Traffic Forecasting for Pavement Design

Research, Development, and Technology

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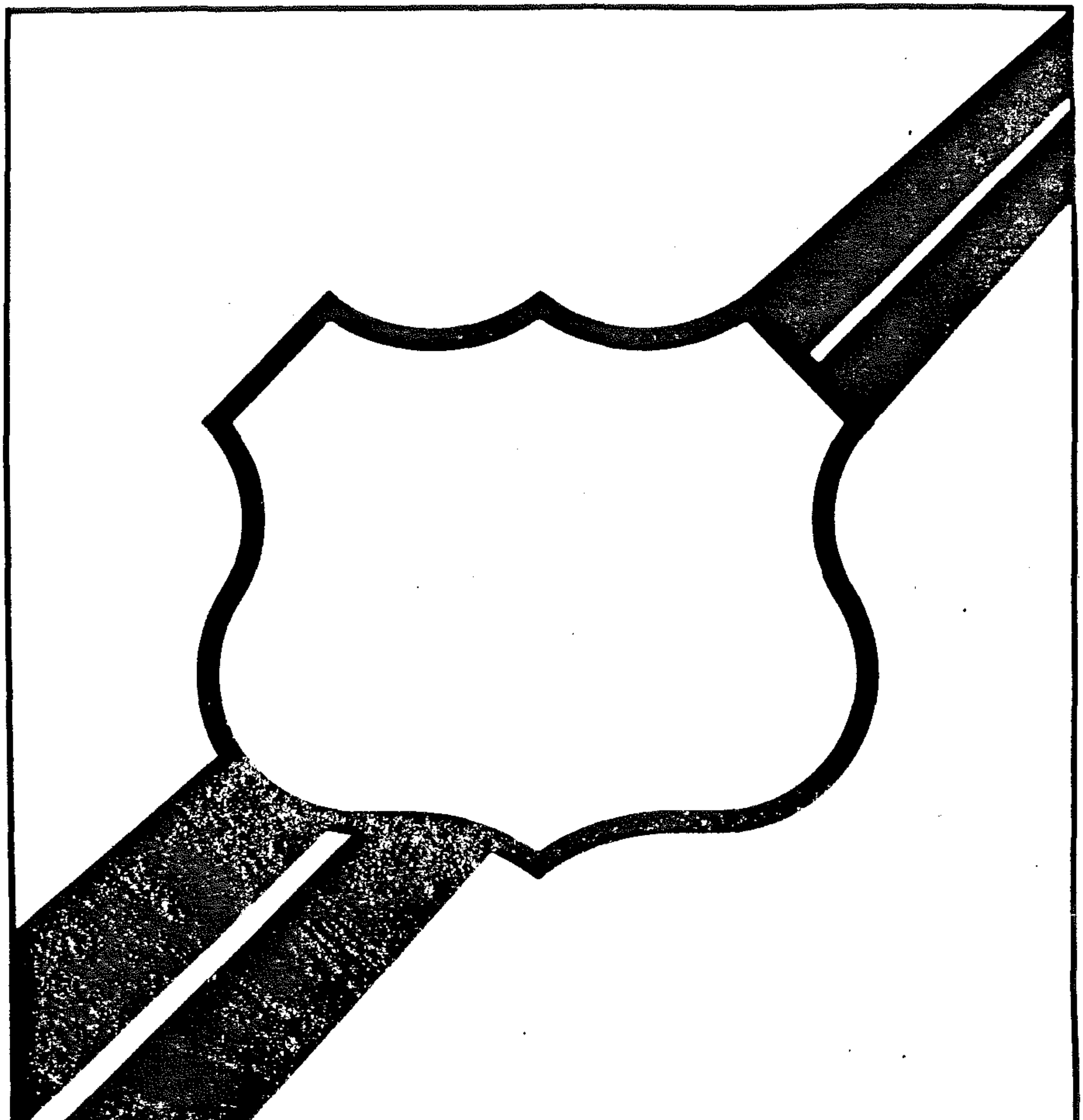

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TRAFFIC FORECASTING FOR PAVEMENT DESIGN

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in cooperation with
The United States Department of Transportation
Federal Highway Administration

July 1987

FOREWORD

A multistate study concerning traffic forecasting for pavement design has been completed. Representatives from four States (Florida, Kentucky, Oregon, and Washington) met on three occasions to discuss the subject. Some specific topics of these discussions included data input needs, equipment and methods used to collect data, algorithms and models used to make predictions, and levels of sophistication for forecasting procedures.

Each participating State contributed to the development of this final report that discusses the various aspects of the traffic forecasting process, including available and anticipated options for each step of the process. The information in this report should be of interest to pavement design engineers and traffic forecasters from those State highway agencies interested in improving their traffic forecasting practices and procedures.

Additional copies of this report may be obtained from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

R. J. Betsold
Director, Office of Implementation

NOTICE

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16. Abstract

The need for improved traffic estimation procedures has been emphasized by several studies that demonstrated that previously available data were not adequate. Some data were not considered representative of actual traffic conditions because of overloaded trucks avoiding weighing scales and insufficient traffic sampling programs. In addition, previous forecasting procedures did not reflect the increases in legal load limits, the significant increase in the number of heavy trucks, or the shift toward larger vehicle types that has occurred in recent years.

Improved estimates of current traffic loadings based on larger samples of much higher quality data would allow development of procedures for making improved estimates of historical traffic loadings and better forecasts of traffic loadings during the design period. The emergence of automatic vehicle classification equipment, permanent and portable weigh-in-motion (WIM) systems, and the application of microprocessors and microcomputers to these data acquisition functions now offer tools that may be used effectively in meeting these needs.

Representatives from four States (Florida, Kentucky, Oregon, and Washington) met on several occasions to discuss the subject of traffic forecasting for pavement design. Information was compiled on all aspects of the traffic forecasting process, options were presented for each step of the process, and recommendations were developed to assist highway agencies in improving current practices and procedures.

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Forecasting, Algorithm, Equivalent Single Axleload (ESAL), Average Annual Daily Traffic (AADT)

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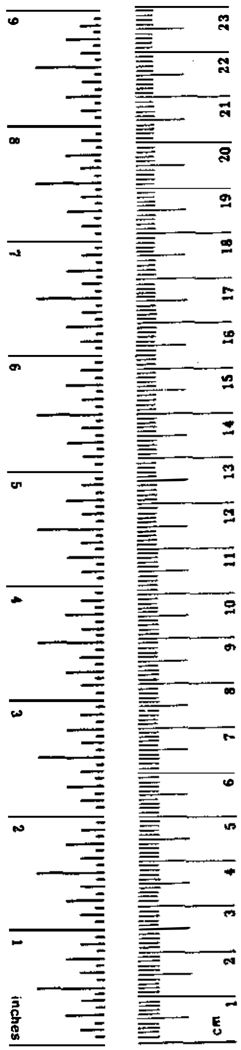
METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

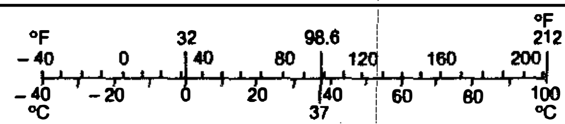
NOTE: Volumes greater than 1000 L shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
AADTT	Annual Average Daily Truck Traffic
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ADTT	Average Daily Truck Traffic
ATR	Automatic Traffic Recorder
AWT	Average Weekday Traffic
BPA	Bonneville Power Administration (Oregon)
DEAL	Design Equivalent Axleloads
DOT	Department of Transportation
DTN	Design Traffic Number
EIS	Environmental Impact Statement
ESAL	Equivalent Single Axleload
EWL	Equivalent Wheel Load
FHWA	Federal Highway Administration
GSP	Gross State Product
HPMS	Highway Performance Monitoring System
PSU	Portland State University (Oregon)
PUC	Public Utility Commissioner (Oregon)
TMG	Traffic Monitoring Guide
VMT	Vehicle-Miles of Travel
WIM	Weigh-In-Motion

SUMMARY

The art or science of highway and airfield pavement design is well advanced. There are a number of reliable and acceptable methods by which the appropriate thickness and material types for the pavement system may be determined and selected. Some of these design procedures are based entirely upon empirical observations, others are based to various degrees upon different theories of material characterizations and behaviors, and others are based upon a merging of theoretical concepts with empirical performance of pavement systems.

