2.7	7.52	8.83
	46	3.58	0.3	0.3	0.36	0.36
	47	3.90	1.3	1.3	5.07	5.07

(continued)

TABLE 3-17. (Continued)

	Representative Axle Load, kips	Equiv. Factor	Number of Axles L	Number of Axles R	Equivalent 18-kip Single Axles L	Equivalent 18-kip Single Axles R
Tandem Axles	48	4.25	—	—	—	—
	49	4.63	1.0	1.4	4.63	6.48
	50 and above	5.04	1.4	1.7	7.06	8.57
				Subtotal	864.20	890.18
Tridem Axles	14	0.0105	0.7	1.1	0.007	0.012
	16	0.0175	0.7	1.1	0.012	0.019
	19	0.0341	0.7	1.1	0.024	0.038
	20	0.0417	1.4	2.2	0.058	0.092
	21	0.0503	1.4	2.2	0.070	0.111
	23	0.0715	1.4	2.2	0.100	0.165
	24	0.0841	0.7	1.1	0.059	0.093
	26	0.1140	0.7	1.1	0.080	0.125
	27	0.1315	0.7	1.1	0.092	0.145
	29	0.172	0.7	1.1	0.120	0.189
	34	0.308	0.7	1.1	0.216	0.339
	38	0.461	0.7	1.1	0.323	0.507
	47	0.992	0.7	1.1	0.694	1.09
	48	1.072	0.7	1.1	0.750	1.18
	49	1.156	0.7	1.1	0.809	1.27
	52	1.439	0.7	1.1	1.01	1.58
	53	1.545	0.7	1.1	1.08	1.70
				Subtotal	5.50	8.66
				Total	976.46	1131.61

Load distribution:

Left Lane = 46%

Right Lane = 54%

CHAPTER 4. LATERAL WHEEL PLACEMENT OF TRUCK TRAFFIC IN THE LANE

The classification analysis described previously indicates that lanewise distribution of heavy trucks on multilane highways changes as traffic volumes change. This conclusion likely has implications for the pavement design process. Lateral placement of truck wheel loads within traffic lanes may also change as highway geometry, and traffic characteristics change. This may also have significant implications for pavement design processes. Observed premature failure of pavement edges especially on curves, indicates that wheel placement may vary and may be an important factor. Westergaard°s empirical stress prediction equations for rigid pavements indicate, for example, that more severe stress conditions result from loads placed near the edge of a slab as opposed to an interior loading position. In this chapter an investigation of truck wheel load lateral placement within traffic lanes is described.

PREVIOUS WORKS ON WHEEL PLACEMENT WITHIN THE LANE

Instrumentation which could be used to measure wheel lateral placement has historically been problematic. Within the last 40 years, however, several significant efforts have been undertaken. W.P. Walker (Ref 44) 1941, studied the effect of bridge width on the lateral positioning of vehicles and concluded that a bridge width of 28 to 30 feet was required for a pavement of 22 feet width and 6 feet shoulders in order to allow traffic to maintain its initial lateral position while crossing the bridge. A study by Taragin (Ref 35) 1943, concluded that trucks travel closer to the pavement edge than passenger cars and do not change lateral positions as severely when meeting oncoming traffic. A second study by Taragin (Ref 34) 1944, which included measurements of lateral positioning for about 95,000 vehicles at 47 different locations in 10 states concluded that

(1) shoulder width in excess of four feet does not influence the effective pavement width, and

(2) use of shoulders increases rapidly on pavements less than 22 feet in width.

F.H. Scrivner (Ref 32) 1955, in his study on lateral wheel placement in Texas concluded that

(1) the probability of pavement edge failure decreased as lane width increased, and

(2) there was no correlation between speed and lane width.

The Texas Highway Department's (Ref 37) 1957 research on vehicle placement used segmented tape switches which allowed point sampling of lateral placement. Data were collected at 14 locations on two-lane rural highways, both with and without shoulders.

In 1972, Weir and Sihilling (Ref 45) reported the use of photographic techniques (a system of cameras mounted inside a bus) to study lateral placement. Two of their conclusions were

(1) there were no differences between the two different buses they studied, for a given combination of wind and geometry conditions in terms of their effect on the adjacent vehicle, and

(2) passenger car lane placement varies with changes in roadway geometry and with the vehicle's location relative to large commercial vehicles.

Recently Miller and Stewart (Ref 25) 1982, used time-lapse photography of traffic on lanes of varying width in Toronto and found this technique superior to other methods of obtaining lateral placement data. Several of their major conclusions were:

(1) direct relationships between forward speed and lateral placements are masked by the presence of more dominant influences like vehicle size and lane width,

(2) lane types (one-way, two-way, and contraflow lanes) have an effect on lateral placement,

(3) smaller vehicles travel closer to the edge than larger vehicles, and

(4) smaller vehicles also show larger variance in lateral placement than larger vehicles.

All these studies were done with specific objectives in mind and most of the interpretations have been with respect to the vehicle center line. The instrumentation systems used did not permit continuous measurement of vehicle position but rather lateral placement was measured at one or more fixed positions.

DATA COLLECTION

The review of previous efforts to study lateral placement, as well as, the basic study objectives indicated that an instrumentation system which could continuously monitor lateral placement would be preferred. Therefore a color video recording system, mounted in a van, was used to follow selected trucks and continuously record their lateral placement.

The selected color video camera recorder system included a time-data generator which provided a reliable time base. The system was mounted on the passenger side of a van and the camera was pointed downward from five degrees to eight degrees from the horizontal.

REDUCTION OF OBSERVED DATA

The recorded video data was replayed on a 19 inch monitor from which distances were measured. The measurements were, however, subject to a number of errors for which compensation procedures were derived.

One of the more serious errors was caused by image distortion due to the complex curvature of the video monitor screen. An empirical compensation process was developed through measurement of known distances in all areas of the video screen. Correction factors were derived for those portions of the screen where they were required. For application, the correction factors were used to develop a reference grid system which was placed over the video screen. Measurement of wheel placement in the lane required two observations:

(1) the number of reference grid divisions encompassed by the lane width, which was a known distance. This measurement provided a calibration value for each reference grid unit, and

(2) the number of reference grid divisions between the inner edge of the continuous lane line and the outer edge of the right wheel.

Along with the lateral placement, other factors which were considered as independent variables namely the truck type, the section type, the lane occupied by the truck, and the type of pavement surface were also noted for each observation.

Two major highways were chosen as sites for collection of lateral placement data. One was IH-35 at Austin and the other was at U.S. 59 north of Houston. The Austin site consisted of a 26-mile interstate section (13 miles either side of the city) having at least two traffic lanes in each direction as well as adequate shoulders and median separation. Data were recorded between 0800 and 1700 hours on weekdays with approximately five hours of continuous data finally produced. The Houston site had similar geometric features with two lanes in each direction, adequate shoulders and median separation. This site was approximately ten miles in length, and due to its proximity to urban Houston, heavy truck traffic was present at virtually all times. Data were collected between 0800 and 1700 hours weekdays with about six total hours of data recorded. Average speeds on the Austin section were 60 to 70 mph while they were somewhat lower, 50 to 60 mph, in Houston.

DATA ANALYSES

Prior to the initiation of data collection, factors which might affect lateral vehicular placement and could likely be captured during data collection were listed. These factors are presented in Table 4-1 along with levels of each which were captured during data reduction.

Thus lateral placement data were collected in concert with four main factors which include truck type, section type, lane type, and pavement type. Apart from this, truck speed, the time, and the section length over which the truck was followed were also noted. The speed was not recorded as frequently as the lateral placement, but only as an average that was indicative of operation as affected by the length and nature of the section and the traffic volume.

Considerable effort was exerted to guarantee that the sample of trucks for which data were collected was representative of the Texas truck population. The percentages of each of the four principal classes of observed trucks and the percentage of the actual truck population are presented in Table 4-2. These data indicate that the sample clearly parallels the Texas truck population.

TABLE 4-1. FACTORS AND LEVELS INCLUDED IN THE SAMPLE

FACTORS	LEVELS
Truck Type	1. 2-axle 2. 3-axle (single unit)
	1. 3-S2 (tractor 2. 2-S1 semi-trailer)
Geometry	1. Straight 2. Down-grade 3. Up-grade 4. Left-curve, level 5. Right-curve, level 6. Left-curve, down-grade 7. Right-curve, down-grade 8. Left-curve, up-grade 9. Right-curve, down-grade
Pavement Surface	1. Rigid pavement (concrete) 2. Flexible pavement (asphalt)
Lanes	1. Inside lane 2. Center lane 3. Outside lane

TABLE 4-2. TYPES OF TRUCKS CONSIDERED

TYPE	TRUCK	PROPORTION ON THE ROAD	PROPORTION IN OUR SAMPLE
1	3-S2	71%	79%
2	3-Axle	4%	7%
3	2-S1	4%	-0-
4	2-Axle	20%	12%

LATERAL PLACEMENT VERSUS TIME

Wheel placement values of each sampled truck were plotted as a nearly continuous function of time. On the average, the time interval between measurements of wheel placement on long straight sections was about five to ten seconds and on curved sections, it was about two to three seconds. These plots indicated that distinctive distribution patterns existed with respect to lateral wheel placement for each truck, and that these patterns varied as the factors shown in Table 4-1 changed.

DIFFERENCES BETWEEN LANES AND PAVEMENT SURFACE TYPE

Conventional Chi-Square tests were employed to determine whether lateral wheel placement varied significantly among individual vehicles of each truck type. These tests indicated that the differences in wheel placement among vehicles of each class were not statistically significant. Based upon this finding, data for individual vehicles were aggregated and analysis of variance was used to determine whether the factors of Table 4-1 significantly affected lateral placement. Within the analyses these factors have been delineated as truck, section, lane, and pavement surface type. As noted in the table, single-unit and articulated trucks represented the two levels of truck type while nine combinations of highway grade and curvative composed the section levels. Median (inside), center, and curb (outside) lanes composed the levels of the lane factor, and rigid or flexible pavements represented the two pavement types.

The analysis of variance indicated that there were significant differences between lateral lane placement of single-unit and articulated trucks. The articulated vehicles traveled generally closer to the pavement edge.

Significant differences were also detected among lateral placement data for the various section types. A series of paired Chi-Square tests were utilized to match sections with common placement characteristics. Lateral placement was found to be different for straight sections as opposed to those with curvature (either with or without gradient). Vehicles generally traveled nearer to the lane edge where the horizontal alignment contained curvature.

No statistically significant effects upon placement could be attributed to the type of pavement surface or to the particular lane in which sampled vehicles traveled.

Frequency distributions in bar chart form have been prepared to show the different patterns of truck wheel placement that were observed under various circumstances. These are presented as Figures 4-1 through 4-4 and include sample data for single-unit and semi-trailer trucks on straight and curved highway sections. In each chart the unit zero on the abscissa represents the right-hand (outside) lane edge.

These frequency distributions of truck wheel placement are generally representative of truck traffic on multilane highways in Texas. No significant difference in wheel placement patterns was seen between the Austin and Houston data for similar conditions. They can be used to calculate the probable effects of wheel placement on traffic load-induced stresses for pavement design and evaluation purposes. Consideration of these effects is particularly important in analyzing rigid pavements and in evaluating the structural aspects of shoulders.

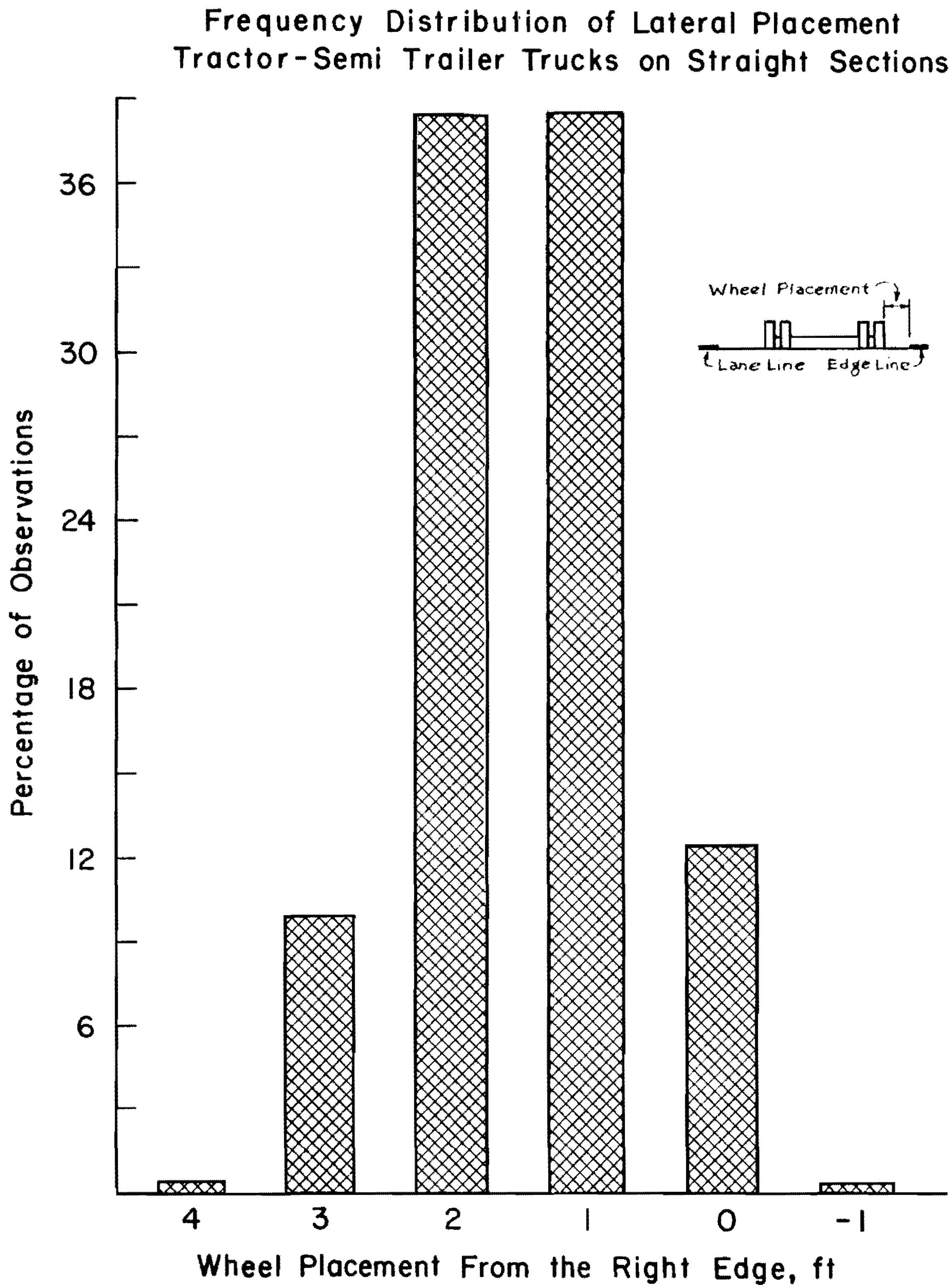

Figure 4-1. Wheel placement from the right edge (placement midpoints in feet).

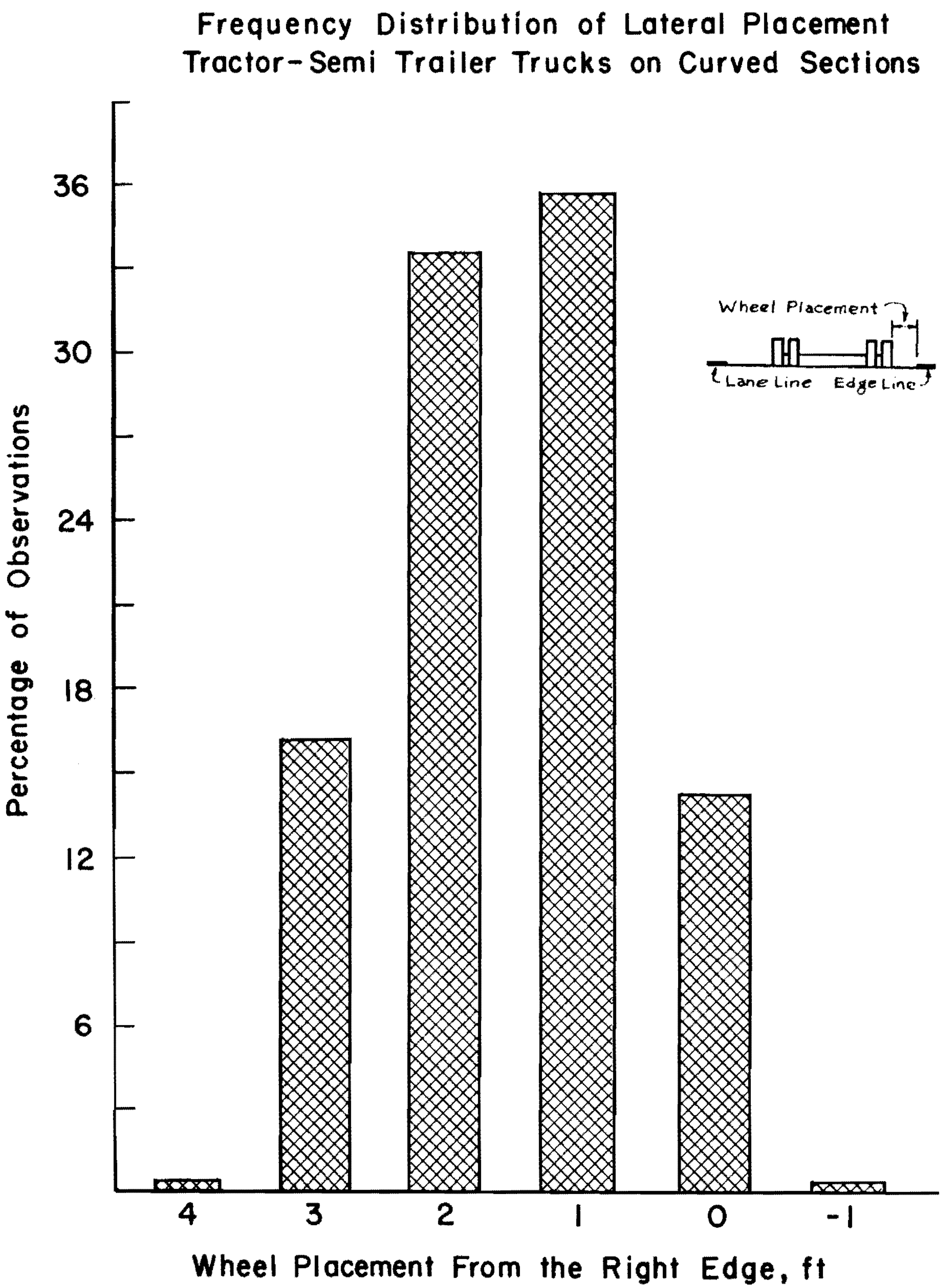

Figure 4-2. Wheel placement from the right edge (placement midpoints in feet).