No matter what technique is used to develop the thickness design and to select component materials for a pavement system, one of the major input parameters is the vehicular loading to which the pavement structure will be subjected. The traffic stream, of course, using the highway network is the source of these vehicular loadings. There are many who feel characterization of the traffic stream, so the vehicular loadings during the design life of a pavement are adequately described, is one of the major problems in the pavement design process. Inaccurate or incomplete estimates of traffic characteristics, on many occasions, is the source of significant differences between the performance of a pavement system and the behavior that was anticipated at the time of the design process.

CONTENT OF REPORT

Because of the significant and major impact that traffic has upon the design of highway pavement systems, the Federal Highway Administration identified four States to meet and consider various problems that are associated with the characterization and prediction of traffic parameters for pavement design purposes. This report is a documentation of those deliberations. It presents a brief discussion and summary of the more salient points of traffic characterization and forecasting.

Appendix A explains the methodology used by the Florida Department of Transportation to convert seasonal traffic counts into average annual

daily traffic based on adjustment factors developed from traffic collection programs. It also explains the estimation of K and D factors used in capacity analyses, which often result in restraining traffic volumes to theoretical maximum volumes. Finally, it explains the methods of developing site-specific traffic growth factors and one method of developing a generalized growth factor.

Appendix B illustrates the use of traffic data to assess the performance of a specific section of highway. The premature failure of a pavement is related to the characteristics of the actual traffic stream and is shown to be in part a result of the significant underestimation of the equivalent single axleloads used to design the pavement thickness.

Appendix C shows that pavement overlay design is significantly influenced by the traffic inputs used to estimate design loadings. It points out the monetary consequences of using poor estimates of traffic in pavement design calculations. The example also demonstrates the need for using site-specific data whenever possible. Statewide and regional averages are necessary in many cases due to limitations in the ability of many States to collect information at project locations, but such average data may cause significant errors in the estimation of design traffic.

Appendix D is a written description of the existing vehicle monitoring and forecasting procedures used in Oregon. The outline includes two sections. "Section A -- Data Collection" addresses subjects such as number of sites, equipment, collection methods, site operation, and availability of data. As part of "Section B -- Data Uses", data use, methods of forecasting, estimating and forecasting for non-data highway sections, availability of state economic data, and legislative changes in truck loadings are addressed.

NEED FOR TRAFFIC DATA

Inasmuch as the basic function of the highway system is to provide for the movement of people and/or goods from one point to another, traffic forecasts are significant. The designer attempts to provide both highway geometrics to satisfy future capacity needs and a pavement system to support the traffic throughout the design period. Even though the designer responsible for the geometrics of the highway system may be a different individual than the one responsible for the design of the thickness of the pavement, both should use the same basic traffic data and projections. Inconsistencies sometimes are introduced when these two design aspects are based upon different traffic trends and forecasts.

The need for improved traffic estimation procedures is emphasized by several studies that demonstrate that previously available data were not adequate. Some data are not representative of actual traffic conditions because of overloaded trucks avoiding weighing scales and inadequate traffic sampling programs. Forecasting procedures often may not reflect the increases in legal load limits, the significant increase in the number of heavy trucks, or the shift toward larger vehicle types.

Improved estimates of current traffic loadings based on larger samples of higher quality data would lead to improved estimates of historical traffic loadings and better forecasts of traffic loadings during the design period. The emergence of automatic vehicle classification equipment, permanent and portable weigh-in-motion systems, and the application of microprocessors and microcomputers to data acquisition and processing functions offer tools to effectively meet these needs.

The objective of this study was to have several States actively studying traffic forecasting for pavement design and analysis jointly evaluate existing procedures and recommend potential improvements. This process is documented in this report that discusses aspects of traffic monitoring and forecasting procedures, including available and anticipated options for each step of the traffic forecasting process.

EQUIVALENCY FACTORS

Most current pavement thickness design methodologies make use of the basic design parameter, the equivalent single axleload (ESAL). Various characteristics of the traffic stream are reduced to and expressed as the "design ESAL." Studies to evaluate the effects of truck sizes, weights, and axle configurations on pavement deterioration, cost responsibilities, benefits and costs of changing legal axleload regulations, funding needs, and operational planning have a common point of beginning in the concept of an equivalent single axleload. As vehicle loads have increased and axle configurations have changed, there is a continuing need to reevaluate from pavement damage data the relevant load equivalency factors for heavier vehicle loadings and higher tire pressures.

TRAFFIC PARAMETERS

Several parameters of traffic statistics are important to pavement thickness design. Basic data most often available and used in various ways include traffic volumes, the distributions of these volumes among various vehicle styles, and distributions of the weights of the vehicles in the traffic stream among axles and axle configurations. A number of traffic parameters and statistics were identified as important factors to be considered in forecasting future traffic demands. These are listed here as a summary.

Vehicle Types, Volumes, and Weights

Pavement thickness designs are based on the number of expected repetitions of the standard 18-kip ESAL. Existing annual average daily traffic, along with other input data, may be used to calculate truck volumes and the number of expected loadings. Truck volume data should be classified as to the types of vehicle (i.e., three-axle, four-axle, five-axle, etc.).

On multilane highways, the lane distribution of truck traffic will vary. Project specific data should be obtained to correctly distribute the truck traffic among lanes.

Traffic on some highways have a directional distribution different from a 50/50 split. In some cases, loaded trucks travel one direction while empty trucks travel in the opposite direction.

The weight of each vehicle has been identified as a major contributor to the damage of pavements. The configuration of the load distribution (i.e., number of axles, number of tires, etc.) is very important in determining a vehicle loading factor.

Demographic and Economic Data

Origin-destination studies relate travel demand to characteristics of an area, such as population and employment. They allow forecasts of future travel based on other predictions of population, employment, and other variables.

Network assignments, in conjunction with origin-destination studies, provide information on traffic route requirements and may be particularly useful in metropolitan areas.

In some situations, vehicle registrations may provide a means of classifying vehicle types.

Gasoline consumption data are an indication only of local growth rates.

Population growth rates are used to establish traffic growth rates and are good indicators for local conditions.

Economic growth rates are a good indicator of potential truck traffic growth rates.

Timeliness of Data

The above listed input data are valid only for the time period the data represents. Extrapolations of data may be made to other time periods, but only with close scrutinization.

Truck traffic may be subjected to seasonal variations, such as farm trucks used for the harvest season, and may be important, especially if they occur at the same time that a subgrade stability problem occurs. Other traffic variations, such as weekday versus weekend and night versus day, are also important for geometric considerations.

Loading history (accumulated ESAL's) has a great value when forecasting future loadings. As much historical data as can be assembled should be used. A minimum of 10 years is preferred.