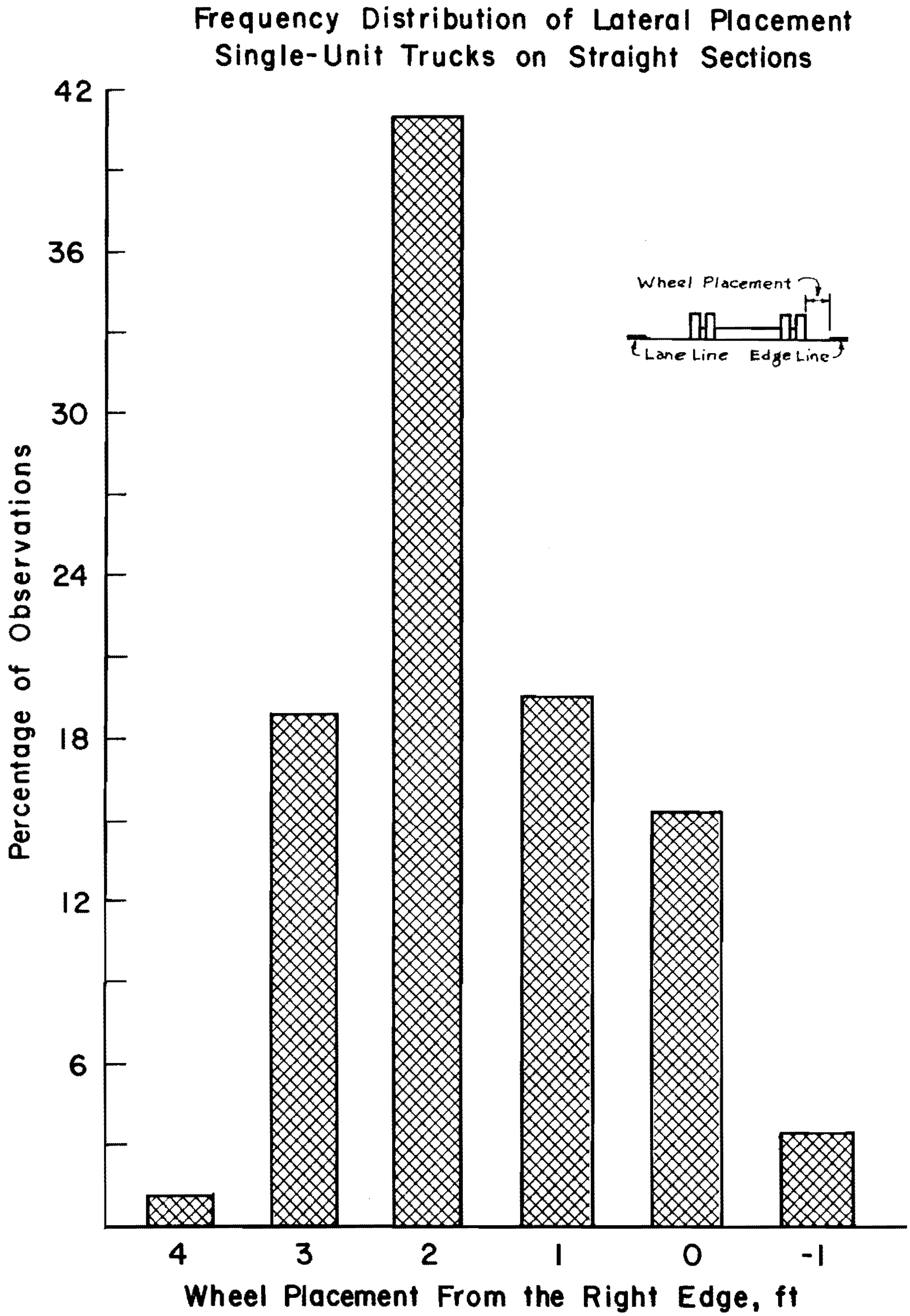

Figure 4-3. Wheel placements from the right edge (placement midpoints in feet).

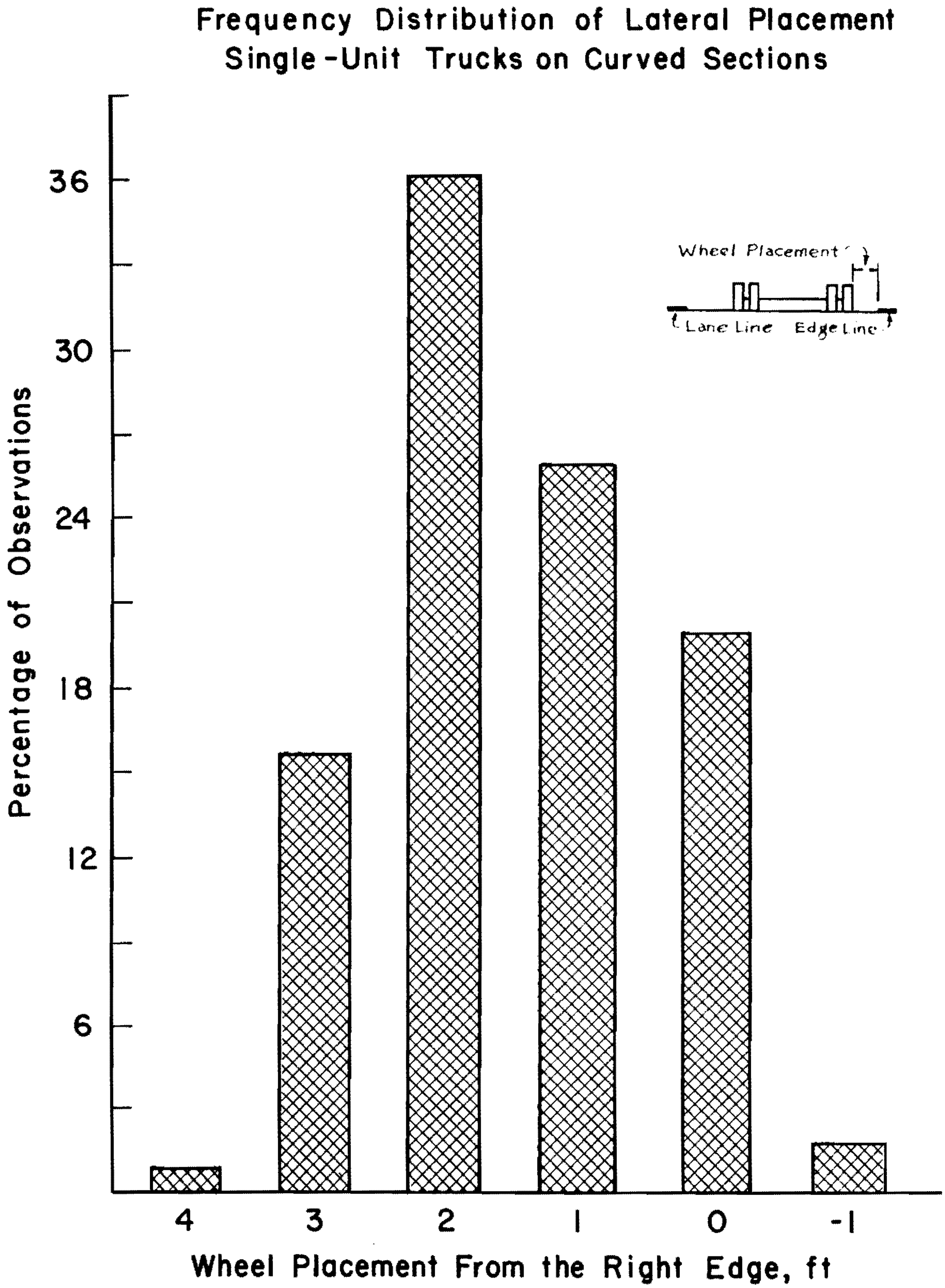

Figure 4-4. Wheel placement from the right edge (placement midpoints in feet).

APPLICATION OF WHEEL PLACEMENT FREQUENCY DISTRIBUTIONS

The frequency distributions that have been developed from analyses of the field data can be incorporated into design procedures for rigid pavements. Design procedures generally base the required pavement thickness on repeated applications of an equivalent 18-kip single axle load applied at one lateral location with respect to the pavement edge. The maximum tensile stress which results from a single load application has been correlated with the strength of the pavement and with the potential damaging effects of repeated applications of the load. A frequently used relationship among the maximum tensile stress, the strength of the pavement, and the number of applications of a single axle load is given by [Ref 3]

$$\log W_t = a + b \log F$$

where W_t = number of applications of a given single axle load to produce a terminal serviceability index of 2.5

$F = S_c/\sigma$

S_c = modulus of rupture of concrete, psi

σ = maximum tensile stress in the concrete calculated from the Spangler equation (for an unprotected corner) [Ref 3]

a = a constant

b = slope of the $\log W_t$ vs $\log S_c/\sigma$ curve

In the design procedure developed originally by AASHTO [Ref 3] and now used by the State Department of Highways and Public Transportation (SDHPT), this equation was combined into the AASHTO Road Test equations to obtain a design pavement thickness, given the total number of equivalent 18-kip single axle loads, the working stress in concrete, the elastic modulus of concrete, and the subgrade reaction. In this procedure, no provision has been made for the possible effects of the lateral positioning of the loads across the transverse cross section of the pavement. The lateral distribution of wheel loads of different magnitudes and number of repetitions across the pavement produces various levels of stress, and therefore damaging effects, at any selected point in the pavement.

The AASHTO and SDHPT design charts use the more conservative of the equations for stress calculations - the equation for the corner loading condition by Spangler [Ref 3, pp. 103] to determine the maximum tensile stress and thus the design thickness. The emphasis of the wheel-placement frequency distributions developed in this work is to take into account the combinations of interior and edge loading conditions that can possibly affect the design thickness of the pavement. To illustrate the relative effect of these distributions, two design thicknesses, one for the laterally-distributed loading condition and one for a single-position loading, are compared.

The AASHTO design nomographs were not used per se for arriving at a design thickness, but a finite element program [Ref 47] which can be used to estimate the stresses at different points in a concrete pavement slab (necessary while considering distributed loading) was used. The program enabled the modelling of stresses in the slab due to loads positioned at various points on the slab. By running the program several times, with an 18-kip single axle load positioned at a different place each time, the various stress levels which would result at any selected point in the slab from each load position were identified. Then, the cumulative damaging effect of repeated applications of these various stress levels at a critical point in the slab was assessed. A pavement thickness which could accommodate a laterally-distributed loading frequency pattern was finally determined by successive approximation. For comparison, the thickness required for repeated applications of an 18-kip single axle load in the conventional edge loading position was determined by using the same procedure.

The Slab Model

A 12-foot by 12-foot slab was considered for evaluation purposes. The slab was divided into 144 square elements so that each node was one foot away from the adjacent node. The loads were imposed on the nodes, and each node had associated with it a certain slab stiffness and a subgrade stiffness. Figure 4-5 gives a schematic of the arrangement of nodes and the position of the wheel loads. The edge or corner loading conditions were simulated by reducing the stiffness of the slab and the spring support to one-half or one-quarter of the original stiffness, respectively, at the appropriate nodes. A computation was then carried out by the program to determine the stresses (both tensile and compressive) at all the nodal points.

Use of Vesic's Fatigue Model

The fatigue model which was incorporated into the AASHTO design nomographs was of the form

$$\log W_t = a + b \log F$$

where W_t and F were as designated earlier; a and b are constants to be evaluated. AASHTO design nomographs provide for a and b in terms of the present serviceability index, and they are not calculated independently.

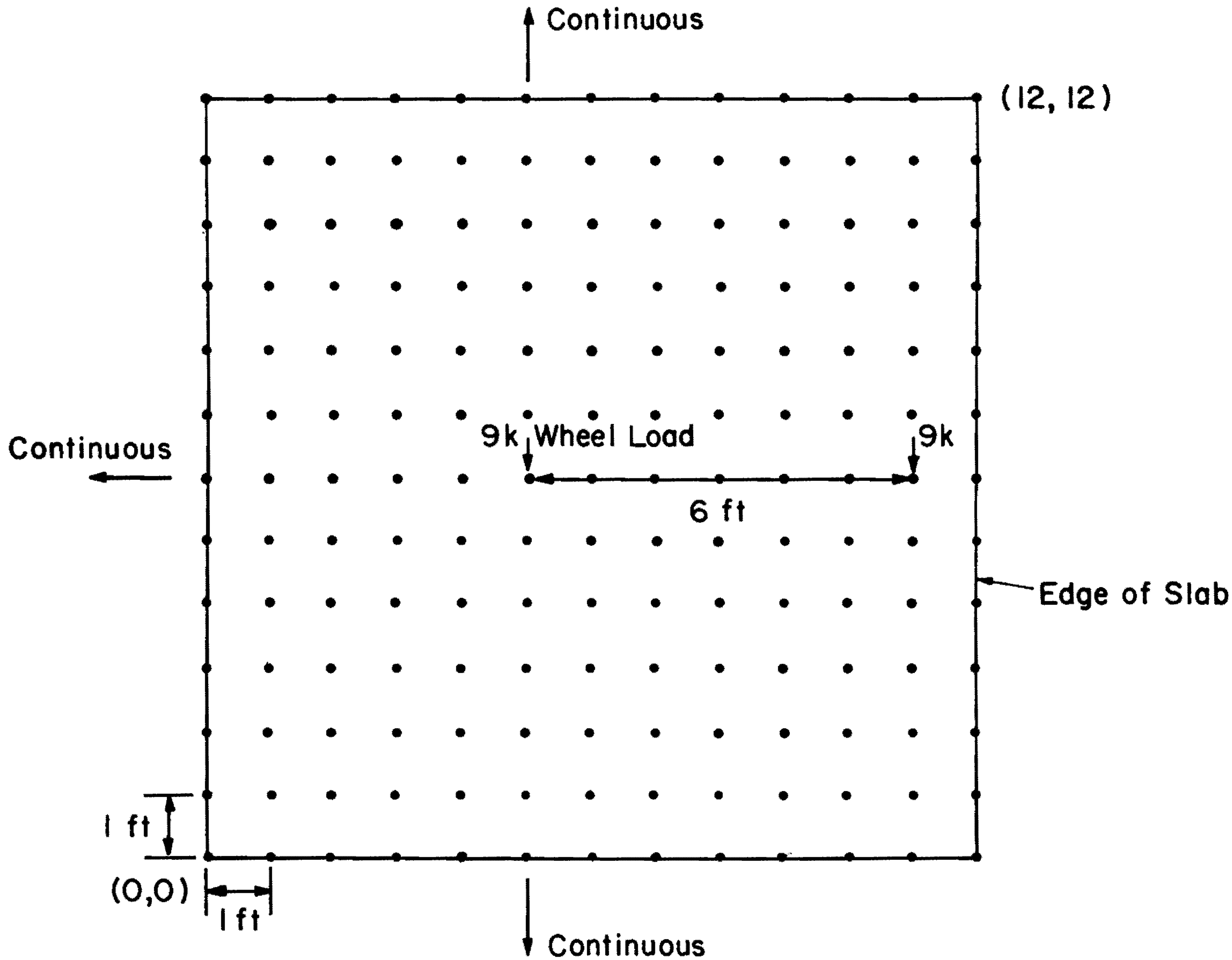

Figure 4-5. Finite element modelling of a slab subjected to an 18-kip axle load.

Vesic [Ref 47] used the AASHTO Road Test data to develop a fatigue model of the same form as above that included several different loading configurations on rigid pavements of various thicknesses.

A concrete slab 30 feet long and 12 feet wide with a joint in the center was used by Vesic for his analysis. Single axle and tandem axle loads were positioned laterally as shown in Fig 4-6 (inset) and were shifted in nodal increments towards the joint. The resulting maximum tensile stresses were then plotted against the distance of the load from the joint. Figure 4-6 shows a sample curve. Similar curves were developed for various magnitudes of loads and pavement thicknesses. The lateral placement of the outer wheel, was however kept 2.5 feet away from the pavement edge (average wheel path) because the AASHTO Road Test data was reported for this condition only.