To the extent historical traffic characteristics are used to make predictions concerning future traffic characteristics, it is necessary to know the sampling plans and quality control measures that were used to obtain the historical data. In using sampling schemes, it is necessary to determine criteria by which sample locations were selected, frequency of sample collection, and time periods for data collection.

Recent data should be as current as possible. Some data, such as lane distributions, directional splits, etc., may be up to two to three years old as long as conditions have not changed significantly. Other data, such as vehicle classifications, ESAL equivalency factors, etc., should be obtained as recently as possible. The importance of the current loadings is hard to overstate in that they serve as the basis for the forecast loadings. Current year traffic design data is normally obtained from one of three types of sources:

- Actual traffic counts (including vehicle classification counts and weighings) from either historical files or special count sessions done specifically for that project.
- Special transportation studies.
- Computer network assignments.

Special studies are most important for new highway projects, where no existing traffic exists. They are also appropriate for those projects that will likely cause significant changes in traffic as a result of the diversion of traffic from other routes or where related development along a highway corridor indicates the potential for increased highway demands.

FORECASTING

In general, models of any type are described in terms of their dependent variable(s), the set of independent variables, and the relationships that exist between the dependent and independent variables. While daily or annual ESAL's could be modeled directly, a major advantage could be realized by modeling a set of more fundamental traffic parameters from which ESAL's could then be derived. If models are developed for the more fundamental traffic parameters, all available volume data (for modeling annual average daily traffic (AADT)), all available classification data (for modeling truck traffic), all weight data (for modeling the damage effects of axleloads), as well as other data related to economic growth could be used.

The decision is clear: models should be developed for fundamental traffic parameters, and the ESAL estimate would then be obtained by calculation.

Conceptually, an aspect of model development is the form of the relationships between the dependent and independent variables. A number of models have been and are being used. These models have included linear regressions, simple- or compound-interest equations, and cross-tabulations.

It is recommended that disaggregated information (e.g., the number of trucks by vehicle type, not just a percentage of trucks) be used whenever that information exists and that efforts be made to collect and monitor the types of information that facilitate forecasting at these levels.

Five alternative levels of data forecasting have been identified. These five levels are listed below in the reverse order of their desirability but in the order of probable ease of use:

Level 1: Forecast simple expansion of current year ESAL's.

Level 2: Forecast changes in AADT's, percent trucks, and average load equivalency factors per truck.

Level 3: Forecast volumes of cars, volumes of trucks, and average load equivalency factors per truck.

Level 4: Forecast volumes of cars, percentage of trucks by vehicle class, and load equivalency factors per vehicle class.

Level 5: Forecast volumes of cars, volumes of trucks by vehicle class, and average load equivalency factors per vehicle class.

The fact that the forecaster makes a special attempt to estimate changing traffic levels for both autos and trucks is important. By disaggregating the number of trucks into specific truck types, the forecaster avoids one of the most common mistakes in pavement design traffic data collection, that is, using a statewide or regional ESAL per truck applied to a simple estimate of percentage of trucks. Further singling out specific types of trucks for forecasting separately from autos and "standard" trucks is advisable.

Unfortunately, there is no "best" method for forecasting. Many of the better forecasts have come from performing several different forecasts using different techniques and then comparing the results to develop a composite forecast. Selecting a forecasting technique or techniques is a function of matching available information with the expertise within the forecasting agency.

Potential forecasting techniques that might be considered include the following:

- Historical trends (regression analyses).
- Judgmental growth rates and engineering estimates.
- Simple-interest equations.
- Straight-line projections.
- Transportation studies.
- Pavement management inputs.

A traffic forecast should not be made without also looking at all related variables. Considering the potential impacts of these variables may significantly affect the expected level of change during the life of the pavement. Such variables include the following:

- Historical traffic levels.
- Legal load limits.
- Population growth.
- Economic activity.
- Availability of alternative routes.
- Availability of alternative modes (for both passengers and freight).
- Political influences on any or all of the above.

Regardless of which model or algorithm is utilized for a specific traffic projection, that model or algorithm is valid only to the extent major discontinuities are not anticipated. Events that may introduce discontinuities and alter future traffic trends include changes in legal load limits and limiting dimensions of vehicles, changes in commodities transported and function of the highway segment (often related to major changes in land use), fuel shortages or gluts and associated changes in fuel costs, changes in utilization of various styles of vehicles (particularly trucks) and the introduction of new vehicle styles, and the introduction into the overall transportation system of alternative modes of transport.

FEEDBACK

All too often, once a set of factors is established, those numbers remain in use regardless of changing traffic levels and characteristics. Such is often the case with statewide or regional default values. Each agency should continually review the factors it is using and update them as necessary. Also important is the comparison of the design (predicted) data on roads with the actual levels of traffic that eventually utilize those roads. In this manner, the forecasting process may be refined to provide better predictions. When used with a comprehensive pavement management system, this continual review of design information also may improve the ability to forecast future pavement needs and defend those needs to State and congressional lawmakers trying to balance scarce funds against competing needs.

GENERALIZED TRAFFIC FORECASTING PROCEDURE

A generalized traffic forecasting procedure is suggested in the flow charts presented in Figure 1. What are considered to be the major items that should be taken into account in a forecasting system are indicated. In some cases, the desirability of the detail and accuracy of data also is indicated. Traffic forecasting procedures involve many details that often are difficult to describe in an overall and generalized manner. It is hoped, however, that the flow charts do suggest the major elements any forecasting procedure should consider in some form and to some degree.

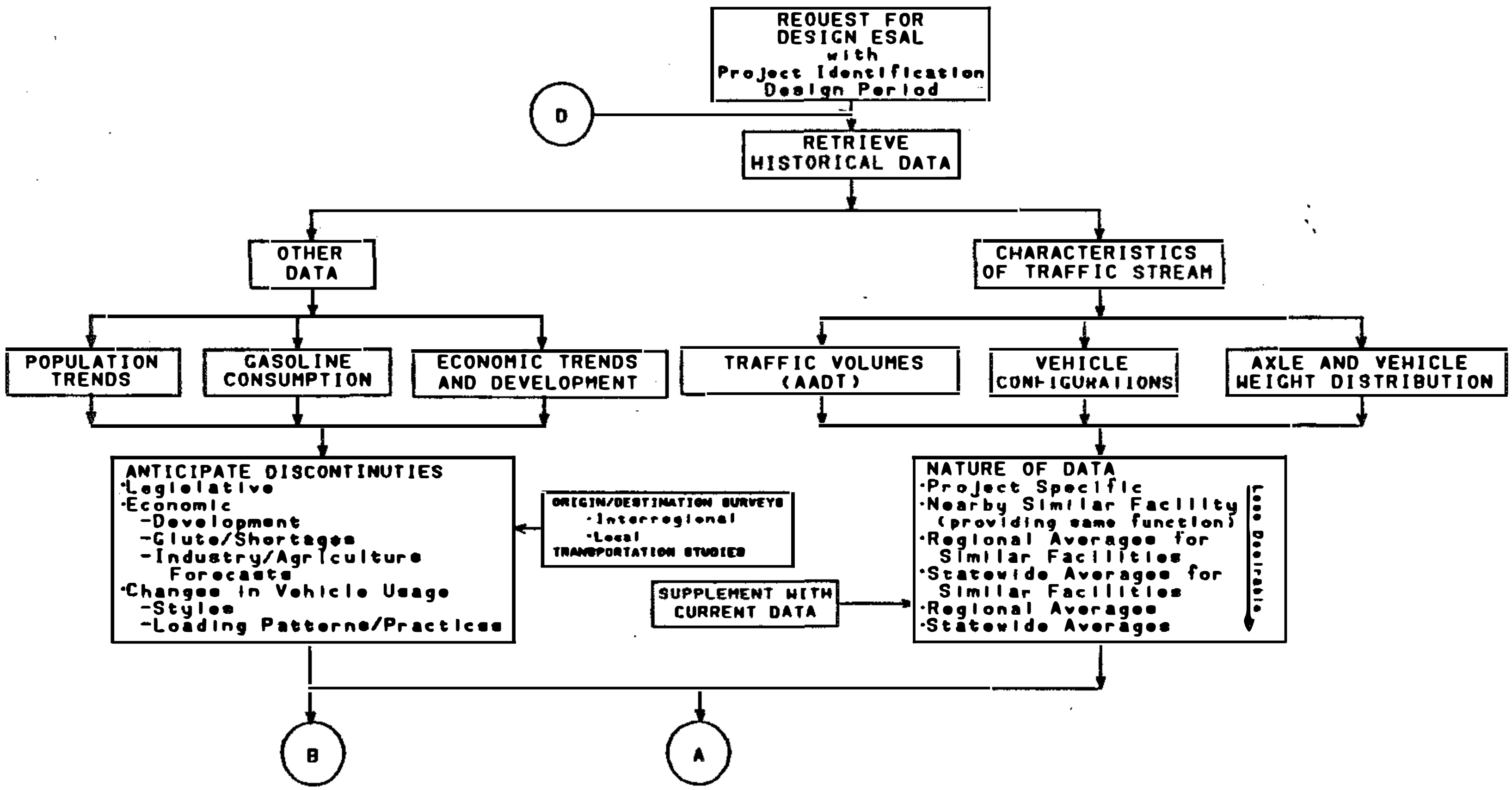


Figure 1. Flow chart for a generalized traffic forecasting procedure.

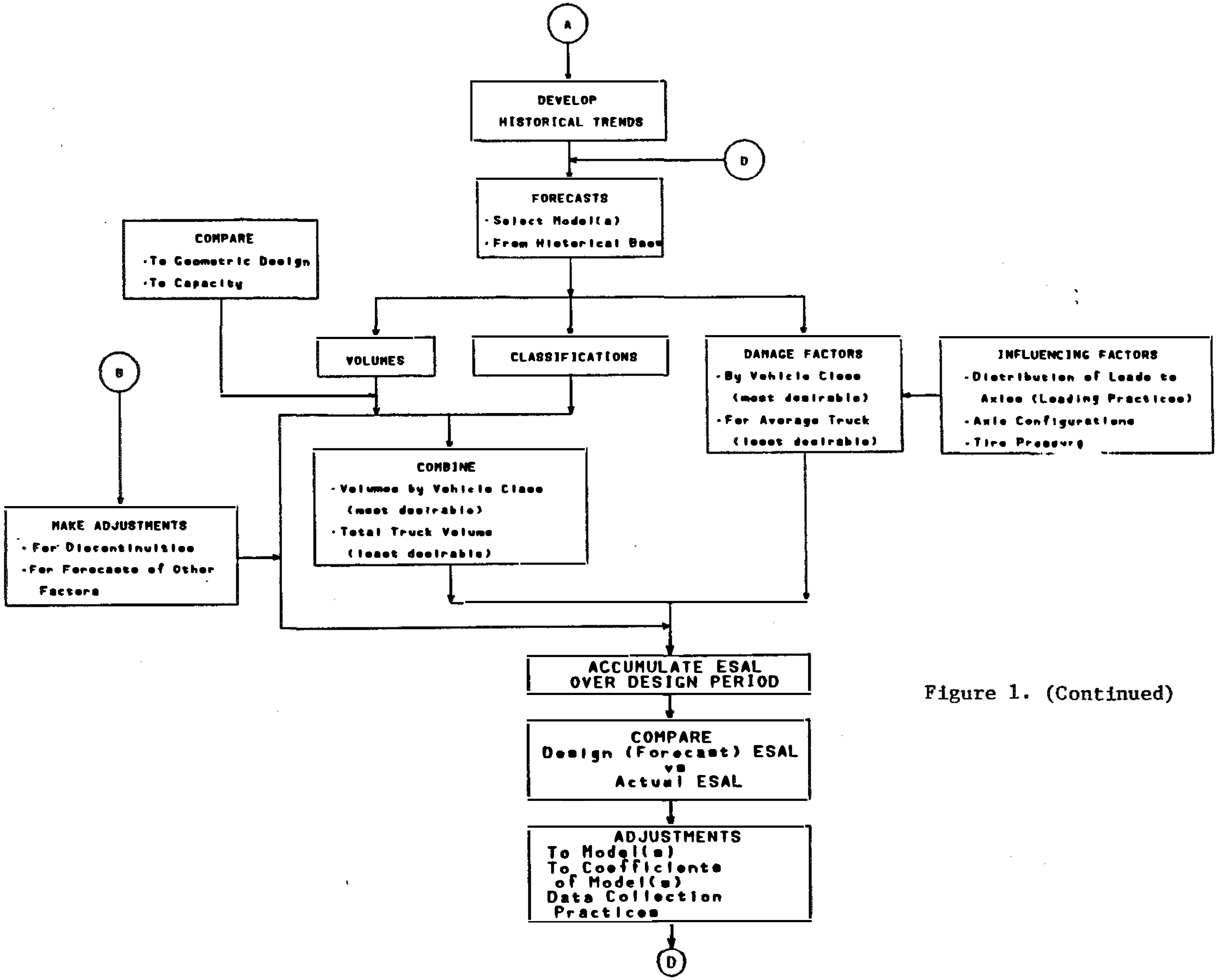


Figure 1. (Continued)

INTRODUCTION

In 1899, President McKinley was encouraged by his Commissioner of the Patent and Trademark Office, Charles H. Duell, to close down the agency. His reasoning was stated simply: "Everything that can be invented has been invented." Some 86 years later, almost four million patents have been issued in this country, indicating the difficulty and lack of imagination as it relates to making forecasts. The effect of technical change on the growth of the economy has been persistently underestimated. There have been major failures to anticipate discontinuities in growth that result from technological changes. Since the beginning of the 19th century, economists often have expressed a pessimism about the future. In dealing with attributes related to the lifestyles and patterns of behavior of people that also are impacted by technological changes, it is difficult to prove anything about the future by looking at the past. It is impossible to know whether society is poised at some genuine discontinuity in history.

In the same manner, the planner, traffic engineer, and highway designer also have difficulties in projecting the characteristics and magnitude of the traffic stream for which he is providing a future highway system. Inasmuch as the basic function of the highway system is to provide for the movement of people and/or goods from one point to another, traffic forecasts have a significant impact upon the design and ultimate service the system provides to the citizens of the country. The designer attempts to provide for the geometrics of the highway to satisfy future capacity needs over some design life. The designer also must provide a pavement system that will support this traffic throughout the design period. Even though the individual designer responsible for the geometrics of the highway system may often be a different individual than the one responsible for the design of the thickness of the pavement, both designers should make use of the same basic traffic data and projections. Inconsistencies sometimes are introduced when these two groups base their final designs upon different traffic trends and forecasts.