The maximum tensile stress that occurred for different load magnitudes and for different pavement thicknesses was then plotted against the number of repetitions accommodated before the pavement reached a present serviceability index of 2.5 (data available from AASHTO Road Test). Vesic found that a unique relationship existed of the form

$$N_t = 225{,}000(f_c/\sigma)^4$$

where N_t = the number of replications of an equivalent 18-kip single axle load needed to reduce the present serviceability index to a value, t

f_c = the modulus of rupture (strength) of the concrete

σ = the maximum tensile stress in the concrete due to axle loading

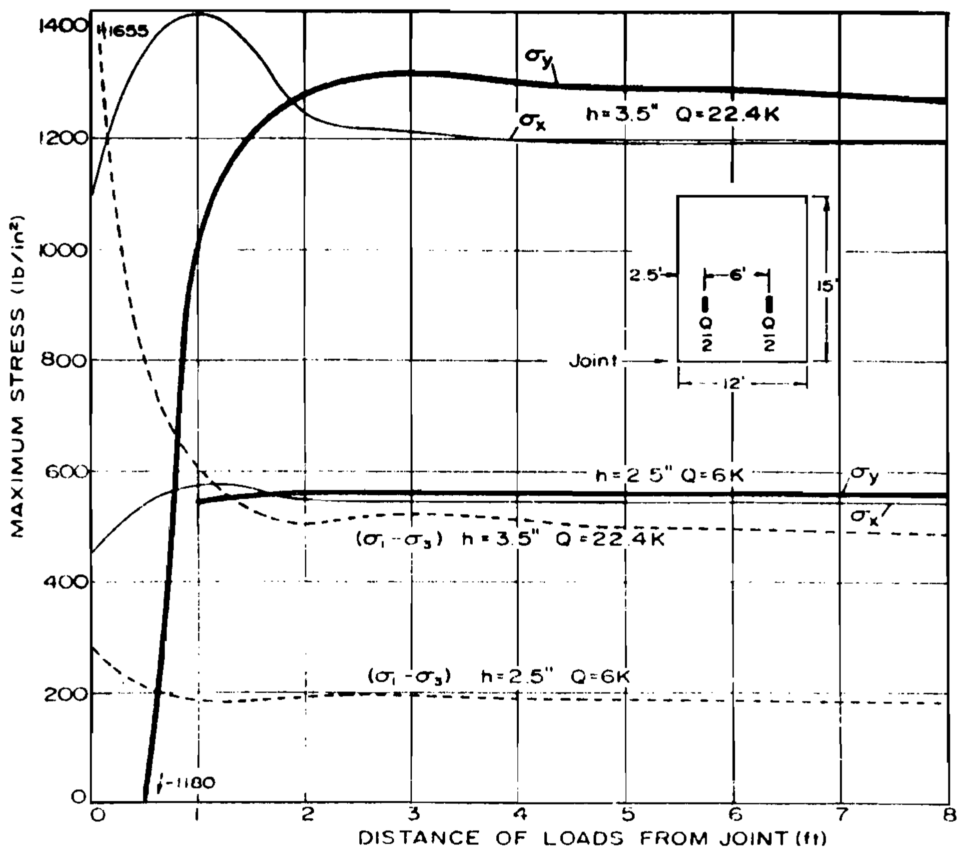

Figure 4-6. Maximum tensile stress as a function of load position for Vesic's Model (Ref 22).

The above fatigue model was used in this work to approximate the effect of distributing wheel-load repetitions laterally across the pavement and to calculate the cumulative damage. The slab model used herein was 12 feet by 12 feet, and no joints were present. The basic load position case - that of applying all the repetitions near the edge of the slab - to a certain extent is similar to the critical loading condition of Vesic with the axle near the joint. The lateral shift case - that of shifting the load repetitions laterally inward from the edge of the slab - compares with Vesic's shifting of the loading configuration longitudinally, away from the joint. Thus a stress distribution curve for the several loading configurations in this work might resemble Vesic's stress distribution curves shown in Fig 4-6. No empirical data concerning the fatigue effects of loads positioned at various lateral positions in the lane is known to exist. Thus, an effort was made in this evaluation procedure to adhere as closely as possible to Vesic's loading configuration so that his fatigue model could be used to compare the cumulative damage which might occur to the pavement for laterally distributed loads. The actual loading configurations and the modelling procedure are described in further detail below.

Thickness Required for Repeated Application in the Edge Loading Position (CASE 1)

The fatigue model used to relate the number of replications to the allowable stress ratio is given by Ref 47:

$$N_{2.5} = 225{,}000(f_c/\sigma)^4$$

where $N_{2.5}$ = the number of replications (of an equivalent 18-kip single axle load) needed to reduce the present serviceability index to 2.5

f_c = the modulus of rupture (strength) of concrete

σ = the maximum tensile stress in concrete

σ / f_c = is known as the stress ratio

The following assumptions were made in applying this model:

(1) that the stress ratio is the best indicator of the effect of the number of load replications, and

(2) that the model is valid regardless of where the loads are positioned and where the maximum tensile stresses occur.

With these assumptions, the following procedure was carried out.

(1) Assuming a million replications of the standard 18-kip single axle load would occur at the edge loading position before failure, the allowable stress ratio was calculated from the fatigue model.

(2) A working stress or (strength) of concrete was assumed as 650 psi, and the maximum allowable stress was then calculated.

The same finite element model [Ref 48] that was employed by Vesic [Ref 47] was used to calculate the maximum tensile stress in a slab of some trial thickness due to an 18-kip single axle load being placed longitudinally at the center of the slab with the center of the outside wheel 1.0 foot from the edge of the slab. This maximum tensile stress (under the outside wheel) was compared with the maximum allowable stress from the fatigue model, and another trial thickness was chosen so as to make the calculated stress more nearly equal to the allowable stress for fatigue loading. By successive adjustments in slab thickness, the stresses were made approximately equal. The resulting thickness was the required thickness for sustaining 1,000,000 applications of an 18-kip single axle load in the edge loading position (CASE 1).

Thickness Required for a Laterally Distributed Application of Loads (CASE 2)

The distribution percentages developed from the analysis represent the frequency of application of heavy axle loads on the right lane of multi-lane highways at the designated transverse sections of one foot intervals. Since the distance measured in this study was to the outer wheel edge, and the load is considered to be applied at the center of the dual wheels, the loading position is a foot away from the wheel position placement as defined in this study. The loading pattern was then shifted leftward to account for the lateral distribution of the loading.

The lateral distribution pattern was as follows:

Within one foot from the edge line - ten percent of total applications (representing edge conditions). The loading coordinates were (5,6),(11,6) each wheel carrying 9 kips

Within two feet from the edge line - 40 percent of applications
Loading position = (4,6),(10,6)

Within three feet from the edge line - 40 percent of applications
Loading position = (3,6),(9,6)

Within four feet from the edge line - ten percent of applications
Loading position = (2,6),(8,6)

The first problem here is to determine where the maximum cumulative stress will occur. Hence for the different loading positions, the stresses under nodes (11,6), (10,6), (9,6) and (8,6) were tabulated.

Loading Position		MAX TENSILE STRESSES UNDER (PSI) (11,6)	(10,6)	(9,6)	(8,6)
(5,6)	(11,6)	-648.2	-435.6	-332.7	-311.4
		-605.7	-407.1	-310.9	-291.0
(4,6)	(10,6)	-409.1	-552.6	-384.0	-304.2
		-382.3	-516.4	-358.8	-284.2
(3,6)	(9,6)	-266.5	-353.3	-519.3	-364.2
		-249.0	-330.2	-485.2	-340.4
(2,6)	(8,6)	-183.5	-232.7	-331.6	-505.8
		-171.5	-217.4	-309.9	-472.6

NOTE: The upper stress value results from CASE 1 and the lower stress value results from CASE 2.

To account for the accumulated damage due to these several loadings, the following procedure incorporating Minor's hypothesis was used.

Assuming that maximum cumulative damage occurs under node (10,6), (where 40 percent of the load repetitions occur) the possible number of replications for the different stress levels were calculated as follows:

1. Stress at (10,6) due to loading at nodes (10,6),(4,6) = 516.4 psi
2. Additional stress at (10,6) due to loading at nodes (11,6),(5,6) = 407.1 psi
3. Additional stress at (10,6) due to loading at nodes (9,6),(3,6) = 330.2 psi
4. Additional stress at (10,6) due to loading at nodes (8,6),(2,6) = 217.4 psi

Each of these stresses, has associated with it a certain number of possible applications of load, which can be calculated from the Vesic fatigue model. The possible replications are listed below.

		Possible	Actual
1	=	565,000	400,000
2	=	1,462,000	100,000
3	=	3,378,000	400,000
4	=	very large	100,000

The cumulative linear damage hypothesis (Minor's hypothesis) states that the sum of the ratio of actual to theoretical or (possible) application for each type of load must be equal to unity before failure occurs. Assuming that failure refers to the pavement reaching a present serviceability index of 2.5, the cumulative damage is as follows.

$$\frac{400{,}000}{565{,}000} + \frac{100{,}000}{1{,}462{,}000} + \frac{400{,}000}{3{,}378{,}000} + \text{negligible}$$

$$= .71 + .06 + .12 = 0.89$$

Note that the above cumulative damage index has been arrived at after an assumed thickness. The actual procedure calls for evaluating the cumulative damage for several different thicknesses until it is close to unity. (The stress values tabulated earlier for the distributed application of lateral loads (CASE 2) are the values obtained for the final thickness.)

Now a comparison of the thicknesses for the edge loading case and a distributed loading case is possible.

Thickness required for the edge loading case = 6.9"

Thickness required for the distributed loading case = 6.0"

Thus, for the conditions assumed, there is a saving of almost one inch in the pavement thickness due to lateral distribution of the wheel loads in this example. A 15 percent thicker pavement was required for the usual edge loading case than for the laterally distributed repetition of load case. The distribution of wheel load repetitions imposes less severe pavement loading conditions and thus suggests that considerable savings in thickness might be possible in pavement design practice.

CHAPTER 5. SUMMARY AND CONCLUSIONS

Traffic loading information is an essential element in the pavement design and performance evaluation process. Conventional traffic survey programs and forecasting procedures generally do not provide sufficient data about the lanewise distribution of traffic on multilane highways nor about the patterns of wheel placement within the traffic lane for this purpose. This study was directed toward developing a practical technique for obtaining estimates of wheel and axle loads in each lane of multilane highways and defining representative frequency distributions for truck wheel placement within the traffic lane.

In addressing the first objective, the concept of using vehicle classification according to axle arrangement as a basis for estimating wheel loads in each lane without actually weighing the wheels was presented, and the important need for a portable multilane vehicle classifier instrument was identified. A proposed configuration of on-road sensors and signal processing logic for such a classifier was devised, but its success depends on the use of a suitable axle detector which did not exist at the time. A new axle detector design utilizing a series of inexpensive piezoelectric elements was developed and field tested. A technique of surface mounting two of these axle detectors along with an inductance loop detector under ordinary asphalt roofing shingles made it possible to install the three required sensors in a traffic lane in less than fifteen minutes.

The feasibility of the vehicle classifier was demonstrated by installing sensors in the northbound lanes of IH-35 near Austin and processing the signals through the SDHPT's existing weigh-in-motion (WIM) system with a modified software program. Excellent accuracy in classification was achieved, but the need for improved durability in the axle detector was demonstrated. Pilot models of a three-lane portable vehicle classifier will be available for use late in 1984, and an improved axle detector is now being tested. Deployment of these portable vehicle classifiers along with judicious operation of a new four-lane WIM system, which was delivered to the SDHPT in June 1984 will make forecasting of lanewise traffic loading on multilane highways practicable in the near future in Texas.

A procedure for using weight data samples, vehicle classification counts, and axle load equivalency factors to estimate cumulative traffic loading that might occur in each highway lane over a period of time is presented in Chapter 3. A numerical example is used to illustrate the procedure for a specific data set.

For defining wheel placement frequency distributions, a video recording technique was used to obtain samples of field data concerning the lateral placement of truck wheels within the traffic lane. Analysis of representative data from study sites near Austin and near Houston indicated that the placement patterns of truck wheels within the lane were not significantly different at these two locations for similar circumstances. This indicates that geographical location within Texas does not have a pronounced effect on wheel placement in the lane. Significantly different frequency distributions for lateral wheel placement were observed, however, for single-unit and tractor-trailer trucks as well as for straight roadway sections and curved roadway sections. A separate bar chart is presented for each of the conditions which was found to influence lateral wheel placement. This information can be used in evaluating the critical stress conditions which might occur in pavement structures due to traffic loading.

An example application of the representative lateral wheel placement frequency distribution patterns developed herein indicated that design thickness of a rigid pavement could be reduced by 14 percent for the laterally distributed wheel loads as compared to the thickness required for all loads placed at the pavement edge in accordance with usual practice. The cumulative damaging effects of the laterally distributed wheel loads was found to be significantly less than for the total edge loading condition. Appropriate recognition of this in pavement design procedures can possibly have considerable economic impact on pavement design and maintenance.

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APPENDIX A.

A REPRESENTATIVE CLASSIFICATION SAMPLE BY LANES FOR HIGHWAY U.S. 59 IN HOUSTON, TEXAS

TABLE A-1. LANE-WISE DISTRIBUTION OF DIFFERENT CLASSES OF VEHICLES

Lane: Right (Outside)
Direction: North Bound
Weather: Sunny/Hot

Day and Date	Time Period	Passenger Cars and Pickups	Trucks: Single Units		Trucks: Tractor-Trailer Combinations					Buses	Travel Trailers
			2 Axle	3 Axle	2-S1	2-S2	3-S2	3-S3	Unusual		
Thursday, July 9, 1981	12:30 - 1:30	841	27	11	4	4	33	1	3	0	4
	1:30 - 2:30	950	48	9	0	6	36	0	5	2	10
	2:30 - 3:30	1094	38	8	0	5	35	4	6	1	1
	3:30 - 4:30	1471	29	10	1	3	41	1	18	6	4
	4:30 - 5:30	1720	33	12	1	2	25	0	2	1	2
	11:15 - 12:00	335	1	2	0	0	8	0	1	0	2
Friday, July 10, 1981	12:00 - 1:00	303	3	0	0	2	24	0	6	0	2
	1:00 - 2:00	174	3	2	0	3	22	0	1	0	1
	2:00 - 2:15	19	2	0	0	1	6	0	0	0	0
	7:30 - 8:00	331	29	10	2	0	12	0	2	3	2
	8:00 - 9:00	665	49	23	0	6	43	2	4	0	5
	9:00 - 10:00	752	42	12	3	1	52	0	7	2	6
	10:00 - 11:00	832	53	12	3	4	49	2	4	2	8
	11:00 - 12:00	933	47	19	3	6	36	1	8	3	0

TABLE A-2. LANE-WISE DISTRIBUTION OF DIFFERENT CLASSES OF VEHICLES

Lane: Left (Inside)
Direction: North Bound
Weather: Sunny/Hot

Day and Date	Time Period	Passenger Cars and Pickups	Trucks							Buses	Travel Trailers
			Single Units		Tractor-Trailer Combinations						
			2 Axle	3 Axle	2-S1	2-S2	3-S2	3-S3	Unusual		
Thursday, July 9, 1981	12:30 - 1:30	662	22	2	1	1	39	0	0	2	1
	1:30 - 2:30	771	19	4	1	2	58	2	3	1	3
	2:30 - 3:30	1031	13	2	2	2	47	1	2	1	2
	3:30 - 4:30	1071	17	4	0	3	39	0	1	3	1
	4:30 - 5:30	1964	10	2	1	3	25	0	2	3	0
	11:15 - 12:00	212	2	0	0	5	4	0	0	0	1
Friday, July 10, 1981	12:00 - 1:00	157	2	0	0	0	7	0	0	0	0
	1:00 - 2:00	91	1	1	0	1	10	0	0	1	0
	2:00 - 2:15	6	0	1	0	0	0	0	0	0	0
	7:30 - 8:00	267	6	7	0	0	10	1	1	0	0
	8:00 - 9:00	562	24	10	0	1	28	0	0	2	1
	9:00 - 10:00	571	13	8	0	1	49	1	0	2	3
	10:00 - 11:00	695	23	6	1	2	40	0	2	1	2
	11:00 - 12:00	844	20	5	2	4	75	2	2	0	0

TABLE A-3. LANE-WISE DISTRIBUTION OF DIFFERENT CLASSES OF VEHICLES

Lane: Right (Outside)
Direction: South Bound
Weather: Sunny/Hot

			Trucks								
			Single Units		Tractor-Trailer Combinations						
Date	Period	Passenger Cars and Pickups	2 Axle	3 Axle	2-S1	2-S2	3-S2	3-S3	Unusual	Buses	Travel Trailers
Thursday, July 9, 1981	12:30 - 1:30	691	31	4	1	9	35	1	6	0	1
	1:30 - 2:30	890	23	7	2	1	29	2	1	1	1
	2:30 - 3:30	793	23	16	1	6	40	0	2	3	0
	3:30 - 4:30	780	23	9	4	2	35	1	0	3	0
	4:30 - 5:30	823	24	3	4	3	26	1	2	4	1
	11:15 - 12:00	205	2	0	0	1	15	0	0	0	0
Friday, July 10, 1981	12:00 - 1:00	174	3	1	1	1	29	0	0	1	0
	1:00 - 2:00	149	0	0	0	1	31	0	0	0	0
	2:00 - 2:15	38	0	0	0	0	5	0	0	0	0
	7:30 - 8:00	717	12	8	1	3	22	0	0	1	0
	8:00 - 9:00	956	35	9	1	2	77	4	2	2	0
	9:00 - 10:00	706	22	19	2	6	65	1	0	2	0
	10:00 - 11:00	742	25	20	1	0	62	1	0	1	1
	11:00 - 12:00	762	35	14	0	3	57	3	0	1	1

TABLE A-4. LANE-WISE DISTRIBUTION OF DIFFERENT CLASSES OF VEHICLES

Lane: Left (Inside)
Direction: South Bound
Weather: Sunny/Hot

Day and Date	Period	Passenger Cars and Pickups	Trucks: Single Units: 2 Axle	Trucks: Single Units: 3 Axle	Trucks: Tractor-Trailer Combinations: 2-S1	2-S2	3-S2	3-S3	Unusual	Buses	Travel Trailers
Thursday, July 9, 1981	12:30 - 1:30	709	10	3	0	1	38	3	2	1	0
	1:30 - 2:30	857	6	1	2	1	27	2	2	0	0
	2:30 - 3:30	817	9	4	2	2	42	1	2	1	2
	3:30 - 4:30	817	6	3	0	3	17	0	1	2	2
	4:30 - 5:30	800	15	2	0	0	20	2	0	1	1
	11:15 - 12:00	110	1	0	0	0	9	0	0	1	0
Friday, July 10, 1981	12:00 - 1:00	81	0	0	0	0	3	0	0	0	0
	1:00 - 2:00	81	0	0	0	0	14	0	0	0	0
	2:00 - 2:15	16	0	0	0	0	1	0	0	0	0
	7:30 - 8:00	962	4	0	0	0	20	0	0	0	0
	8:00 - 9:00	1276	10	9	0	0	38	0	1	1	0
	9:00 - 10:00	922	4	4	1	2	30	0	2	2	1
	10:00 - 11:00	841	9	2	0	1	31	0	0	0	1
	11:00 - 12:00	856	11	16	0	0	28	1	1	1	1

APPENDIX B.

EQUIVALENCY FACTORS

after

AASHTO (Ref 3)

TABLE B-1. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, SINGLE AXLES, PT = 1.5

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
2	8.9	.0001	.0001	.0001	.0001	.0001	.0001
3	13.3	.0006	.0006	.0006	.0006	.0006	.0006
4	17.8	.0017	.0017	.0017	.0017	.0017	.0017
5	22.3	.0040	.0040	.0040	.0040	.0040	.0040
6	26.7	.0084	.0084	.0084	.0084	.0084	.0084
7	31.1	.0159	.0159	.0159	.0159	.0159	.0159
8	35.6	.0279	.0279	.0279	.0279	.0279	.0279
9	40.0	.0462	.0462	.0462	.0462	.0462	.0462
10	44.5	.0730	.0730	.0730	.0730	.0730	.0730
11	48.9	.1107	.1107	.1107	.1107	.1107	.1107
12	53.4	.1624	.1624	.1624	.1624	.1624	.1624
13	57.8	.2316	.2316	.2316	.2316	.2316	.2316
14	62.3	.3223	.3223	.3223	.3223	.3223	.3223
15	66.7	.4390	.4390	.4390	.4390	.4390	.4390
16	71.2	.5870	.5870	.5870	.5870	.5870	.5870
17	75.6	.7718	.7718	.7718	.7718	.7718	.7718
18	80.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	84.5	1.2785	1.2785	1.2785	1.2785	1.2785	1.2785
20	89.0	1.6151	1.6151	1.6151	1.6151	1.6151	1.6151
21	93.4	2.0182	2.0182	2.0182	2.0182	2.0182	2.0182
22	97.9	2.4972	2.4972	2.4972	2.4972	2.4972	2.4972
23	102.3	3.0618	3.0618	3.0618	3.0618	3.0618	3.0618
24	106.8	3.7231	3.7231	3.7231	3.7231	3.7231	3.7231
25	111.2	4.4925	4.4925	4.4925	4.4925	4.4925	4.4925
26	115.7	5.3827	5.3827	5.3827	5.3827	5.3827	5.3827
27	120.1	6.4070	6.4070	6.4070	6.4070	6.4070	6.4070
28	124.6	7.5798	7.5798	7.5798	7.5798	7.5798	7.5798
29	129.0	8.9162	8.9162	8.9162	8.9162	8.9162	8.9162
30	133.5	10.4326	10.4326	10.4326	10.4326	10.4326	10.4326
31	137.9	12.1462	12.1462	12.1462	12.1462	12.1462	12.1462
32	142.4	14.0751	14.0751	14.0751	14.0751	14.0751	14.0751
33	146.8	16.2388	16.2388	16.2388	16.2388	16.2388	16.2388
34	151.3	18.6576	18.6576	18.6576	18.6576	18.6576	18.6576
35	155.7	21.3530	21.3530	21.3530	21.3530	21.3530	21.3530
36	160.2	24.3476	24.3476	24.3476	24.3476	24.3476	24.3476
37	164.6	27.6652	27.6652	27.6652	27.6652	27.6652	27.6652
38	169.1	31.3307	31.3307	31.3307	31.3307	31.3307	31.3307
39	173.5	35.3702	35.3702	35.3702	35.3702	35.3702	35.3702
40	178.0	39.8112	39.8112	39.8112	39.8112	39.8112	39.8112

TABLE B-2. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, TANDEM AXLES, PT = 1.5

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
6	26.7	.0008	.0008	.0008	.0008	.0008	.0008
7	31.1	.0014	.0014	.0014	.0014	.0014	.0014
8	35.6	.0023	.0023	.0023	.0023	.0023	.0023
9	40.0	.0036	.0036	.0036	.0036	.0036	.0036
10	44.5	.0055	.0055	.0055	.0055	.0055	.0055
11	48.9	.0081	.0081	.0081	.0081	.0081	.0081
12	53.4	.0115	.0115	.0115	.0115	.0115	.0115
13	57.8	.0160	.0160	.0160	.0160	.0160	.0160
14	62.3	.0218	.0218	.0218	.0218	.0218	.0218
15	66.7	.0292	.0292	.0292	.0292	.0292	.0292
16	71.2	.0384	.0384	.0384	.0384	.0384	.0384
17	75.6	.0497	.0497	.0497	.0497	.0497	.0497
18	80.1	.0636	.0636	.0636	.0636	.0636	.0636
19	84.5	.0803	.0803	.0803	.0803	.0803	.0803
20	89.0	.1003	.1003	.1003	.1003	.1003	.1003
21	93.4	.1242	.1242	.1242	.1242	.1242	.1242
22	97.9	.1522	.1522	.1522	.1522	.1522	.1522
23	102.3	.1851	.1851	.1851	.1851	.1851	.1851
24	106.8	.2234	.2234	.2234	.2234	.2234	.2234
25	111.2	.2676	.2676	.2676	.2676	.2676	.2676
26	115.7	.3186	.3186	.3186	.3186	.3186	.3186
27	120.1	.3769	.3769	.3769	.3769	.3769	.3769
28	124.6	.4433	.4433	.4433	.4433	.4433	.4433
29	129.0	.5187	.5187	.5187	.5187	.5187	.5187
30	133.5	.6039	.6039	.6039	.6039	.6039	.6039
31	137.9	.6998	.6998	.6998	.6998	.6998	.6998
32	142.4	.8074	.8074	.8074	.8074	.8074	.8074
33	146.8	.9277	.9277	.9277	.9277	.9277	.9277
34	151.3	1.0617	1.0617	1.0617	1.0617	1.0617	1.0617
35	155.7	1.2106	1.2106	1.2106	1.2106	1.2106	1.2106
36	160.2	1.3755	1.3755	1.3755	1.3755	1.3755	1.3755
37	164.6	1.5578	1.5578	1.5578	1.5578	1.5578	1.5578
38	169.1	1.7586	1.7586	1.7586	1.7586	1.7586	1.7586
39	173.5	1.9795	1.9795	1.9795	1.9795	1.9795	1.9795
40	178.0	2.2216	2.2216	2.2216	2.2216	2.2216	2.2216
41	182.4	2.4867	2.4867	2.4867	2.4867	2.4867	2.4867
42	186.9	2.7762	2.7762	2.7762	2.7762	2.7762	2.7762
43	191.3	3.0917	3.0917	3.0917	3.0917	3.0917	3.0917
44	195.8	3.4349	3.4349	3.4349	3.4349	3.4349	3.4349
45	200.2	3.8077	3.8077	3.8077	3.8077	3.8077	3.8077
46	204.7	4.2117	4.2117	4.2117	4.2117	4.2117	4.2117
47	209.1	4.6489	4.6489	4.6489	4.6489	4.6489	4.6489
48	213.6	5.1213	5.1213	5.1213	5.1213	5.1213	5.1213
49	218.0	5.6308	5.6308	5.6308	5.6308	5.6308	5.6308
50	222.5	6.1797	6.1797	6.1797	6.1797	6.1797	6.1797

TABLE B-3. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, SINGLE AXLES, PT = 2.0

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
2	8.9	.0002	.0002	.0002	.0002	.0002	.0002
3	13.3	.0008	.0009	.0008	.0007	.0006	.0006
4	17.8	.0021	.0025	.0023	.0020	.0018	.0018
5	22.3	.0048	.0058	.0055	.0049	.0044	.0042
6	26.7	.0095	.0116	.0114	.0101	.0092	.0088
7	31.1	.0173	.0210	.0211	.0190	.0174	.0167
8	35.6	.0296	.0352	.0364	.0332	.0306	.0292
9	40.0	.0482	.0558	.0587	.0544	.0504	.0483
10	44.5	.0752	.0847	.0901	.0847	.0791	.0761
11	48.9	.1131	.1243	.1327	.1267	.1193	.1151
12	53.4	.1649	.1774	.1890	.1829	.1737	.1682
13	57.8	.2341	.2473	.2617	.2563	.2456	.2389
14	62.3	.3247	.3378	.3540	.3500	.3385	.3309
15	66.7	.4412	.4531	.4696	.4673	.4561	.4482
16	71.2	.5887	.5982	.6126	.6120	.6026	.5955
17	75.6	.7728	.7784	.7876	.7881	.7824	.7777
18	80.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	84.5	1.2772	1.2695	1.2555	1.2525	1.2604	1.2680
20	89.0	1.6121	1.5944	1.5607	1.5510	1.5689	1.5877
21	93.4	2.0132	1.9826	1.9226	1.9012	1.9309	1.9654
22	97.9	2.4895	2.4429	2.3490	2.3097	2.3523	2.4076
23	102.3	3.0510	2.9849	2.8482	2.7833	2.8396	2.9211
24	106.8	3.7084	3.6187	3.4295	3.3298	3.3995	3.5134
25	111.2	4.4734	4.3556	4.1026	3.9574	4.0391	4.1918
26	115.7	5.3583	5.2073	4.8782	4.6750	4.7663	4.9643
27	120.1	6.3764	6.1867	5.7674	5.4923	5.5894	5.8393
28	124.6	7.5419	7.3073	6.7825	6.4196	6.5174	6.8255
29	129.0	8.8701	8.5836	7.9363	7.4680	7.5599	7.9320
30	133.5	10.3770	10.0310	9.2426	8.6493	8.7272	9.1685
31	137.9	12.0798	11.6660	10.7159	9.9760	10.0301	10.5453
32	142.4	13.9965	13.5059	12.3717	11.4614	11.4804	12.0732
33	146.8	16.1464	15.5691	14.2262	13.1196	13.0906	13.7635
34	151.3	18.5498	17.8749	16.2968	14.9655	14.8737	15.6284
35	155.7	21.2278	20.4437	18.6016	17.0148	16.8438	17.6805
36	160.2	24.2031	23.2972	21.1597	19.2841	19.0155	19.9334
37	164.6	27.4992	26.4577	23.9912	21.7907	21.4045	22.4012
38	169.1	31.1409	29.9491	27.1171	24.5529	24.0270	25.0989
39	173.5	35.1541	33.7962	30.5597	27.5898	26.9003	28.0423
40	178.0	39.5660	38.0251	34.3421	30.9216	30.0423	31.2479

TABLE B-4. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, TANDEM AXLES, PT = 2.0

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
6	26.7	.0011	.0012	.0011	.0010	.0009	.0008
7	31.1	.0019	.0021	.0019	.0017	.0015	.0015
8	35.6	.0029	.0034	.0032	.0028	.0025	.0024
9	40.0	.0045	.0053	.0050	.0044	.0040	.0038
10	44.5	.0066	.0080	.0076	.0067	.0061	.0058
11	48.9	.0093	.0114	.0110	.0098	.0089	.0085
12	53.4	.0130	.0159	.0156	.0139	.0127	.0121
13	57.8	.0177	.0217	.0216	.0193	.0176	.0168
14	62.3	.0238	.0288	.0291	.0262	.0240	.0229
15	66.7	.0313	.0376	.0385	.0348	.0320	.0306
16	71.2	.0407	.0484	.0500	.0456	.0420	.0402
17	75.6	.0523	.0613	.0640	.0588	.0544	.0520
18	80.1	.0663	.0767	.0807	.0748	.0693	.0665
19	84.5	.0832	.0950	.1006	.0939	.0874	.0839
20	89.0	.1034	.1165	.1239	.1166	.1089	.1047
21	93.4	.1274	.1417	.1511	.1432	.1343	.1293
22	97.9	.1556	.1710	.1826	.1743	.1641	.1583
23	102.3	.1886	.2049	.2187	.2103	.1988	.1921
24	106.8	.2269	.2441	.2600	.2517	.2390	.2314
25	111.2	.2712	.2889	.3069	.2989	.2851	.2767
26	115.7	.3221	.3402	.3600	.3526	.3378	.3286
27	120.1	.3803	.3985	.4198	.4132	.3978	.3879
28	124.6	.4467	.4646	.4870	.4814	.4656	.4551
29	129.0	.5219	.5392	.5622	.5577	.5419	.5311
30	133.5	.6069	.6232	.6460	.6428	.6274	.6166
31	137.9	.7025	.7175	.7392	.7373	.7228	.7123
32	142.4	.8097	.8228	.8426	.8418	.8289	.8192
33	146.8	.9295	.9402	.9571	.9572	.9465	.9380
34	151.3	1.0630	1.0708	1.0834	1.0841	1.0762	1.0698
35	155.7	1.2113	1.2155	1.2226	1.2233	1.2189	1.2153
36	160.2	1.3755	1.3755	1.3755	1.3755	1.3755	1.3755
37	164.6	1.5570	1.5520	1.5433	1.5418	1.5469	1.5515
38	169.1	1.7569	1.7463	1.7270	1.7229	1.7338	1.7442
39	173.5	1.9766	1.9595	1.9278	1.9198	1.9372	1.9547
40	178.0	2.2175	2.1931	2.1468	2.1335	2.1580	2.1840
41	182.4	2.4812	2.4485	2.3853	2.3649	2.3973	2.4332
42	186.9	2.7692	2.7271	2.6446	2.6152	2.6560	2.7035
43	191.3	3.0830	3.0305	2.9261	2.8856	2.9351	2.9959
44	195.8	3.4244	3.3603	3.2311	3.1771	3.2357	3.3117
45	200.2	3.7950	3.7182	3.5612	3.4910	3.5590	3.6520
46	204.7	4.1968	4.1058	3.9179	3.8286	3.9060	4.0182
47	209.1	4.6315	4.5250	4.3027	4.1912	4.2780	4.4113
48	213.6	5.1011	4.9777	4.7175	4.5803	4.6761	4.8328
49	218.0	5.6077	5.4658	5.1637	4.9972	5.1016	5.2839
50	222.5	6.1533	5.9913	5.6434	5.4435	5.5559	5.7660

TABLE B-5. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, SINGLE AXLES, PT = 2.5

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
2	8.9	.0004	.0004	.0003	.0002	.0002	.0002
3	13.3	.0012	.0015	.0012	.0009	.0007	.0006
4	17.8	.0029	.0042	.0035	.0026	.0021	.0019
5	22.3	.0059	.0092	.0082	.0062	.0050	.0045
6	26.7	.0110	.0174	.0167	.0128	.0104	.0094
7	31.1	.0192	.0297	.0304	.0239	.0197	.0177
8	35.6	.0319	.0470	.0507	.0412	.0343	.0310
9	40.0	.0509	.0706	.0793	.0667	.0562	.0511
10	44.5	.0781	.1022	.1175	.1023	.0877	.0802
11	48.9	.1162	.1439	.1668	.1503	.1311	.1209
12	53.4	.1682	.1984	.2288	.2126	.1891	.1759
13	57.8	.2374	.2686	.3053	.2912	.2645	.2485
14	62.3	.3278	.3583	.3985	.3882	.3600	.3420
15	66.7	.4439	.4714	.5112	.5055	.4786	.4601
16	71.2	.5908	.6126	.6464	.6450	.6229	.6065
17	75.6	.7740	.7869	.8080	.8091	.7959	.7852
18	80.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	84.5	1.2756	1.2583	1.2272	1.2206	1.2380	1.2550
20	89.0	1.6084	1.5686	1.4948	1.4739	1.5125	1.5539
21	93.4	2.0068	1.9385	1.8086	1.7635	1.8262	1.9008
22	97.9	2.4798	2.3762	2.1749	2.0936	2.1819	2.2993
23	102.3	3.0374	2.8907	2.6004	2.4684	2.5826	2.7532
24	106.8	3.6901	3.4915	3.0926	2.8932	3.0317	3.2661
25	111.2	4.4494	4.1891	3.6595	3.3733	3.5327	3.8416
26	115.7	5.3276	4.9946	4.3096	3.9148	4.0896	4.4835
27	120.1	6.3379	5.9200	5.0521	4.5240	4.7068	5.1955
28	124.6	7.4945	6.9780	5.8969	5.2081	5.3891	5.9816
29	129.0	8.8124	8.1823	6.8543	5.9745	6.1418	6.8458
30	133.5	10.3074	9.5473	7.9355	6.8310	6.9707	7.7925
31	137.9	11.9967	11.0885	9.1522	7.7864	7.8821	8.8265
32	142.4	13.8982	12.8220	10.5171	8.8495	8.8828	9.9526
33	146.8	16.0309	14.7651	12.0433	10.0299	9.9799	11.1765
34	151.3	18.4149	16.9360	13.7447	11.3378	11.1813	12.5040
35	155.7	21.0713	19.3539	15.6360	12.7836	12.4952	13.9414
36	160.2	24.0224	22.0389	17.7328	14.3787	13.9303	15.4956
37	164.6	27.2916	25.0122	20.0514	16.1348	15.4960	17.1740
38	169.1	30.9035	28.2961	22.6086	18.0643	17.2020	18.9844
39	173.5	34.8838	31.9139	25.4226	20.1800	19.0585	20.9353
40	178.0	39.2596	35.8900	28.5120	22.4956	21.0764	23.0355

TABLE B-6. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, TANDEM AXLES, PT = 2.5