The predictor of traffic characteristics on highways in this country has a difficult task. The individual forecaster, for example, has problems predicting his own personal travel patterns over the next few days, much less predicting travel patterns of the citizens that might use the highway system over design periods extending as much as 20 years or more into the future. The traffic engineer, however, has not yet reached the point that Charles Duell had in thinking that all of the traffic that is going to be generated has already been generated.

STUDY BACKGROUND

In recent years, the allowable sizes and weights of heavy trucks on the interstate system and other designated routes have increased significantly. Although substantial economic benefits to both the trucking industry and the U. S. economy have resulted from the legislative and administrative actions that mandated these changes, their costs also have been substantial. As a result, there has been an increased awareness of and interest in improved monitoring of actual truck loadings and improved traffic forecasting procedures for pavement management and design.

The need for improved traffic estimation procedures has been emphasized by several studies that have found that previously available data were not adequate. This deficiency has been attributed to limited amounts of data not representative of the actual traffic conditions because of overloaded trucks avoiding weighing scales and insufficient traffic sampling programs. In addition, previous forecasting procedures did not reflect the increases in legal load limits, the significant increase in number of heavy trucks, or the shift toward larger vehicle types that has occurred in recent years.

Improved estimates of current traffic loadings based on larger samples of much higher quality data would allow development of procedures for making improved estimates of historical traffic loadings and better forecasts of traffic loadings during the design period. The emergence of automatic vehicle classification equipment, permanent and portable weigh-in-motion (WIM) systems, and the application of microprocessors and microcomputers to these data acquisition functions now offer tools that may be effectively used in meeting these needs.

The development of this document has been carried out using the mechanism of a multi-state study. This approach has been useful in the past in developing practical procedures that can be quickly implemented in the States. The sharing of experiences usually results in an improved technical approach that avoids some of the problems encountered when a single State addresses a problem of this magnitude. Approximately 20 States expressed interest in participating in this study. Four States (Florida, Kentucky, Oregon, and Washington) were finally selected and agreed to perform the work.

STUDY OBJECTIVE

The objective of this study was to have several States actively studying the topic of traffic forecasting for pavement design and analysis jointly evaluate their existing procedures, recommend potential improvements to their procedures, and share these ideas with others. This process and its results have been coordinated with other related ongoing activities.

SCOPE OF WORK

During the course of the study, it was decided that the product of this task was to be a document that discusses aspects of traffic monitoring and forecasting procedures, including available and anticipated options for each step of the traffic forecasting process. This resulting document has been prepared by the participants.

PAVEMENT THICKNESS DESIGN

Historical Background

One of the first published methods for the structural design of highway pavements was the Massachusetts Rule and was presented in the eighth annual report of the Massachusetts Highway Commission in 1901. The essence of that procedure was a rather intuitive assumption concerning the distribution of vertical pressures beneath a loaded area. This required the selection of a design load that, since failure was assumed to be catastrophic and not cumulative, could be taken as the largest load that could reasonably be anticipated during the design life of the pavement. The prediction of such a design load was, in itself, a rather formidable task.

As early as the late 1930's, pavement designers began to appreciate that pavements could become distressed not only catastrophically as a result of the single application of a very large load but also cumulatively as a result of the repetitive application of loads of lesser magnitudes. In 1938, Bradbury hypothesized that portland cement concrete pavements could fail as a result of fatigue. The primary type of failure in flexible pavements was identified by Porter in 1942 as resulting from progressive plastic deformation of the foundation as large repetitions of load were accumulated. Soon thereafter, Hveem and Carmany postulated that repetitive load applications on flexible pavements could cause fatigue-associated distress in the asphalt-bound layers in addition to distress associated with the accumulation of irrecoverable plastic deformations. To apply this knowledge in any gainful way required that the cumulative destructive effects of the diverse spectrum of traffic loads be evaluated and, for design purposes, predicted. This greatly magnified the problems associated with traffic predictions, which heretofore had concentrated on the design-load concept.

A first indication as to how the destructive effects of various repetitive traffic loads might be reduced to a single measure was that made by Bradbury. He introduced the problem of flexural-fatigue failure in portland cement concrete pavements and proposed a design procedure based on the linear summation of cycle ratios concept (commonly known as "Miner's hypothesis" in the study of metals) whereby estimates could be made of the age of a pavement at which fatigue cracking would be initiated.

One of the first investigators to be significantly influenced by Bradbury's work was Grumm, who, in the early 1940's, sought a means whereby the destructive influence of the magnitude and number of applications of any particular wheel load might be expressed in terms of an equivalent number of applications of a reference wheel load. A reference wheel load of 5,000 pounds was selected since it was felt that high-type pavements could withstand an almost unlimited number of applications of wheel loads of smaller magnitudes without exhibiting distress. Grumm introduced the concept of equivalent wheel load (EWL) or load equivalency factor, defined as the number of applications of the standard 5,000-pound wheel load equivalent in destructive effect to one application of a wheel load of different magnitude. These factors were represented by a simple geometric progression for the stipulated wheel loads.

Using these equivalency factors and traffic estimates that yielded the total number of applications of each wheel load anticipated during a given design period, Grumm further suggested that one could estimate by summation the total equivalent number of applications of the standard 5,000-pound wheel load (the total number of EWL's) anticipated during the design period. Thus, if two different traffic estimates yielded identical estimates of total EWL's, the composite destructive effects of the traffic in the two circumstances were assumed to be the same. California investigators were the first to incorporate this means for traffic evaluation into empirical methods for flexible pavement design. This concept has continued to the present, though in a somewhat different form.

A nationwide resurgence of interest in the load equivalence concept followed analyses of the AASHO Road Test results. These analyses focused attention on the validity of expressing the destructive effects of traffic in terms of equivalent loadings, at least insofar as empirical design procedures are concerned. The reference or base load, the method for deriving the equivalency factors, the factors themselves, and some of the methods of analysis were modified to reflect the vast amounts of data from the road test and improved capabilities for analysis. However, the equivalency concept was verified and retained.

Equivalency Factors

All studies that are made to evaluate the effects of truck sizes, weights, and axle configurations on pavement deterioration rates, cost responsibilities, benefits and costs of changing legal axleload regulations, funding needs projections, and operational planning have a common point of beginning in the concept of an equivalent single axleload (ESAL). The definition most often used for ESAL was derived from statistical analyses of axle configurations: a single 18,000-pound (18-kip) axleload and a tandem 32,000-pound (32-kip) axleload. The maximum axle loadings used at the AASHO Road Test were 40 and 48 kips, respectively, at tire inflation pressures generally less than 90 pounds per square inch. As loads have increased and axle configurations have changed in recent years, it has been common to extrapolate the original AASHO Road Test results beyond the range where they are valid. There is, therefore, a need to determine from pavment damage data what the relevant load equivalency factors are for heavier vehicle loadings and higher tire pressures than were used at the AASHO Road Test. These data are obtained from the truck weighing element of the suggested FHWA minimum traffic monitoring program.

Fundamentally, load equivalence first requires the definition of a particular type of damage. In general, damage is a normalized distress that starts at zero (0) and reaches an unacceptable condition at one (1). With the AASHO Road Test, damage was defined in terms of a loss of serviceability index as follows:

$$g = (P_i - P)/(P_i - P_t) \quad (1)$$

in which g = the "damage,"

P_i = the initial serviceability index,

P = the present serviceability index, and

P_t = the "terminal" or unacceptable level of serviceability index.