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
6	26.7	.0017	.0021	.0017	.0012	.0010	.0009
7	31.1	.0027	.0036	.0030	.0022	.0017	.0016
8	35.6	.0040	.0057	.0048	.0036	.0029	.0026
9	40.0	.0058	.0087	.0076	.0056	.0045	.0041
10	44.5	.0082	.0127	.0113	.0085	.0069	.0062
11	48.9	.0112	.0177	.0164	.0124	.0101	.0090
12	53.4	.0152	.0240	.0230	.0176	.0143	.0129
13	57.8	.0202	.0317	.0313	.0243	.0199	.0179
14	62.3	.0264	.0409	.0418	.0329	.0270	.0243
15	66.7	.0343	.0518	.0545	.0436	.0360	.0325
16	71.2	.0439	.0647	.0698	.0567	.0472	.0426
17	75.6	.0557	.0797	.0879	.0726	.0608	.0551
18	80.1	.0700	.0971	.1091	.0917	.0773	.0703
19	84.5	.0871	.1173	.1336	.1143	.0971	.0886
20	89.0	.1075	.1406	.1617	.1408	.1206	.1104
21	93.4	.1316	.1673	.1936	.1714	.1482	.1361
22	97.9	.1599	.1980	.2295	.2067	.1803	.1663
23	102.3	.1930	.2330	.2698	.2469	.2175	.2014
24	106.8	.2313	.2729	.3147	.2924	.2601	.2420
25	111.2	.2757	.3182	.3646	.3435	.3087	.2886
26	115.7	.3265	.3695	.4199	.4006	.3638	.3418
27	120.1	.3847	.4275	.4809	.4640	.4258	.4022
28	124.6	.4509	.4929	.5482	.5340	.4952	.4704
29	129.0	.5259	.5662	.6220	.6110	.5725	.5471
30	133.5	.6106	.6484	.7031	.6953	.6583	.6328
31	137.9	.7059	.7403	.7920	.7873	.7529	.7283
32	142.4	.8126	.8426	.8892	.8873	.8569	.8343
33	146.8	.9319	.9563	.9954	.9957	.9707	.9513
34	151.3	1.0647	1.0824	1.1114	1.1129	1.0947	1.0800
35	155.7	1.2122	1.2217	1.2378	1.2394	1.2295	1.2212
36	160.2	1.3755	1.3755	1.3755	1.3755	1.3755	1.3755
37	164.6	1.5559	1.5448	1.5253	1.5219	1.5332	1.5437
38	169.1	1.7546	1.7308	1.6881	1.6789	1.7029	1.7263
39	173.5	1.9730	1.9347	1.8647	1.8472	1.8852	1.9240
40	178.0	2.2124	2.1577	2.0562	2.0274	2.0805	2.1375
41	182.4	2.4744	2.4012	2.2636	2.2200	2.2893	2.3675
42	186.9	2.7604	2.6665	2.4878	2.4258	2.5120	2.6146
43	191.3	3.0721	2.9552	2.7301	2.6455	2.7492	2.8795
44	195.8	3.4111	3.2686	2.9916	2.8798	3.0013	3.1628
45	200.2	3.7791	3.6084	3.2735	3.1295	3.2689	3.4651
46	204.7	4.1780	3.9763	3.5770	3.3955	3.5525	3.7871
47	209.1	4.6096	4.3738	3.9034	3.6786	3.8528	4.1294
48	213.6	5.0758	4.8028	4.2540	3.9797	4.1703	4.4926
49	218.0	5.5787	5.2650	4.6304	4.2999	4.5056	4.8773
50	222.5	6.1203	5.7623	5.0338	4.6401	4.8594	5.2843

TABLE B-7. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, SINGLE AXLES, PT = 3.0

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
2	8.9	.0008	.0009	.0006	.0003	.0002	.0002
3	13.3	.0022	.0032	.0022	.0013	.0009	.0007
4	17.8	.0045	.0083	.0062	.0036	.0025	.0020
5	22.3	.0080	.0172	.0142	.0086	.0059	.0049
6	26.7	.0136	.0303	.0281	.0176	.0123	.0102
7	31.1	.0222	.0477	.0495	.0325	.0231	.0192
8	35.6	.0353	.0697	.0796	.0553	.0400	.0336
9	40.0	.0547	.0972	.1192	.0879	.0652	.0551
10	44.5	.0823	.1317	.1683	.1320	.1007	.0862
11	48.9	.1206	.1754	.2273	.1892	.1489	.1292
12	53.4	.1727	.2306	.2962	.2603	.2121	.1868
13	57.8	.2419	.3004	.3759	.3461	.2923	.2620
14	62.3	.3320	.3880	.4676	.4466	.3913	.3576
15	66.7	.4476	.4973	.5732	.5621	.5107	.4765
16	71.2	.5937	.6325	.6951	.6925	.6515	.6216
17	75.6	.7757	.7984	.8363	.8383	.8144	.7953
18	80.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	84.5	1.2734	1.2433	1.1899	1.1787	1.2084	1.2375
20	89.0	1.6033	1.5345	1.4102	1.3758	1.4396	1.5094
21	93.4	1.9982	1.8806	1.6653	1.5932	1.6938	1.8169
22	97.9	2.4668	2.2891	1.9600	1.8333	1.9711	2.1608
23	102.3	3.0191	2.7682	2.2995	2.0989	2.2720	2.5415
24	106.8	3.6654	3.3268	2.6894	2.3929	2.5973	2.9594
25	111.2	4.4171	3.9743	3.1359	2.7188	2.9479	3.4145
26	115.7	5.2864	4.7210	3.6453	3.0802	3.3254	3.9071
27	120.1	6.2864	5.5779	4.2247	3.4813	3.7315	4.4371
28	124.6	7.4310	6.5567	4.8813	3.9262	4.1685	5.0048
29	129.0	8.7350	7.6699	5.6230	4.4196	4.6389	5.6108
30	133.5	10.2142	8.9308	6.4582	4.9662	5.1456	6.2557
31	137.9	11.8854	10.3533	7.3959	5.5712	5.6919	6.9406
32	142.4	13.7665	11.9527	8.4452	6.2400	6.2812	7.6668
33	146.8	15.8761	13.7445	9.6163	6.9783	6.9174	8.4363
34	151.3	18.2342	15.7454	10.9196	7.7921	7.6046	9.2510
35	155.7	20.8616	17.9732	12.3662	8.6877	8.3470	10.1136
36	160.2	23.7804	20.4462	13.9676	9.6718	9.1493	11.0270
37	164.6	27.0137	23.1840	15.7361	10.7512	10.0163	11.9943
38	169.1	30.5858	26.2069	17.6845	11.9335	10.9530	13.0193
39	173.5	34.5221	29.5363	19.8263	13.2260	11.9647	14.1059
40	178.0	38.8493	33.1947	22.1756	14.6370	13.0569	15.2583

TABLE B-8. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, TANDEM AXLES, PT = 3.0

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
6	26.7	.0030	.0044	.0030	.0017	.0012	.0010
7	31.1	.0044	.0073	.0052	.0030	.0021	.0017
8	35.6	.0062	.0115	.0085	.0050	.0034	.0028
9	40.0	.0083	.0169	.0132	.0078	.0054	.0044
10	44.5	.0110	.0237	.0195	.0118	.0082	.0067
11	48.9	.0144	.0320	.0279	.0172	.0119	.0098
12	53.4	.0187	.0417	.0386	.0242	.0169	.0140
13	57.8	.0240	.0529	.0519	.0333	.0235	.0194
14	62.3	.0306	.0656	.0680	.0447	.0318	.0264
15	66.7	.0387	.0799	.0872	.0589	.0422	.0352
16	71.2	.0486	.0959	.1095	.0760	.0551	.0462
17	75.6	.0607	.1137	.1351	.0966	.0708	.0596
18	80.1	.0752	.1337	.1639	.1209	.0897	.0758
19	84.5	.0925	.1561	.1961	.1491	.1121	.0954
20	89.0	.1131	.1812	.2316	.1816	.1385	.1185
21	93.4	.1374	.2095	.2704	.2186	.1693	.1458
22	97.9	.1659	.2412	.3126	.2602	.2049	.1777
23	102.3	.1991	.2770	.3582	.3067	.2455	.2146
24	106.8	.2375	.3172	.4074	.3581	.2917	.2570
25	111.2	.2819	.3624	.4603	.4145	.3438	.3054
26	115.7	.3327	.4132	.5170	.4760	.4020	.3604
27	120.1	.3907	.4701	.5779	.5426	.4667	.4224
28	124.6	.4567	.5338	.6431	.6143	.5382	.4919
29	129.0	.5314	.6049	.7132	.6912	.6167	.5694
30	133.5	.6157	.6841	.7884	.7732	.7024	.6555
31	137.9	.7105	.7723	.8693	.8603	.7955	.7506
32	142.4	.8166	.8701	.9562	.9526	.8961	.8550
33	146.8	.9351	.9784	1.0497	1.0502	1.0043	.9694
34	151.3	1.0670	1.0982	1.1504	1.1531	1.1203	1.0940
35	155.7	1.2135	1.2302	1.2588	1.2615	1.2440	1.2293
36	160.2	1.3755	1.3755	1.3755	1.3755	1.3755	1.3755
37	164.6	1.5545	1.5352	1.5013	1.4954	1.5149	1.5331
38	169.1	1.7516	1.7102	1.6368	1.6213	1.6621	1.7023
39	173.5	1.9681	1.9016	1.7827	1.7535	1.8172	1.8832
40	178.0	2.2055	2.1107	1.9398	1.8924	1.9802	2.0763
41	182.4	2.4651	2.3387	2.1089	2.0383	2.1511	2.2816
42	186.9	2.7486	2.5868	2.2907	2.1915	2.3298	2.4992
43	191.3	3.0574	2.8563	2.4861	2.3526	2.5166	2.7294
44	195.8	3.3933	3.1487	2.6960	2.5218	2.7113	2.9722
45	200.2	3.7578	3.4654	2.9213	2.6998	2.9142	3.2277
46	204.7	4.1529	3.8078	3.1630	2.8871	3.1253	3.4959
47	209.1	4.5803	4.1775	3.4221	3.0841	3.3447	3.7769
48	213.6	5.0419	4.5761	3.6994	3.2915	3.5727	4.0707
49	218.0	5.5398	5.0053	3.9963	3.5098	3.8094	4.3774
50	222.5	6.0759	5.4668	4.3136	3.7398	4.0550	4.6968

TABLE B-9. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, SINGLE AXLES, PT = 1.5

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
2	8.9	.0002	.0002	.0002	.0002	.0002	.0002
3	13.3	.0007	.0007	.0007	.0007	.0007	.0007
4	17.8	.0021	.0021	.0021	.0021	.0021	.0021
5	22.3	.0049	.0049	.0049	.0049	.0049	.0049
6	26.7	.0099	.0099	.0099	.0099	.0099	.0099
7	31.1	.0184	.0184	.0184	.0184	.0184	.0184
8	35.6	.0317	.0317	.0317	.0317	.0317	.0317
9	40.0	.0515	.0515	.0515	.0515	.0515	.0515
10	44.5	.0801	.0801	.0801	.0801	.0801	.0801
11	48.9	.1197	.1197	.1197	.1197	.1197	.1197
12	53.4	.1732	.1732	.1732	.1732	.1732	.1732
13	57.8	.2439	.2439	.2439	.2439	.2439	.2439
14	62.3	.3355	.3355	.3355	.3355	.3355	.3355
15	66.7	.4521	.4521	.4521	.4521	.4521	.4521
16	71.2	.5982	.5982	.5982	.5982	.5982	.5982
17	75.6	.7790	.7790	.7790	.7790	.7790	.7790
18	80.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	84.5	1.2674	1.2674	1.2674	1.2674	1.2674	1.2674
20	89.0	1.5879	1.5879	1.5879	1.5879	1.5879	1.5879
21	93.4	1.9686	1.9686	1.9686	1.9686	1.9686	1.9686
22	97.9	2.4174	2.4174	2.4174	2.4174	2.4174	2.4174
23	102.3	2.9426	2.9426	2.9426	2.9426	2.9426	2.9426
24	106.8	3.5534	3.5534	3.5534	3.5534	3.5534	3.5534
25	111.2	4.2593	4.2593	4.2593	4.2593	4.2593	4.2593
26	115.7	5.0706	5.0706	5.0706	5.0706	5.0706	5.0706
27	120.1	5.9983	5.9983	5.9983	5.9983	5.9983	5.9983
28	124.6	7.0540	7.0540	7.0540	7.0540	7.0540	7.0540
29	129.0	8.2501	8.2501	8.2501	8.2501	8.2501	8.2501
30	133.5	9.5995	9.5995	9.5995	9.5995	9.5995	9.5995
31	137.9	11.1161	11.1161	11.1161	11.1161	11.1161	11.1161
32	142.4	12.8142	12.8142	12.8142	12.8142	12.8142	12.8142
33	146.8	14.7093	14.7093	14.7093	14.7093	14.7093	14.7093
34	151.3	16.8172	16.8172	16.8172	16.8172	16.8172	16.8172
35	155.7	19.1547	19.1547	19.1547	19.1547	19.1547	19.1547
36	160.2	21.7395	21.7395	21.7395	21.7395	21.7395	21.7395
37	164.6	24.5900	24.5900	24.5900	24.5900	24.5900	24.5900
38	169.1	27.7253	27.7253	27.7253	27.7253	27.7253	27.7253
39	173.5	31.1656	31.1656	31.1656	31.1656	31.1656	31.1656
40	178.0	34.9317	34.9317	34.9317	34.9317	34.9317	34.9317

TABLE B-10. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, TANDEM AXLES, PT = 1.5

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
6	26.7	.0019	.0019	.0019	.0019	.0019	.0019
7	31.1	.0033	.0033	.0033	.0033	.0033	.0033
8	35.6	.0053	.0053	.0053	.0053	.0053	.0053
9	40.0	.0082	.0082	.0082	.0082	.0082	.0082
10	44.5	.0123	.0123	.0123	.0123	.0123	.0123
11	48.9	.0178	.0178	.0178	.0178	.0178	.0178
12	53.4	.0251	.0251	.0251	.0251	.0251	.0251
13	57.8	.0345	.0345	.0345	.0345	.0345	.0345
14	62.3	.0465	.0465	.0465	.0465	.0465	.0465
15	66.7	.0616	.0616	.0616	.0616	.0616	.0616
16	71.2	.0802	.0802	.0802	.0802	.0802	.0802
17	75.6	.1029	.1029	.1029	.1029	.1029	.1029
18	80.1	.1305	.1305	.1305	.1305	.1305	.1305
19	84.5	.1635	.1635	.1635	.1635	.1635	.1635
20	89.0	.2027	.2027	.2027	.2027	.2027	.2027
21	93.4	.2489	.2489	.2489	.2489	.2489	.2489
22	97.9	.3029	.3029	.3029	.3029	.3029	.3029
23	102.3	.3658	.3658	.3658	.3658	.3658	.3658
24	106.8	.4385	.4385	.4385	.4385	.4385	.4385
25	111.2	.5220	.5220	.5220	.5220	.5220	.5220
26	115.7	.6175	.6175	.6175	.6175	.6175	.6175
27	120.1	.7262	.7262	.7262	.7262	.7262	.7262
28	124.6	.8493	.8493	.8493	.8493	.8493	.8493
29	129.0	.9883	.9883	.9883	.9883	.9883	.9883
30	133.5	1.1444	1.1444	1.1444	1.1444	1.1444	1.1444
31	137.9	1.3192	1.3192	1.3192	1.3192	1.3192	1.3192
32	142.4	1.5143	1.5143	1.5143	1.5143	1.5143	1.5143
33	146.8	1.7313	1.7313	1.7313	1.7313	1.7313	1.7313
34	151.3	1.9720	1.9720	1.9720	1.9720	1.9720	1.9720
35	155.7	2.2381	2.2381	2.2381	2.2381	2.2381	2.2381
36	160.2	2.5315	2.5315	2.5315	2.5315	2.5315	2.5315
37	164.6	2.8543	2.8543	2.8543	2.8543	2.8543	2.8543
38	169.1	3.2085	3.2085	3.2085	3.2085	3.2085	3.2085
39	173.5	3.5962	3.5962	3.5962	3.5962	3.5962	3.5962
40	178.0	4.0197	4.0197	4.0197	4.0197	4.0197	4.0197
41	182.4	4.4813	4.4813	4.4813	4.4813	4.4813	4.4813
42	186.9	4.9835	4.9835	4.9835	4.9835	4.9835	4.9835
43	191.3	5.5287	5.5287	5.5287	5.5287	5.5287	5.5287
44	195.8	6.1196	6.1196	6.1196	6.1196	6.1196	6.1196
45	200.2	6.7588	6.7588	6.7588	6.7588	6.7588	6.7588
46	204.7	7.4493	7.4493	7.4493	7.4493	7.4493	7.4493
47	209.1	8.1938	8.1938	8.1938	8.1938	8.1938	8.1938
48	213.6	8.9954	8.9954	8.9954	8.9954	8.9954	8.9954
49	218.0	9.8572	9.8572	9.8572	9.8572	9.8572	9.8572
50	222.5	10.7824	10.7824	10.7824	10.7824	10.7824	10.7824

TABLE B-11. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, SINGLE AXLES, PT = 2.0

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
2	8.9	.0002	.0002	.0002	.0002	.0002	.0002
3	13.3	.0008	.0008	.0008	.0008	.0008	.0007
4	17.8	.0023	.0022	.0021	.0021	.0021	.0021
5	22.3	.0054	.0051	.0050	.0049	.0049	.0049
6	26.7	.0109	.0104	.0101	.0100	.0100	.0099
7	31.1	.0202	.0193	.0188	.0186	.0185	.0184
8	35.6	.0348	.0332	.0324	.0320	.0318	.0317
9	40.0	.0564	.0540	.0526	.0520	.0518	.0516
10	44.5	.0872	.0838	.0817	.0808	.0804	.0802
11	48.9	.1296	.1250	.1220	.1207	.1202	.1199
12	53.4	.1862	.1804	.1765	.1747	.1739	.1735
13	57.8	.2597	.2530	.2481	.2458	.2448	.2444
14	62.3	.3533	.3462	.3406	.3378	.3366	.3360
15	66.7	.4701	.4636	.4576	.4546	.4532	.4526
16	71.2	.6140	.6090	.6036	.6007	.5993	.5987
17	75.6	.7890	.7864	.7828	.7807	.7798	.7794
18	80.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	84.5	1.2524	1.2546	1.2602	1.2639	1.2657	1.2666
20	89.0	1.5522	1.5553	1.5686	1.5783	1.5832	1.5856
21	93.4	1.9062	1.9077	1.9307	1.9492	1.9591	1.9638
22	97.9	2.3216	2.3181	2.3523	2.3830	2.4002	2.4088
23	102.3	2.8063	2.7936	2.8397	2.8863	2.9141	2.9282
24	106.8	3.3688	3.3419	3.3995	3.4661	3.5082	3.5303
25	111.2	4.0180	3.9713	4.0390	4.1294	4.1906	4.2237
26	115.7	4.7635	4.6909	4.7663	4.8840	4.9696	5.0176
27	120.1	5.6156	5.5104	5.5901	5.7378	5.8535	5.9213
28	124.6	6.5849	6.4403	6.5197	6.6994	6.8513	6.9445
29	129.0	7.6830	7.4916	7.5655	7.7778	7.9722	8.0973
30	133.5	8.9217	8.6758	8.7385	8.9829	9.2258	9.3902
31	137.9	10.3139	10.0053	10.0505	10.3253	10.6219	10.8337
32	142.4	11.8728	11.4928	11.5139	11.8164	12.1713	12.4389
33	146.8	13.6125	13.1520	13.1419	13.4684	13.8850	14.2173
34	151.3	15.5477	14.9969	14.9486	15.2944	15.7749	16.1806
35	155.7	17.6938	17.0424	16.9484	17.3083	17.8535	18.3410
36	160.2	20.0671	19.3039	19.1566	19.5249	20.1344	20.7113
37	164.6	22.6844	21.7977	21.5893	21.9597	22.6317	23.3049
38	169.1	25.5634	24.5407	24.2629	24.6293	25.3608	26.1358
39	173.5	28.7225	27.5505	27.1949	27.5506	28.3378	29.2188
40	178.0	32.1810	30.8454	30.4033	30.7418	31.5797	32.5694

TABLE B-12. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, TANDEM AXLES, PT = 2.0

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
6	26.7	.0021	.0020	.0019	.0019	.0019	.0019
7	31.1	.0036	.0034	.0033	.0033	.0033	.0033
8	35.6	.0058	.0056	.0054	.0054	.0053	.0053
9	40.0	.0091	.0087	.0084	.0083	.0083	.0083
10	44.5	.0136	.0129	.0126	.0124	.0124	.0123
11	48.9	.0196	.0187	.0182	.0180	.0179	.0179
12	53.4	.0276	.0264	.0257	.0254	.0252	.0252
13	57.8	.0379	.0362	.0353	.0349	.0347	.0346
14	62.3	.0509	.0488	.0475	.0470	.0467	.0466
15	66.7	.0672	.0645	.0629	.0622	.0618	.0617
16	71.2	.0873	.0839	.0818	.0809	.0805	.0804
17	75.6	.1116	.1075	.1050	.1039	.1034	.1032
18	80.1	.1408	.1361	.1330	.1316	.1310	.1307
19	84.5	.1755	.1701	.1665	.1648	.1641	.1638
20	89.0	.2163	.2104	.2062	.2042	.2034	.2030
21	93.4	.2639	.2576	.2529	.2507	.2497	.2493
22	97.9	.3189	.3126	.3075	.3050	.3039	.3034
23	102.3	.3822	.3761	.3707	.3680	.3668	.3663
24	106.8	.4545	.4489	.4435	.4408	.4396	.4390
25	111.2	.5366	.5319	.5269	.5243	.5231	.5225
26	115.7	.6295	.6260	.6218	.6195	.6185	.6180
27	120.1	.7342	.7322	.7293	.7276	.7269	.7265
28	124.6	.8518	.8513	.8504	.8498	.8496	.8495
29	129.0	.9836	.9844	.9862	.9873	.9878	.9880
30	133.5	1.1306	1.1326	1.1378	1.1412	1.1429	1.1436
31	137.9	1.2944	1.2971	1.3064	1.3129	1.3162	1.3177
32	142.4	1.4764	1.4790	1.4932	1.5037	1.5092	1.5117
33	146.8	1.6781	1.6797	1.6994	1.7150	1.7233	1.7273
34	151.3	1.9011	1.9005	1.9263	1.9482	1.9602	1.9661
35	155.7	2.1471	2.1430	2.1753	2.2047	2.2214	2.2297
36	160.2	2.4179	2.4088	2.4478	2.4861	2.5086	2.5199
37	164.6	2.7154	2.6995	2.7451	2.7937	2.8234	2.8386
38	169.1	3.0414	3.0170	3.0690	3.1293	3.1675	3.1875
39	173.5	3.3981	3.3630	3.4209	3.4943	3.5427	3.5686
40	178.0	3.7874	3.7396	3.8027	3.8904	3.9509	3.9840
41	182.4	4.2116	4.1489	4.2162	4.3194	4.3939	4.4355
42	186.9	4.6728	4.5930	4.6633	4.7830	4.8734	4.9254
43	191.3	5.1735	5.0741	5.1460	5.2831	5.3916	5.4556
44	195.8	5.7161	5.5946	5.6665	5.8215	5.9503	6.0285
45	200.2	6.3030	6.1570	6.2270	6.4003	6.5516	6.6461
46	204.7	6.9368	6.7636	6.8299	7.0216	7.1975	7.3108
47	209.1	7.6203	7.4171	7.4777	7.6875	7.8902	8.0249
48	213.6	8.3562	8.1202	8.1729	8.4005	8.6318	8.7906
49	218.0	9.1473	8.8756	8.9181	9.1628	9.4246	9.6105
50	222.5	9.9966	9.6862	9.7162	9.9770	10.2709	10.4868

TABLE B-13. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, SINGLE AXLES, PT = 2.5

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
2	8.9	.0002	.0002	.0002	.0002	.0002	.0002
3	13.3	.0009	.0008	.0008	.0008	.0008	.0008
4	17.8	.0026	.0023	.0022	.0021	.0021	.0021
5	22.3	.0060	.0054	.0051	.0050	.0049	.0049
6	26.7	.0123	.0111	.0104	.0101	.0100	.0100
7	31.1	.0227	.0205	.0193	.0188	.0186	.0185
8	35.6	.0390	.0352	.0332	.0324	.0320	.0318
9	40.0	.0630	.0572	.0540	.0526	.0520	.0518
10	44.5	.0969	.0886	.0838	.0817	.0808	.0804
11	48.9	.1430	.1318	.1250	.1220	.1207	.1202
12	53.4	.2034	.1895	.1805	.1764	.1747	.1739
13	57.8	.2805	.2645	.2533	.2481	.2459	.2449
14	62.3	.3763	.3598	.3468	.3406	.3379	.3366
15	66.7	.4932	.4782	.4646	.4577	.4547	.4533
16	71.2	.6338	.6225	.6102	.6037	.6008	.5994
17	75.6	.8014	.7955	.7875	.7829	.7808	.7799
18	80.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	84.5	1.2343	1.2391	1.2515	1.2597	1.2637	1.2656
20	89.0	1.5097	1.5163	1.5454	1.5666	1.5776	1.5828
21	93.4	1.8326	1.8357	1.8854	1.9257	1.9475	1.9580
22	97.9	2.2096	2.2022	2.2751	2.3416	2.3795	2.3983
23	102.3	2.6480	2.6215	2.7186	2.8189	2.8795	2.9105
24	106.8	3.1558	3.1001	3.2202	3.3621	3.4538	3.5022
25	111.2	3.7411	3.6451	3.7849	3.9759	4.1081	4.1807
26	115.7	4.4128	4.2646	4.4187	4.6650	4.8486	4.9535
27	120.1	5.1802	4.9670	5.1280	5.4344	5.6810	5.8284
28	124.6	6.0530	5.7614	5.9205	6.2895	6.6112	6.8128
29	129.0	7.0416	6.6575	6.8045	7.2364	7.6449	7.9142
30	133.5	8.1569	7.6654	7.7891	8.2819	8.7881	9.1401
31	137.9	9.4104	8.7957	8.8843	9.4337	10.0470	10.4978
32	142.4	10.8141	10.0595	10.1005	10.7003	11.4281	11.9945
33	146.8	12.3808	11.4686	11.4491	12.0913	12.9388	13.6375
34	151.3	14.1236	13.0350	12.9417	13.6171	14.5867	15.4341
35	155.7	16.0565	14.7714	14.5908	15.2889	16.3806	17.3920
36	160.2	18.1942	16.6912	16.4092	17.1190	18.3302	19.5188
37	164.6	20.5519	18.8081	18.4103	19.1203	20.4459	21.8231
38	169.1	23.1454	21.1365	20.6081	21.3065	22.7395	24.3139
39	173.5	25.9915	23.6916	23.0170	23.6919	25.2236	27.0008
40	178.0	29.1074	26.4888	25.6520	26.2914	27.9118	29.8945

TABLE B-14. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, TANDEM AXLES, PT = 2.5

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
6	26.7	.0023	.0021	.0020	.0019	.0019	.0019
7	31.1	.0040	.0036	.0034	.0033	.0033	.0033
8	35.6	.0066	.0059	.0056	.0054	.0054	.0053
9	40.0	.0102	.0092	.0087	.0084	.0083	.0083
10	44.5	.0152	.0137	.0129	.0126	.0124	.0124
11	48.9	.0220	.0199	.0187	.0182	.0180	.0179
12	53.4	.0309	.0279	.0263	.0256	.0254	.0252
13	57.8	.0424	.0384	.0362	.0353	.0349	.0347
14	62.3	.0569	.0517	.0488	.0475	.0470	.0468
15	66.7	.0749	.0682	.0645	.0629	.0622	.0619
16	71.2	.0968	.0886	.0839	.0818	.0809	.0806
17	75.6	.1232	.1134	.1076	.1050	.1039	.1034
18	80.1	.1546	.1432	.1362	.1330	.1316	.1310
19	84.5	.1915	.1786	.1703	.1665	.1649	.1641
20	89.0	.2343	.2203	.2107	.2062	.2043	.2035
21	93.4	.2835	.2688	.2580	.2529	.2507	.2498
22	97.9	.3397	.3249	.3132	.3075	.3051	.3040
23	102.3	.4032	.3890	.3768	.3708	.3681	.3669
24	106.8	.4748	.4620	.4498	.4436	.4409	.4397
25	111.2	.5550	.5443	.5330	.5270	.5244	.5232
26	115.7	.6445	.6366	.6271	.6220	.6196	.6185
27	120.1	.7441	.7395	.7331	.7294	.7277	.7269
28	124.6	.8549	.8537	.8516	.8504	.8499	.8496
29	129.0	.9778	.9797	.9836	.9860	.9872	.9877
30	133.5	1.1140	1.1184	1.1297	1.1373	1.1410	1.1427
31	137.9	1.2647	1.2705	1.2909	1.3052	1.3124	1.3159
32	142.4	1.4313	1.4369	1.4677	1.4909	1.5029	1.5086
33	146.8	1.6151	1.6186	1.6612	1.6953	1.7136	1.7225
34	151.3	1.8178	1.8166	1.8719	1.9196	1.9460	1.9589
35	155.7	2.0408	2.0322	2.1009	2.1646	2.2012	2.2195
36	160.2	2.2858	2.2667	2.3490	2.4316	2.4808	2.5058
37	164.6	2.5545	2.5215	2.6172	2.7214	2.7860	2.8194
38	169.1	2.8488	2.7980	2.9065	3.0350	3.1181	3.1620
39	173.5	3.1704	3.0981	3.2180	3.3735	3.4784	3.5352
40	178.0	3.5213	3.4233	3.5531	3.7379	3.8684	3.9407
41	182.4	3.9034	3.7754	3.9130	4.1292	4.2891	4.3801
42	186.9	4.3189	4.1565	4.2993	4.5486	4.7421	4.8552
43	191.3	4.7698	4.5683	4.7135	4.9973	5.2285	5.3675
44	195.8	5.2583	5.0131	5.1574	5.4764	5.7495	5.9188
45	200.2	5.7867	5.4928	5.6327	5.9873	6.3066	6.5107
46	204.7	6.3574	6.0097	6.1416	6.5314	6.9009	7.1448
47	209.1	6.9727	6.5660	6.6858	7.1103	7.5338	7.8228
48	213.6	7.6353	7.1641	7.2678	7.7256	8.2066	8.5463
49	218.0	8.3476	7.8063	7.8896	8.3790	8.9208	9.3169
50	222.5	9.1123	8.4951	8.5537	9.0726	9.6778	10.1361

TABLE B-15. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, SINGLE AXLES, PT = 3.0

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
2	8.9	.0003	.0002	.0002	.0002	.0002	.0002
3	13.3	.0011	.0009	.0008	.0008	.0008	.0008
4	17.8	.0030	.0025	.0023	.0022	.0021	.0021
5	22.3	.0070	.0059	.0053	.0050	.0049	.0049
6	26.7	.0143	.0119	.0108	.0103	.0101	.0100
7	31.1	.0264	.0221	.0200	.0191	.0187	.0185
8	35.6	.0452	.0380	.0344	.0328	.0322	.0319
9	40.0	.0727	.0616	.0558	.0534	.0524	.0520
10	44.5	.1110	.0952	.0865	.0829	.0813	.0807
11	48.9	.1623	.1411	.1290	.1237	.1215	.1206
12	53.4	.2281	.2020	.1859	.1788	.1757	.1744
13	57.8	.3097	.2802	.2602	.2511	.2472	.2455
14	62.3	.4082	.3782	.3551	.3442	.3395	.3375
15	66.7	.5246	.4977	.4737	.4618	.4566	.4542
16	71.2	.6604	.6404	.6189	.6076	.6026	.6003
17	75.6	.8178	.8074	.7935	.7857	.7821	.7805
18	80.1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	84.5	1.2113	1.2194	1.2403	1.2542	1.2611	1.2643
20	89.0	1.4566	1.4675	1.5160	1.5518	1.5703	1.5791
21	93.4	1.7418	1.7469	1.8285	1.8959	1.9327	1.9506
22	97.9	2.0731	2.0613	2.1793	2.2893	2.3529	2.3848
23	102.3	2.4571	2.4152	2.5701	2.7343	2.8356	2.8880
24	106.8	2.9010	2.8140	3.0029	3.2327	3.3848	3.4663
25	111.2	3.4122	3.2639	3.4808	3.7864	4.0042	4.1258
26	115.7	3.9986	3.7717	4.0076	4.3971	4.6970	4.8721
27	120.1	4.6683	4.3447	4.5883	5.0667	5.4662	5.7107
28	124.6	5.4302	4.9906	5.2286	5.7978	6.3139	6.6466
29	129.0	6.2931	5.7177	5.9353	6.5937	7.2426	7.6843
30	133.5	7.2669	6.5344	6.7157	7.4583	8.2543	8.8276
31	137.9	8.3614	7.4495	7.5782	8.3969	9.3514	10.0801
32	142.4	9.5874	8.4722	8.5313	9.4156	10.5366	11.4449
33	146.8	10.9558	9.6122	9.5843	10.5216	11.8134	12.9248
34	151.3	12.4784	10.8795	10.7468	11.7231	13.1860	14.5224
35	155.7	14.1673	12.2843	12.0287	13.0291	14.6596	16.2405
36	160.2	16.0353	13.8376	13.4404	14.4495	16.2406	18.0822
37	164.6	18.0957	15.5506	14.9926	15.9945	17.9365	20.0510
38	169.1	20.3625	17.4350	16.6965	17.6754	19.7559	22.1512
39	173.5	22.8502	19.5031	18.5634	19.5036	21.7083	24.3879
40	178.0	25.5739	21.7676	20.6052	21.4910	23.8045	26.7676

TABLE B-16. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, TANDEM AXLES, PT = 3.0