A load equivalency factor is defined as the ratio of the number of passes of a standard load to cause a specified level of damage divided by the number of passes of some other load to cause the same level of damage. The load equivalency factor may be determined from empirical data such as those obtained at the AASHO Road Test or from calculations, as was done with flexible pavements in the recent Federal Cost Allocation Study. In that study, it was shown that damage may be defined for each type of distress, and load equivalency factor tables were generated for fatigue cracking and rutting as well as for loss of serviceability index. The results of those calculations, which were made with the FHWA's VESYS-IIIB computer program, showed that load equivalency factors depend upon the load level, the thickness and modulus of each layer in the pavement, and the stiffness of the subgrade. The latter was a new discovery that, of course, could not have been made at the AASHO Road Test since there was only one subgrade present on that site. This finding alone, which means that load equivalence factors in arid regions are different from those in wet regions, makes it imperative these newly developed capabilities to refine, update, and expand the range of load equivalency factors be used in truck and pavement studies.

Because tire pressures on trucks at the AASHO Road Test were less than 90 psi, recent increases in tire pressure cause each of the vehicles to have larger equivalencies than those included in the AASHTO design guide. It is imperative that these increases in tire pressures be taken into account when selecting the appropriate equivalency values for use in calculating the total load experience for a specific project.

Predictive Models

Pavement structures are generally designed to provide satisfactory service for a certain number of years. Initially, the pavement will have a high serviceability and then, as traffic usage increases on the pavement, serviceability will decrease. For design purposes, it is assumed that a decrease in pavement serviceability is proportional to an increase in number of repetitions of equivalent axleloads. When a pavement is designed to reach a designated level of serviceability by the end of a number of years of service, the designer determines pavement layer thicknesses that will accommodate the number of repetitions of equivalent axleloads expected to be applied to that pavement during its service life.

The 18,000-pound single axle is now widely accepted as the reference axle. Other magnitudes of axleloads are related to the 18,000-pound axle by equivalency factors. Accurate estimations of future traffic volumes and their axleloads are necessary ingredients in the design process in order that the pavement, as designed, will provide service at the designated level for the desired time.

In general, models of any type are described in terms of their dependent variable(s), the set of independent variables, and the relationships that exist between the dependent and independent variables. In developing the ESAL model, attention is first directed to the selection of appropriate dependent variables. While daily or annual ESAL's could have been modeled directly, one major advantage could be realized by modeling a set of more fundamental traffic parameters from which ESAL's could then be derived, namely, that of obtaining maximum use of available data.

If a model were to be developed for the direct estimation of ESAL's, only data taken at truck weigh stations could be used for its calibration -- it is only at these locations that all the necessary information for calculating ESAL's is available. Useless to the model calibration effort would be the very extensive files of volume and classification data obtained at other locations. However, if models were independently developed for the more fundamental traffic parameters, all available volume data (for modeling average annual daily traffic (AADT)), all available classification data (for modeling truck traffic), all weight data (for modeling the damage effects of axleloads), as well as other data related to economic growth could be used.

The decision is clear: models should be developed for fundamental traffic parameters, and the ESAL estimate would then be obtained by calculation.

Traffic volume, composition, and weight -- and, hence, the parameters used for computing equivalent axleloads -- vary over an extremely wide range from one location to another. Such variations are considered in the modeling process by selecting a set of independent variables, termed local conditions (such as population trends, vehicle registrations, economic growth, etc.), that are most highly correlated with the dependent variables of interest and that can be evaluated both for model-development and for forecasting purposes.

Conceptually, another aspect of model development is the form of the relationships between the dependent and independent variables. There is, of course, no theoretical basis for developing such relationships; furthermore, a literature review failed to identify any empirical relationship that seemed widely valid. A number of models have been and are being used in various agencies to describe the desired relationships. These models have included linear regressions, simple- or compound-interest equations, and cross-tabulation models wherein no specific mathematical relationships are needed and full interaction effects among the independent variables may be treated.

TRAFFIC AND TRAFFIC-RELATED PARAMETERS

Even though the future may not be predicted with complete confidence on the basis of past experience, the basic data available to the highway engineer for forecasting future traffic characteristics are the raw data of historical experiences. The basic data most often available and used in various ways include traffic volumes, the distributions of these volumes among various vehicle styles, and distributions of the weights of the vehicles in the traffic stream among axles and axle configurations. Additional information concerning directional splits and lane distributions of the traffic stream also may be important and of value in selecting the ultimate designs. Other characteristics of the traffic stream recently recognized as significant, particularly with regard to pavement thickness design, are the increase in tire inflation and contact pressures and the unequal distribution of loads among the axles of tandem or tridem configurations. Recent research using finite element analyses indicate tire contact pressures may not be uniform, as has been assumed. Effects of nonuniform contact pressures on fatigue life have not yet been quantified.

To the extent historical traffic characteristics are going to be used to assist in making predictions concerning future traffic characteristics over the design period for a highway segment, it is necessary to know the sampling plans and quality control measures that were used to obtain the historical data. It is well established and understandable, because of the size of the traffic stream and of the highway system, that it would be impossible to obtain a 100-percent sample (i.e., to collect data at all highway locations at all times) of the traffic stream on the entire highway system. Even if such data could be obtained, the masses of data would be so great that the meaningful processing and manipulation of that data would not be possible. In using sampling schemes, it is necessary to determine criteria by which sample locations were selected, frequency of sample collection, and time periods for data collection. Consideration of sampling sites, frequency, and time intervals is often neglected but is important in obtaining data that are representative of the traffic stream with the desired degree of reasonableness and reliability.

In addition to looking at the historical trends of the more basic raw traffic data, such as traffic volumes, vehicle classifications, axleload distributions, etc., other variables related to the traffic stream also may have significant influence upon the characteristics of future traffic streams. The impact of statutes establishing legal load limits and limitations on vehicle sizes is often overlooked, particularly by the legislative body enacting the statute. Characteristics of the traffic stream, of course, are related to the function served by the particular section of highway under consideration. Commodities or goods normally transported over the segment of highway are important. Characteristics of the traffic stream often are related to such commodities as coal, grain, lumber, or ores of various kinds, as well as to the function of the highway segment, such as service to recreational or residential travel. The availability of alternate routes also may have an impact on the characteristics of the traffic stream, particularly as one or more alternate routes approach a limiting capacity. The highway engineer must be concerned with other modes of transportation inasmuch as alternate modes of travel may influence the quantities and characteristics of commodities moved over the highway system as well as the number of people using the highway system for their transportation purposes.

In making predictions about future traffic stream characteristics, it is necessary to decide how to express the values of the attributes used in the models. Should, for example, statewide average values for various traffic attributes be used as opposed to averages for certain geographic or economic regions? In dealing with a site-specific situation, it also is possible to utilize averages obtained from data from similar locations. The most desirable situation, however, is to use data related to the specific highway segment under consideration.

Other information that may be of value to the traffic forecaster include such data as vehicle registrations, gasoline consumption, and population trends. Even though these data do not deal directly with traffic stream characteristics for site-specific situations, they may be useful in providing information concerning overall trends of economic growth as well as trends in the utilization in general of the highway system.

The typical approach to forecasting traffic stream characteristics for highway design purposes has been to develop algorithms and models that will utilize historical raw traffic data to characterize future traffic streams. In spite of problems associated with proving the future with the past, it is suggested that the use of historical data is still one of the most valuable tools available to the highway designer. Models based upon regression analyses of historical trends are often used. A review of these trends for a number of types of highways over large geographic areas may suggest the applicability in certain situations of simple- or compound-interest equations or straight-line projections. Transportation studies that attempt to assign traffic on the basis of the desire of the public to travel from various origins to various destinations, changes in land use patterns, and other factors may be used to model traffic streams.

Several algorithms or models may be utilized by a single agency to make projections concerning traffic characteristics for particular highway segments. Regardless of which model or algorithm is utilized for a specific projection, that model or algorithm is valid only to the extent major discontinuities are not anticipated during the design period. To the extent such discontinuities are not anticipated, the use of past trends may be indicative of future utilization. It is the inability to foresee these major discontinuities that causes problems in predicting future traffic demands. Events that may introduce discontinuities and alter future traffic trends include changes in legal load limits and limiting dimensions of vehicles, changes in commodities transported and function of the highway segment (often related to major changes in land use), fuel shortages or gluts and the associated changes in fuel costs, changes in utilization of various styles of vehicles (particularly trucks) and the introduction of new vehicle styles, and the introduction into the overall transportation system of alternative modes of transport. The length of time over which these discontinuities occur may be rather short or may extend over a period of five to ten years. Some of the changes in the traffic stream associated with these discontinuities are more gradual than others.

TRAFFIC PROJECTION FACTORS

Characteristics of the traffic stream that are predicted for the expected life of the facility are used in well established procedures to design the geometric elements of a highway segment as well as the thicknesses of the pavements. In many agencies, the design of the geometrics and the pavement thicknesses is often done by different subunits. The designs, however, should be based upon the same basic raw traffic data as well as the same projections for the design period. Inconsistencies introduced may be significant if different approaches are used to process traffic data for geometric design and for pavement thickness design. The highway administrator is in a difficult position when it is necessary to explain why the two basic designs of a highway segment were based upon different projections of the characteristics of the traffic stream.

Even though it is recognized that the traffic stream is significant both to geometric design and pavement design, the concerns of this report are basically related to the use of traffic forecasting for the purpose of pavement thickness design. The ultimate objective of forecasting is to obtain reliable design parameters. It is desired that these projections be as reliable and realistic as possible.

Axleload Distributions

The number of 18-kip ESAL's is a function of not only the appropriate equivalence factors but also of the number of axleloads of each configuration and weight that travel over a road. Therefore, the procedures used to estimate the number of each type of vehicle as well as the axleload distribution for that type of vehicle must be accurate in order to have acceptable estimates of equivalent 18-kip ESAL's.

Number of Vehicles

There are, however, several factors not usually considered that could significantly affect the accuracy of total 18-kip ESAL estimates. The first factor is the effect of the methodology used to predict the number of axles used in the axle distribution charts. Many states use the procedure developed at the AASHO Road Test and included in the 1972 AASHTO Interim Guide for Pavement Structures. Research has shown there is a significant difference between the total ESAL's predicted using the AASHTO procedure and ESAL's calculated by predicting the number of individual truck units and multiplying that by an appropriate equivalency factor. The U.S. Forest Service uses a procedure in which each truck type has an associated truck equivalency factor. Kentucky also has developed adjustments to equivalency factors to account for increased tire pressures and unequal distribution of loads among axles in a configuration.

Directional Distribution Factors

Another very important factor is a directional distribution factor associated with loaded trucks. This factor is especially important when agricultural or mineral products are being hauled from a production area to a distribution or consumption point. Consideration of this loaded truck directional distribution factor would be especially important for the agricultural areas of each State and for high growth areas or in areas surrounding rock quarries or mines. The use of traditional traffic vehicle directional distribution values may be inadequate to reflect this type of truck movement that makes the total 18-kip ESAL's highly directional.

Lane Distribution Factors

A lane distribution factor that reflects the truck lane occupancy must be included. This lane distribution factor will vary with the time of day, total volume of traffic, pavement surface condition of the lanes, geometric alignment, number and types of lanes, composition of traffic, and type of commodity being hauled.

DESIGN INPUTS

PARAMETERS

The design of highway pavements is based upon several primary factors, one of which is traffic. Several parameters of traffic statistics important to pavement design are listed in Table 1. Other factors are listed that relate to and act upon these traffic parameters.

The data available to the design engineer are generally not that which are most desirable. Most data bases are deficient in some manner. But to obtain potential solutions to design tasks, the best data available should be used. The most site-specific data that can be obtained should be utilized; and the engineer should know the source of the data so as to assess their reliability and applicability to the task at hand.

Vehicle Loadings Factors

Pavement structures are designed to carry the vehicles that travel the highways. However, all types of vehicles do not affect the pavement structure in the same manner. The weight of each vehicle has been determined to be the main damage factor for the pavement. The configuration of the load distribution (i.e., number of axles, number of tires, etc.) is very important in determining a vehicle loading factor. The standard unit of measurement for load distribution is 18,000 pounds per axle, or 18-kip ESAL. The effects of all types of vehicles are related to this unit of measurement. Damage factors were developed that equate a wide range of axle groupings and weights and tire pressures to 18-kip ESAL's. Load equivalency factors are calculated from the accumulation of vehicle weights and number of axles for each vehicle type. Not only are the number of trucks increasing on the highways, but the average load that each truck carries has been increasing at an alarming rate (see Figure 2).

Each State highway agency is responsible for calculating these 18-kip ESAL factors. Factors should be developed for various situations and conditions, such as vehicle styles, commodities being hauled, and

Table 1. Pavement design input data

Traffic Parameters
Vehicle Loading Factors
Annual Average Daily Traffic Volumes (AADT)
Vehicle Classifications, Types of Vehicles
Lane Distributions
Directional Distributions
Origin-Destination Studies
Vehicle Registrations
Network Assignments
Seasonal Variations
Other Parameters
Gasoline Consumption
Population Growth
Economic Growth