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
6	26.7	.0027	.0023	.0021	.0020	.0019	.0019
7	31.1	.0047	.0039	.0035	.0034	.0033	.0033
8	35.6	.0077	.0064	.0058	.0055	.0054	.0053
9	40.0	.0119	.0099	.0090	.0085	.0084	.0083
10	44.5	.0177	.0148	.0134	.0128	.0125	.0124
11	48.9	.0256	.0214	.0194	.0185	.0181	.0180
12	53.4	.0359	.0302	.0273	.0260	.0255	.0253
13	57.8	.0490	.0414	.0375	.0358	.0351	.0348
14	62.3	.0656	.0556	.0504	.0482	.0473	.0469
15	66.7	.0860	.0734	.0666	.0638	.0626	.0621
16	71.2	.1106	.0952	.0866	.0830	.0815	.0808
17	75.6	.1400	.1215	.1110	.1065	.1046	.1037
18	80.1	.1744	.1530	.1403	.1348	.1324	.1314
19	84.5	.2143	.1903	.1753	.1686	.1658	.1646
20	89.0	.2597	.2337	.2165	.2088	.2055	.2040
21	93.4	.3110	.2839	.2647	.2559	.2521	.2504
22	97.9	.3684	.3414	.3206	.3108	.3066	.3047
23	102.3	.4321	.4064	.3848	.3743	.3698	.3677
24	106.8	.5023	.4794	.4580	.4473	.4426	.4405
25	111.2	.5796	.5607	.5409	.5306	.5260	.5240
26	115.7	.6643	.6505	.6341	.6251	.6211	.6193
27	120.1	.7571	.7491	.7380	.7317	.7288	.7275
28	124.6	.8589	.8568	.8533	.8512	.8502	.8498
29	129.0	.9705	.9737	.9803	.9844	.9864	.9874
30	133.5	1.0929	1.1003	1.1195	1.1322	1.1386	1.1415
31	137.9	1.2274	1.2370	1.2711	1.2953	1.3077	1.3135
32	142.4	1.3751	1.3844	1.4356	1.4744	1.4948	1.5046
33	146.8	1.5375	1.5431	1.6131	1.6702	1.7012	1.7162
34	151.3	1.7157	1.7139	1.8041	1.8832	1.9277	1.9497
35	155.7	1.9114	1.8978	2.0087	2.1140	2.1755	2.2064
36	160.2	2.1261	2.0958	2.2276	2.3631	2.4454	2.4877
37	164.6	2.3612	2.3091	2.4610	2.6308	2.7385	2.7949
38	169.1	2.6183	2.5391	2.7096	2.9176	3.0555	3.1294
39	173.5	2.8992	2.7871	2.9741	3.2239	3.3972	3.4926
40	178.0	3.2056	3.0546	3.2553	3.5500	3.7645	3.8856
41	182.4	3.5392	3.3431	3.5541	3.8963	4.1578	4.3097
42	186.9	3.9018	3.6543	3.8716	4.2633	4.5780	4.7661
43	191.3	4.2953	3.9899	4.2091	4.6515	5.0254	5.2560
44	195.8	4.7217	4.3516	4.5679	5.0615	5.5006	5.7803
45	200.2	5.1830	4.7411	4.9495	5.4939	6.0041	6.3401
46	204.7	5.6812	5.1604	5.3554	5.9496	6.5364	6.9364
47	209.1	6.2184	5.6112	5.7874	6.4296	7.0980	7.5698
48	213.6	6.7969	6.0956	6.2472	6.9349	7.6893	8.2413
49	218.0	7.4189	6.6155	6.7367	7.4667	8.3108	8.9515
50	222.5	8.0867	7.1729	7.2577	8.0265	8.9633	9.7012

TABLE B-17. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, TRIDEM AXLES, PT = 1.5

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
16	71.2	.0086	.0086	.0086	.0086	.0086	.0086
17	75.6	.0110	.0110	.0110	.0110	.0110	.0110
18	80.1	.0139	.0139	.0139	.0139	.0139	.0139
19	84.5	.0173	.0173	.0173	.0173	.0173	.0173
20	89.0	.0215	.0215	.0215	.0215	.0215	.0215
21	93.4	.0263	.0263	.0263	.0263	.0263	.0263
22	97.9	.0320	.0320	.0320	.0320	.0320	.0320
23	102.3	.0386	.0386	.0386	.0386	.0386	.0386
24	106.8	.0462	.0462	.0462	.0462	.0462	.0462
25	111.2	.0550	.0550	.0550	.0550	.0550	.0550
26	115.7	.0651	.0651	.0651	.0651	.0651	.0651
27	120.1	.0766	.0766	.0766	.0766	.0766	.0766
28	124.6	.0896	.0896	.0896	.0896	.0896	.0896
29	129.0	.1044	.1044	.1044	.1044	.1044	.1044
30	133.5	.1209	.1209	.1209	.1209	.1209	.1209
31	137.9	.1395	.1395	.1395	.1395	.1395	.1395
32	142.4	.1603	.1603	.1603	.1603	.1603	.1603
33	146.8	.1835	.1835	.1835	.1835	.1835	.1835
34	151.3	.2092	.2092	.2092	.2092	.2092	.2092
35	155.7	.2377	.2377	.2377	.2377	.2377	.2377
36	160.2	.2692	.2692	.2692	.2692	.2692	.2692
37	164.6	.3039	.3039	.3039	.3039	.3039	.3039
38	169.1	.3420	.3420	.3420	.3420	.3420	.3420
39	173.5	.3839	.3839	.3839	.3839	.3839	.3839
40	178.0	.4297	.4297	.4297	.4297	.4297	.4297
41	182.4	.4797	.4797	.4797	.4797	.4797	.4797
42	186.9	.5342	.5342	.5342	.5342	.5342	.5342
43	191.3	.5935	.5935	.5935	.5935	.5935	.5935
44	195.8	.6579	.6579	.6579	.6579	.6579	.6579
45	200.2	.7277	.7277	.7277	.7277	.7277	.7277
46	204.7	.8033	.8033	.8033	.8033	.8033	.8033
47	209.1	.8849	.8849	.8849	.8849	.8849	.8849
48	213.6	.9730	.9730	.9730	.9730	.9730	.9730
49	218.0	1.0678	1.0678	1.0678	1.0678	1.0678	1.0678
50	222.5	1.1698	1.1698	1.1698	1.1698	1.1698	1.1698
51	226.9	1.2794	1.2794	1.2794	1.2794	1.2794	1.2794
52	231.4	1.3969	1.3969	1.3969	1.3969	1.3969	1.3969
53	235.8	1.5228	1.5228	1.5228	1.5228	1.5228	1.5228
54	240.3	1.6576	1.6576	1.6576	1.6576	1.6576	1.6576
55	244.7	1.8016	1.8016	1.8016	1.8016	1.8016	1.8016
56	249.2	1.9553	1.9553	1.9553	1.9553	1.9553	1.9553
57	253.6	2.1192	2.1192	2.1192	2.1192	2.1192	2.1192
58	258.1	2.2939	2.2939	2.2939	2.2939	2.2939	2.2939
59	262.5	2.4797	2.4797	2.4797	2.4797	2.4797	2.4797
60	267.0	2.6772	2.6772	2.6772	2.6772	2.6772	2.6772
61	271.4	2.8869	2.8869	2.8869	2.8869	2.8869	2.8869
62	275.9	3.1095	3.1095	3.1095	3.1095	3.1095	3.1095
63	280.3	3.3454	3.3454	3.3454	3.3454	3.3454	3.3454
64	284.8	3.5953	3.5953	3.5953	3.5953	3.5953	3.5953
65	289.3	3.8597	3.8597	3.8597	3.8597	3.8597	3.8597
66	293.7	4.1393	4.1393	4.1393	4.1393	4.1393	4.1393

TABLE B-23. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, TRIDEM AXLES, PT = 2.5

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
16	71.2	.0335	.0303	.0286	.0278	.0275	.0274
17	75.6	.0423	.0384	.0362	.0352	.0348	.0347
18	80.1	.0529	.0480	.0453	.0441	.0437	.0434
19	84.5	.0653	.0594	.0561	.0547	.0541	.0539
20	89.0	.0798	.0728	.0689	.0672	.0664	.0661
21	93.4	.0965	.0885	.0838	.0817	.0809	.0805
22	97.9	.1158	.1066	.1011	.0987	.0976	.0972
23	102.3	.1378	.1274	.1211	.1182	.1170	.1165
24	106.8	.1627	.1512	.1440	.1407	.1393	.1386
25	111.2	.1907	.1782	.1700	.1663	.1647	.1640
26	115.7	.2219	.2087	.1996	.1954	.1936	.1928
27	120.1	.2567	.2430	.2330	.2284	.2264	.2255
28	124.6	.2952	.2812	.2706	.2655	.2633	.2623
29	129.0	.3376	.3238	.3126	.3071	.3047	.3037
30	133.5	.3841	.3708	.3593	.3536	.3511	.3500
31	137.9	.4349	.4227	.4112	.4054	.4028	.4016
32	142.4	.4904	.4795	.4685	.4627	.4602	.4590
33	146.8	.5508	.5417	.5316	.5262	.5237	.5226
34	151.3	.6164	.6094	.6008	.5960	.5939	.5929
35	155.7	.6876	.6829	.6764	.6728	.6711	.6703
36	160.2	.7648	.7625	.7589	.7568	.7558	.7554
37	164.6	.8483	.8484	.8485	.8486	.8486	.8486
38	169.1	.9386	.9409	.9455	.9485	.9499	.9505
39	173.5	1.0363	1.0403	1.0503	1.0569	1.0602	1.0617
40	178.0	1.1418	1.1469	1.1632	1.1744	1.1801	1.1827
41	182.4	1.2556	1.2612	1.2845	1.3014	1.3100	1.3141
42	186.9	1.3784	1.3835	1.4146	1.4382	1.4506	1.4565
43	191.3	1.5108	1.5141	1.5537	1.5853	1.6023	1.6104
44	195.8	1.6533	1.6537	1.7022	1.7432	1.7657	1.7767
45	200.2	1.8066	1.8025	1.8605	1.9122	1.9413	1.9557
46	204.7	1.9714	1.9613	2.0289	2.0928	2.1298	2.1483
47	209.1	2.1483	2.1304	2.2078	2.2854	2.3316	2.3551
48	213.6	2.3382	2.3106	2.3976	2.4903	2.5473	2.5767
49	218.0	2.5416	2.5024	2.5987	2.7081	2.7775	2.8138
50	222.5	2.7595	2.7065	2.8115	2.9392	3.0227	3.0671
51	226.9	2.9924	2.9236	3.0367	3.1839	3.2834	3.3372
52	231.4	3.2413	3.1543	3.2746	3.4426	3.5601	3.6250
53	235.8	3.5069	3.3996	3.5259	3.7159	3.8535	3.9309
54	240.3	3.7901	3.6600	3.7911	4.0042	4.1641	4.2559
55	244.7	4.0918	3.9364	4.0709	4.3078	4.4923	4.6004
56	249.2	4.4128	4.2297	4.3660	4.6274	4.8387	4.9652
57	253.6	4.7540	4.5406	4.6770	4.9635	5.2039	5.3511
58	258.1	5.1164	4.8700	5.0046	5.3165	5.5883	5.7586
59	262.5	5.5009	5.2189	5.3498	5.6870	5.9925	6.1885
60	267.0	5.9085	5.5881	5.7132	6.0756	6.4170	6.6415
61	271.4	6.3402	5.9785	6.0957	6.4830	6.8624	7.1181
62	275.9	6.7970	6.3912	6.4983	6.9099	7.3291	7.6192
63	280.3	7.2800	6.8270	6.9217	7.3569	7.8179	8.1452
64	284.8	7.7902	7.2870	7.3670	7.8247	8.3292	8.6970
65	289.3	8.3288	7.7721	7.8352	8.3143	8.8637	9.2751
66	293.7	8.8968	8.2835	8.3271	8.8263	9.4220	9.8803

TABLE B-24. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, TRIDEM AXLES, PT = 3.0

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
16	71.2	.0388	.0327	.0295	.0282	.0277	.0274
17	75.6	.0489	.0413	.0374	.0358	.0351	.0348
18	80.1	.0610	.0517	.0468	.0448	.0439	.0436
19	84.5	.0750	.0639	.0580	.0555	.0545	.0540
20	89.0	.0914	.0783	.0712	.0681	.0669	.0663
21	93.4	.1102	.0950	.0865	.0829	.0814	.0807
22	97.9	.1316	.1142	.1043	.1001	.0983	.0975
23	102.3	.1557	.1363	.1248	.1198	.1177	.1168
24	106.8	.1828	.1613	.1483	.1425	.1401	.1391
25	111.2	.2128	.1896	.1750	.1684	.1657	.1645
26	115.7	.2459	.2214	.2052	.1978	.1947	.1934
27	120.1	.2822	.2569	.2392	.2311	.2276	.2261
28	124.6	.3218	.2962	.2773	.2684	.2646	.2630
29	129.0	.3648	.3396	.3198	.3103	.3062	.3044
30	133.5	.4112	.3872	.3669	.3570	.3526	.3507
31	137.9	.4611	.4391	.4189	.4088	.4044	.4024
32	142.4	.5149	.4955	.4761	.4662	.4618	.4598
33	146.8	.5726	.5565	.5388	.5294	.5252	.5234
34	151.3	.6344	.6221	.6071	.5990	.5952	.5936
35	155.7	.7007	.6925	.6814	.6751	.6722	.6708
36	160.2	.7718	.7679	.7617	.7581	.7565	.7557
37	164.6	.8480	.8482	.8484	.8485	.8486	.8486
38	169.1	.9298	.9336	.9415	.9465	.9490	.9501
39	173.5	1.0176	1.0243	1.0413	1.0525	1.0581	1.0607
40	178.0	1.1119	1.1205	1.1478	1.1668	1.1764	1.1809
41	182.4	1.2131	1.2223	1.2612	1.2896	1.3043	1.3112
42	186.9	1.3218	1.3301	1.3816	1.4213	1.4423	1.4523
43	191.3	1.4386	1.4441	1.5092	1.5621	1.5908	1.6047
44	195.8	1.5641	1.5647	1.6441	1.7123	1.7502	1.7689
45	200.2	1.6988	1.6922	1.7863	1.8720	1.9210	1.9455
46	204.7	1.8433	1.8271	1.9361	2.0415	2.1036	2.1350
47	209.1	1.9982	1.9698	2.0937	2.2210	2.2984	2.3381
48	213.6	2.1643	2.1208	2.2591	2.4106	2.5057	2.5552
49	218.0	2.3422	2.2807	2.4327	2.6106	2.7259	2.7871
50	222.5	2.5325	2.4500	2.6148	2.8210	2.9593	3.0340
51	226.9	2.7360	2.6292	2.8056	3.0420	3.2063	3.2968
52	231.4	2.9533	2.8191	3.0054	3.2738	3.4671	3.5757
53	235.8	3.1852	3.0203	3.2147	3.5165	3.7421	3.8715
54	240.3	3.4324	3.2333	3.4340	3.7703	4.0314	4.1845
55	244.7	3.6957	3.4590	3.6635	4.0355	4.3354	4.5152
56	249.2	3.9759	3.6980	3.9040	4.3121	4.6542	4.8641
57	253.6	4.2737	3.9509	4.1559	4.6006	4.9880	5.2317
58	258.1	4.5900	4.2186	4.4199	4.9010	5.3372	5.6183
59	262.5	4.9256	4.5018	4.6965	5.2138	5.7017	6.0243
60	267.0	5.2814	4.8013	4.9864	5.5394	6.0820	6.4502
61	271.4	5.6583	5.1177	5.2904	5.8780	6.4780	6.8962
62	275.9	6.0571	5.4520	5.6091	6.2301	6.8901	7.3628
63	280.3	6.4789	5.8050	5.9433	6.5962	7.3185	7.8501
64	284.8	6.9244	6.1773	6.2938	6.9769	7.7634	8.3585
65	289.3	7.3947	6.5700	6.6613	7.3727	8.2250	8.8883
66	293.7	7.8908	6.9839	7.0468	7.7842	8.7037	9.4398

TABLE B-18. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, TRIDEM AXLES, PT = 2.0

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
16	71.2	.0100	.0123	.0118	.0104	.0095	.0090
17	75.6	.0126	.0154	.0150	.0133	.0121	.0115
18	80.1	.0157	.0192	.0188	.0167	.0153	.0146
19	84.5	.0193	.0236	.0234	.0209	.0191	.0182
20	89.0	.0236	.0288	.0288	.0258	.0236	.0225
21	93.4	.0286	.0347	.0351	.0315	.0289	.0276
22	97.9	.0345	.0416	.0423	.0382	.0351	.0336
23	102.3	.0413	.0494	.0507	.0460	.0423	.0405
24	106.8	.0491	.0583	.0603	.0550	.0507	.0485
25	111.2	.0581	.0683	.0711	.0652	.0602	.0576
26	115.7	.0683	.0797	.0835	.0769	.0711	.0681
27	120.1	.0799	.0924	.0973	.0901	.0836	.0801
28	124.6	.0931	.1067	.1128	.1050	.0976	.0936
29	129.0	.1079	.1226	.1301	.1217	.1134	.1089
30	133.5	.1246	.1404	.1494	.1405	.1312	.1261
31	137.9	.1434	.1601	.1707	.1613	.1510	.1454
32	142.4	.1642	.1819	.1942	.1845	.1732	.1669
33	146.8	.1875	.2061	.2200	.2100	.1977	.1908
34	151.3	.2133	.2327	.2484	.2383	.2249	.2173
35	155.7	.2419	.2620	.2794	.2693	.2549	.2466
36	160.2	.2734	.2941	.3133	.3032	.2879	.2789
37	164.6	.3081	.3293	.3502	.3404	.3242	.3144
38	169.1	.3463	.3679	.3903	.3809	.3638	.3534
39	173.5	.3881	.4099	.4338	.4249	.4071	.3960
40	178.0	.4339	.4558	.4809	.4726	.4543	.4426
41	182.4	.4838	.5057	.5319	.5243	.5055	.4933
42	186.9	.5383	.5599	.5869	.5801	.5610	.5484
43	191.3	.5974	.6186	.6461	.6403	.6212	.6082
44	195.8	.6617	.6822	.7099	.7050	.6861	.6730
45	200.2	.7313	.7510	.7784	.7746	.7561	.7430
46	204.7	.8066	.8253	.8520	.8492	.8313	.8185
47	209.1	.8880	.9053	.9309	.9291	.9122	.8998
48	213.6	.9758	.9915	1.0154	1.0145	.9989	.9872
49	218.0	1.0702	1.0842	1.1058	1.1056	1.0917	1.0810
50	222.5	1.1719	1.1837	1.2024	1.2028	1.1910	1.1815
51	226.9	1.2810	1.2903	1.3056	1.3064	1.2969	1.2891
52	231.4	1.3981	1.4046	1.4156	1.4165	1.4097	1.4041
53	235.8	1.5234	1.5269	1.5328	1.5334	1.5299	1.5268
54	240.3	1.6576	1.6576	1.6576	1.6576	1.6576	1.6576
55	244.7	1.8009	1.7971	1.7903	1.7892	1.7932	1.7968
56	249.2	1.9539	1.9458	1.9314	1.9286	1.9370	1.9448
57	253.6	2.1171	2.1043	2.0812	2.0762	2.0892	2.1019
58	258.1	2.2908	2.2730	2.2401	2.2322	2.2504	2.2685
59	262.5	2.4757	2.4523	2.4086	2.3969	2.4207	2.4450
60	267.0	2.6722	2.6428	2.5870	2.5709	2.6005	2.6318
61	271.4	2.8809	2.8449	2.7759	2.7544	2.7902	2.8293
62	275.9	3.1023	3.0592	2.9757	2.9478	2.9901	3.0378
63	280.3	3.3370	3.2863	3.1869	3.1515	3.2006	3.2578
64	284.8	3.5855	3.5266	3.4099	3.3659	3.4220	3.4897
65	289.3	3.8485	3.7807	3.6453	3.5914	3.6547	3.7338
66	293.7	4.1265	4.0493	3.8936	3.8285	3.8992	3.9907

TABLE B-19. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, TRIDEM AXLES, PT = 2.5

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
16	71.2	.0122	.0192	.0175	.0132	.0107	.0096
17	75.6	.0150	.0237	.0222	.0169	.0137	.0123
18	80.1	.0183	.0289	.0277	.0212	.0173	.0155
19	84.5	.0221	.0349	.0341	.0264	.0216	.0194
20	89.0	.0266	.0417	.0417	.0325	.0266	.0239
21	93.4	.0319	.0493	.0503	.0396	.0326	.0293
22	97.9	.0379	.0578	.0602	.0479	.0395	.0356
23	102.3	.0449	.0674	.0715	.0574	.0476	.0429
24	106.8	.0529	.0780	.0841	.0683	.0568	.0514
25	111.2	.0621	.0897	.0983	.0807	.0674	.0611
26	115.7	.0725	.1027	.1140	.0947	.0795	.0721
27	120.1	.0843	.1171	.1315	.1105	.0932	.0847
28	124.6	.0976	.1329	.1507	.1282	.1086	.0990
29	129.0	.1127	.1503	.1718	.1478	.1260	.1150
30	133.5	.1295	.1694	.1948	.1696	.1453	.1330
31	137.9	.1483	.1904	.2199	.1937	.1669	.1531
32	142.4	.1693	.2134	.2471	.2201	.1909	.1755
33	146.8	.1927	.2385	.2766	.2491	.2173	.2004
34	151.3	.2186	.2660	.3083	.2807	.2464	.2279
35	155.7	.2472	.2961	.3425	.3151	.2784	.2582
36	160.2	.2788	.3288	.3793	.3523	.3135	.2916
37	164.6	.3135	.3644	.4187	.3926	.3517	.3282
38	169.1	.3517	.4032	.4609	.4361	.3933	.3682
39	173.5	.3935	.4453	.5060	.4827	.4384	.4119
40	178.0	.4392	.4909	.5542	.5328	.4872	.4594
41	182.4	.4891	.5404	.6057	.5863	.5399	.5110
42	186.9	.5434	.5939	.6606	.6435	.5967	.5669
43	191.3	.6024	.6517	.7190	.7044	.6578	.6273
44	195.8	.6664	.7141	.7812	.7692	.7232	.6924
45	200.2	.7358	.7814	.8473	.8379	.7933	.7626
46	204.7	.8109	.8538	.9176	.9107	.8681	.8380
47	209.1	.8919	.9317	.9922	.9878	.9478	.9188
48	213.6	.9793	1.0154	1.0715	1.0692	1.0326	1.0053
49	218.0	1.0733	1.1051	1.1556	1.1552	1.1226	1.0978
50	222.5	1.1745	1.2013	1.2448	1.2457	1.2181	1.1964
51	226.9	1.2831	1.3043	1.3393	1.3411	1.3192	1.3015
52	231.4	1.3995	1.4144	1.4394	1.4414	1.4260	1.4132
53	235.8	1.5242	1.5320	1.5454	1.5469	1.5388	1.5318
54	240.3	1.6576	1.6576	1.6576	1.6576	1.6576	1.6576
55	244.7	1.8001	1.7914	1.7762	1.7737	1.7826	1.7907
56	249.2	1.9522	1.9340	1.9017	1.8955	1.9141	1.9315
57	253.6	2.1144	2.0857	2.0342	2.0232	2.0521	2.0802
58	258.1	2.2871	2.2470	2.1742	2.1568	2.1968	2.2370
59	262.5	2.4708	2.4183	2.3219	2.2967	2.3484	2.4021
60	267.0	2.6660	2.6001	2.4778	2.4431	2.5071	2.5758
61	271.4	2.8734	2.7928	2.6422	2.5961	2.6730	2.7583
62	275.9	3.0933	2.9971	2.8154	2.7561	2.8462	2.9499
63	280.3	3.3264	3.2132	2.9979	2.9232	3.0271	3.1507
64	284.8	3.5732	3.4419	3.1901	3.0978	3.2156	3.3611
65	289.3	3.8344	3.6836	3.3923	3.2800	3.4121	3.5812
66	293.7	4.1105	3.9388	3.6050	3.4702	3.6167	3.8113

TABLE B-20. TRAFFIC EQUIVALENCE FACTORS, FLEXIBLE PAVEMENTS, TRIDEM AXLES, PT = 3.0

AXLE LOAD		STRUCTURAL NUMBER, SN					
KIPS	KN	1	2	3	4	5	6
16	71.2	.0159	.0350	.0300	.0183	.0127	.0105
17	75.6	.0190	.0423	.0376	.0233	.0162	.0134
18	80.1	.0225	.0503	.0465	.0292	.0204	.0169
19	84.5	.0266	.0591	.0569	.0362	.0254	.0211
20	89.0	.0313	.0687	.0686	.0444	.0313	.0260
21	93.4	.0368	.0791	.0820	.0539	.0383	.0318
22	97.9	.0431	.0903	.0970	.0649	.0463	.0386
23	102.3	.0503	.1025	.1136	.0774	.0557	.0465
24	106.8	.0586	.1155	.1320	.0916	.0664	.0556
25	111.2	.0680	.1296	.1520	.1077	.0786	.0660
26	115.7	.0786	.1448	.1739	.1256	.0924	.0779
27	120.1	.0906	.1611	.1975	.1456	.1080	.0914
28	124.6	.1041	.1787	.2229	.1678	.1256	.1066
29	129.0	.1193	.1978	.2501	.1921	.1452	.1237
30	133.5	.1363	.2184	.2790	.2188	.1669	.1428
31	137.9	.1553	.2406	.3098	.2479	.1911	.1642
32	142.4	.1765	.2647	.3423	.2795	.2177	.1879
33	146.8	.1999	.2907	.3767	.3136	.2469	.2141
34	151.3	.2259	.3189	.4129	.3503	.2788	.2430
35	155.7	.2546	.3493	.4510	.3896	.3137	.2748
36	160.2	.2862	.3823	.4909	.4315	.3515	.3097
37	164.6	.3210	.4179	.5329	.4762	.3926	.3477
38	169.1	.3591	.4564	.5769	.5236	.4368	.3892
39	173.5	.4009	.4979	.6230	.5736	.4844	.4342
40	178.0	.4465	.5428	.6713	.6265	.5356	.4831
41	182.4	.4962	.5911	.7220	.6820	.5902	.5358
42	186.9	.5504	.6432	.7750	.7403	.6486	.5927
43	191.3	.6092	.6993	.8306	.8013	.7107	.6539
44	195.8	.6729	.7596	.8889	.8651	.7766	.7196
45	200.2	.7420	.8244	.9501	.9317	.8465	.7899
46	204.7	.8166	.8940	1.0142	1.0010	.9202	.8650
47	209.1	.8972	.9686	1.0816	1.0731	.9980	.9451
48	213.6	.9840	1.0485	1.1522	1.1479	1.0798	1.0304
49	218.0	1.0775	1.1341	1.2264	1.2256	1.1658	1.1209
50	222.5	1.1780	1.2256	1.3044	1.3061	1.2558	1.2168
51	226.9	1.2858	1.3233	1.3862	1.3896	1.3500	1.3183
52	231.4	1.4014	1.4277	1.4722	1.4759	1.4483	1.4256
53	235.8	1.5252	1.5390	1.5626	1.5652	1.5509	1.5386
54	240.3	1.6576	1.6576	1.6576	1.6576	1.6576	1.6576
55	244.7	1.7990	1.7838	1.7574	1.7531	1.7685	1.7826
56	249.2	1.9499	1.9181	1.8623	1.8518	1.8836	1.9138
57	253.6	2.1107	2.0608	1.9724	1.9537	2.0030	2.0513
58	258.1	2.2820	2.2123	2.0882	2.0591	2.1265	2.1951
59	262.5	2.4641	2.3731	2.2098	2.1680	2.2542	2.3453
60	267.0	2.6577	2.5435	2.3376	2.2804	2.3862	2.5020
61	271.4	2.8632	2.7240	2.4717	2.3967	2.5224	2.6653
62	275.9	3.0812	2.9151	2.6125	2.5168	2.6629	2.8351
63	280.3	3.3122	3.1172	2.7604	2.6409	2.8075	3.0117
64	284.8	3.5567	3.3308	2.9155	2.7692	2.9565	3.1949
65	289.3	3.8155	3.5563	3.0782	2.9018	3.1097	3.3849
66	293.7	4.0890	3.7943	3.2488	3.0389	3.2673	3.5816

TABLE B-21. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, TRIDEM AXLES, PT = 1.5

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
16	71.2	.0272	.0272	.0272	.0272	.0272	.0272
17	75.6	.0345	.0345	.0345	.0345	.0345	.0345
18	80.1	.0432	.0432	.0432	.0432	.0432	.0432
19	84.5	.0536	.0536	.0536	.0536	.0536	.0536
20	89.0	.0658	.0658	.0658	.0658	.0658	.0658
21	93.4	.0801	.0801	.0801	.0801	.0801	.0801
22	97.9	.0968	.0968	.0968	.0968	.0968	.0968
23	102.3	.1160	.1160	.1160	.1160	.1160	.1160
24	106.8	.1381	.1381	.1381	.1381	.1381	.1381
25	111.2	.1633	.1633	.1633	.1633	.1633	.1633
26	115.7	.1921	.1921	.1921	.1921	.1921	.1921
27	120.1	.2246	.2246	.2246	.2246	.2246	.2246
28	124.6	.2614	.2614	.2614	.2614	.2614	.2614
29	129.0	.3027	.3027	.3027	.3027	.3027	.3027
30	133.5	.3489	.3489	.3489	.3489	.3489	.3489
31	137.9	.4005	.4005	.4005	.4005	.4005	.4005
32	142.4	.4579	.4579	.4579	.4579	.4579	.4579
33	146.8	.5216	.5216	.5216	.5216	.5216	.5216
34	151.3	.5920	.5920	.5920	.5920	.5920	.5920
35	155.7	.6696	.6696	.6696	.6696	.6696	.6696
36	160.2	.7550	.7550	.7550	.7550	.7550	.7550
37	164.6	.8486	.8486	.8486	.8486	.8486	.8486
38	169.1	.9512	.9512	.9512	.9512	.9512	.9512
39	173.5	1.0632	1.0632	1.0632	1.0632	1.0632	1.0632
40	178.0	1.1853	1.1853	1.1853	1.1853	1.1853	1.1853
41	182.4	1.3181	1.3181	1.3181	1.3181	1.3181	1.3181
42	186.9	1.4623	1.4623	1.4623	1.4623	1.4623	1.4623
43	191.3	1.6186	1.6186	1.6186	1.6186	1.6186	1.6186
44	195.8	1.7877	1.7877	1.7877	1.7877	1.7877	1.7877
45	200.2	1.9703	1.9703	1.9703	1.9703	1.9703	1.9703
46	204.7	2.1672	2.1672	2.1672	2.1672	2.1672	2.1672
47	209.1	2.3793	2.3793	2.3793	2.3793	2.3793	2.3793
48	213.6	2.6072	2.6072	2.6072	2.6072	2.6072	2.6072
49	218.0	2.8519	2.8519	2.8519	2.8519	2.8519	2.8519
50	222.5	3.1143	3.1143	3.1143	3.1143	3.1143	3.1143
51	226.9	3.3952	3.3952	3.3952	3.3952	3.3952	3.3952
52	231.4	3.6955	3.6955	3.6955	3.6955	3.6955	3.6955
53	235.8	4.0163	4.0163	4.0163	4.0163	4.0163	4.0163
54	240.3	4.3586	4.3586	4.3586	4.3586	4.3586	4.3586
55	244.7	4.7232	4.7232	4.7232	4.7232	4.7232	4.7232
56	249.2	5.1114	5.1114	5.1114	5.1114	5.1114	5.1114
57	253.6	5.5241	5.5241	5.5241	5.5241	5.5241	5.5241
58	258.1	5.9624	5.9624	5.9624	5.9624	5.9624	5.9624
59	262.5	6.4276	6.4276	6.4276	6.4276	6.4276	6.4276
60	267.0	6.9208	6.9208	6.9208	6.9208	6.9208	6.9208
61	271.4	7.4431	7.4431	7.4431	7.4431	7.4431	7.4431
62	275.9	7.9958	7.9958	7.9958	7.9958	7.9958	7.9958
63	280.3	8.5801	8.5801	8.5801	8.5801	8.5801	8.5801
64	284.8	9.1974	9.1974	9.1974	9.1974	9.1974	9.1974
65	289.3	9.8490	9.8490	9.8490	9.8490	9.8490	9.8490
66	293.7	10.5362	10.5362	10.5362	10.5362	10.5362	10.5362

TABLE B-22. TRAFFIC EQUIVALENCE FACTORS, RIGID PAVEMENTS, TRIDEM AXLES, PT = 2.0

AXLE LOAD		D-SLAB THICKNESS-INCHES					
KIPS	KN	6	7	8	9	10	11
16	71.2	.0299	.0286	.0278	.0275	.0273	.0273
17	75.6	.0378	.0362	.0353	.0348	.0347	.0346
18	80.1	.0473	.0453	.0442	.0436	.0434	.0433
19	84.5	.0586	.0561	.0547	.0541	.0538	.0537
20	89.0	.0718	.0689	.0672	.0664	.0661	.0660
21	93.4	.0871	.0838	.0818	.0808	.0805	.0803
22	97.9	.1049	.1011	.0987	.0976	.0972	.0969
23	102.3	.1253	.1210	.1182	.1170	.1164	.1162
24	106.8	.1486	.1438	.1407	.1392	.1386	.1383
25	111.2	.1751	.1699	.1663	.1647	.1639	.1636
26	115.7	.2050	.1994	.1954	.1936	.1928	.1924
27	120.1	.2385	.2327	.2284	.2263	.2254	.2250
28	124.6	.2761	.2701	.2655	.2632	.2622	.2618
29	129.0	.3179	.3120	.3071	.3047	.3036	.3031
30	133.5	.3643	.3586	.3536	.3510	.3499	.3494
31	137.9	.4157	.4103	.4053	.4027	.4015	.4010
32	142.4	.4723	.4675	.4626	.4601	.4589	.4584
33	146.8	.5345	.5305	.5260	.5236	.5225	.5220
34	151.3	.6028	.5997	.5959	.5938	.5928	.5924
35	155.7	.6776	.6755	.6727	.6710	.6703	.6699
36	160.2	.7594	.7583	.7567	.7558	.7553	.7551
37	164.6	.8485	.8485	.8486	.8486	.8486	.8486
38	169.1	.9455	.9465	.9486	.9500	.9506	.9509
39	173.5	1.0510	1.0528	1.0574	1.0604	1.0618	1.0625
40	178.0	1.1655	1.1679	1.1753	1.1804	1.1829	1.1841
41	182.4	1.2896	1.2922	1.3029	1.3106	1.3145	1.3163
42	186.9	1.4240	1.4263	1.4406	1.4514	1.4570	1.4597
43	191.3	1.5692	1.5708	1.5891	1.6035	1.6112	1.6149
44	195.8	1.7259	1.7261	1.7487	1.7675	1.7778	1.7827
45	200.2	1.8949	1.8930	1.9202	1.9440	1.9572	1.9637
46	204.7	2.0769	2.0721	2.1039	2.1334	2.1503	2.1587
47	209.1	2.2725	2.2640	2.3006	2.3366	2.3577	2.3684
48	213.6	2.4826	2.4694	2.5108	2.5540	2.5801	2.5934
49	218.0	2.7080	2.6891	2.7351	2.7863	2.8182	2.8347
50	222.5	2.9494	2.9238	2.9743	3.0343	3.0727	3.0930
51	226.9	3.2078	3.1744	3.2290	3.2985	3.3444	3.3690
52	231.4	3.4839	3.4415	3.5000	3.5796	3.6340	3.6636
53	235.8	3.7787	3.7262	3.7879	3.8784	3.9423	3.9777
54	240.3	4.0931	4.0293	4.0936	4.1955	4.2700	4.3121
55	244.7	4.4281	4.3516	4.4179	4.5317	4.6180	4.6676
56	249.2	4.7845	4.6942	4.7616	4.8878	4.9869	5.0451
57	253.6	5.1635	5.0579	5.1257	5.2646	5.3777	5.4456
58	258.1	5.5660	5.4438	5.5109	5.6628	5.7912	5.8699
59	262.5	5.9930	5.8529	5.9184	6.0833	6.2282	6.3190
60	267.0	6.4457	6.2861	6.3490	6.5271	6.6895	6.7938
61	271.4	6.9252	6.7447	6.8038	6.9949	7.1761	7.2952
62	275.9	7.4326	7.2296	7.2839	7.4878	7.6888	7.8242
63	280.3	7.9690	7.7421	7.7902	8.0067	8.2286	8.3818
64	284.8	8.5357	8.2832	8.3240	8.5527	8.7964	8.9689
65	289.3	9.1338	8.8541	8.8863	9.1267	9.3931	9.5867
66	293.7	9.7647	9.4560	9.4784	9.7298	10.0197	10.2360