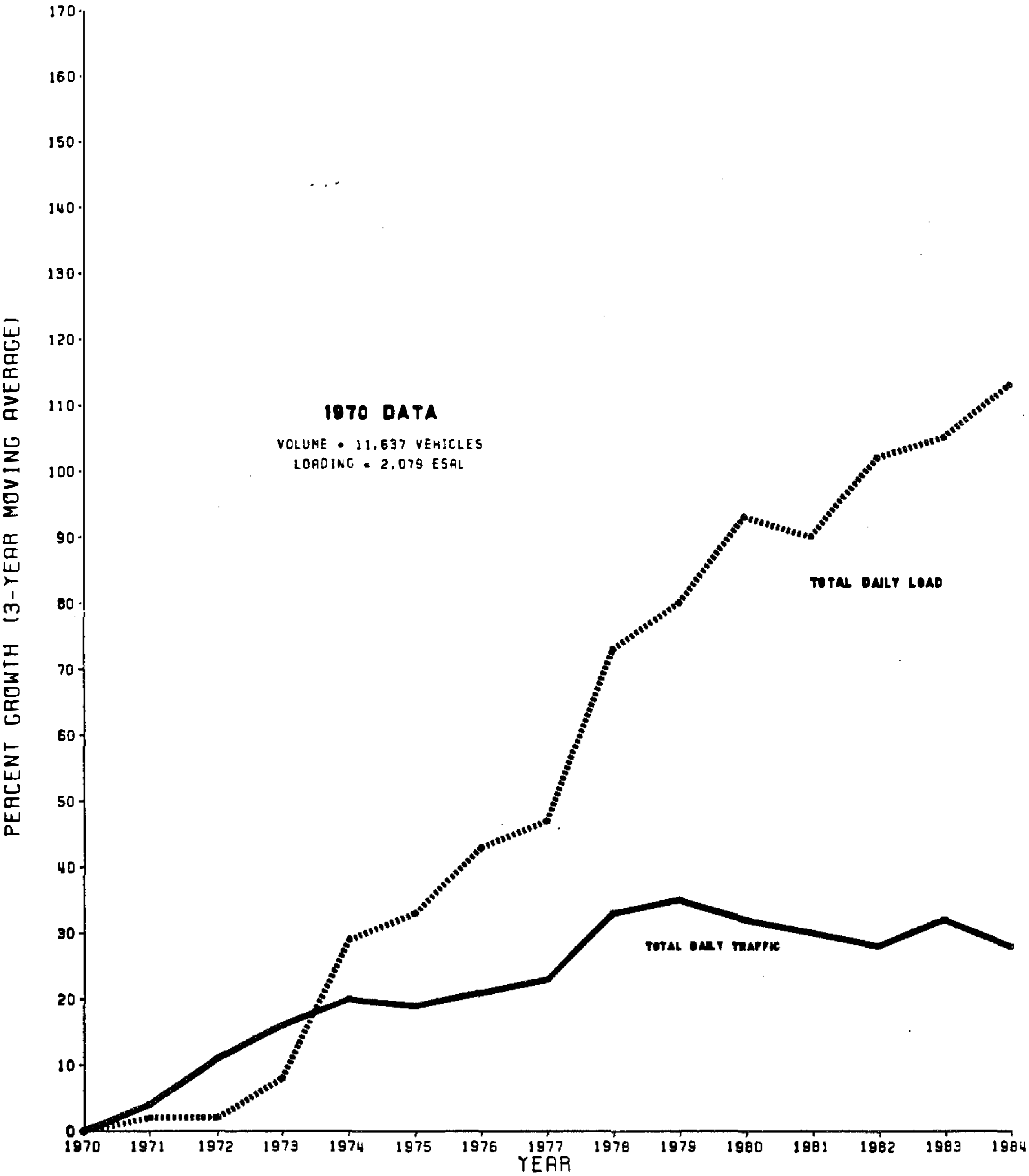


Figure 2. Comparison of growth in volumes and loadings on the rural interstate system at truck weight sites.

different classes of highways (interstate, primary, etc.). Errors can be introduced when forecasting traffic if factors developed for one class of highway are used for another class of highway that has a different loading distribution and loading factors. High truck tire pressures as well as different axle/load configurations could have a major effect on the damage factors. Studies should be conducted to determine these effects. Kentucky, for example, has attempted to define some of these effects.

Annual Average Daily Traffic

Pavement designs are based on a number of expected repetitions of the standard 18-kip ESAL. Existing AADT, along with other input data, can be used to calculate truck volumes and the number of expected loadings. The AADT is the vehicular volume that can be anticipated on the average on any and every day of the year. The volume count on any given day is not likely to be the same as the AADT. Such daily counts must be adjusted for daily and seasonal effects to obtain the AADT.

Traffic volumes also are needed for geometric design and capacity determinations. These determinations are beyond the scope of this document. However, as the AADT is forecast for a future date, the predicted volumes should be closely checked to insure that geometric and capacity constraints are not exceeded. A typical error would involve forecasting AADT for a two-lane facility for 20 years and have a future condition where the capacity for a two-lane facility is exceeded.

Some agencies work with Annual Average Daily Truck Traffic (AADTT) volumes only since the ESAL factors for automobiles and light trucks (pickups) are very small in comparison with the ESAL factors for heavy trucks. However, analyses of Kentucky traffic data indicate the equivalency factor assigned to automobiles should be five to ten times greater than that assigned by the AASHTO method.

Vehicle Classifications

Current truck volume data should be classified as to the types of vehicle (i.e., three-axle, four-axle, five-axle, etc.) (see Table 2).

Table 2. Vehicle classifications

1. Motorcycles (optional)
2. Passenger Cars (with and without trailers)
3. Other Two-Axle, Four-Tire Single-Unit Vehicles (pickups, vans, and motor homes)
4. Buses
5. Two-Axle, Six-Tire, Single-Unit Trucks
6. Three-Axle Single-Unit Trucks
7. Four-or-More Axle Single-Unit Trucks
8. Four-or-Less Axle Single-Trailer Trucks
9. Five-Axle Single-Trailer Trucks
10. Six-or-More Axle Single-Trailer Trucks
11. Five-or-Less Axle Multi-Trailer Trucks
12. Six-Axle Multi-Trailer Trucks
13. Seven-or-More Axle Multi-Trailer Trucks

Each vehicle class has a specific ESAL factor. Project-specific data should include the actual numbers of vehicles of each type or style (adjusted to an annual basis (AADT)) or the vehicle classification percentages. If actual classification data are not available, an estimate of the types of vehicles should be made.

Lane Distributions

On two-lane highways, 100 percent of the directional truck traffic travels in each lane. However, on multilane highways, the lane distribution of truck traffic will vary. The lane distribution for four-lane highways is normally 80 - 90 percent in the outside lane (design lane) and 10 - 20 percent in the inside lane. For six-lane highways, the lane distribution may be 65 percent in the outside lane, 25 percent in the middle lane, and 10 percent in the inside lane. As traffic volumes increase, these lane distributions become more uniform. Project specific data should be obtained to correctly distribute the truck traffic among lanes.

Continuous traffic monitoring sites may provide lane distribution factors. Typically, most engineers use the lane factors recommended on page II-9 of the 1986 AASHTO Guide for Design of Pavement Structures.

Directional Distributions

The usual procedure for determining directional traffic is to assume a 50/50 split. However, traffic on some highways have a different directional distribution, e.g., 60 percent northbound, 40 percent southbound. In some cases, loaded trucks travel one direction while empty trucks travel in the opposite direction. For example, in Oregon, loaded log trucks (five-axle) travel from the forests to the mills while empty log trucks (three-axle) return to the forests. A directional traffic split may have a definite effect on the accumulated ESAL's in these cases.

Origin-Destination Studies

Origin-destination studies compose a special category of transportation study that relates travel demand to characteristics of an area, such as population and employment. They allow forecasts of future travel based on other predictions of population, employment, and other variables, and are particularly useful for predicting travel that would be induced to use a facility that is either being built or significantly upgraded. Such studies also allow the examination of the effects of population growth on expected traffic levels when that growth does not immediately border on the project corridor.

Origin-destination studies are important in determining existing traffic movements. The identification of traffic patterns, and in particular truck traffic patterns, are useful in forecasting growth rates. These types of studies, for pavement design, should be focused on travel patterns of trucks to provide data for forecasting truck volumes.

The typical origin-destination study generally is limited to a small geographical area. For certain highways, those serving termini separated by long distances, a new approach to origin-destination studies might be in order. It may be important to the traffic forecasting process to have knowledge of traffic demands of long-distance travelers. These long-range studies as well as the more geographically limited origin-destination studies should be useful to verify traffic assignments made by other specialized transportation and urban studies.

Vehicle Registrations

In some counties and local areas, vehicle registrations can provide a means of classifying vehicle types. However, with the case of "through" highways, vehicle registrations will not reflect the actual types of vehicles on the highways. Historic vehicle registration data may be used to show growth rates, but only for the immediate local area. Growth rates estimated in this manner may be misleading.

Network Assignments

Network assignments, in conjunction with Origin-Destination studies, provide information on traffic route requirements. Metropolitan transportation agencies plan for future traffic needs on a network level. Truck traffic needs may be addressed in the same manner.

Seasonal Variations

Truck traffic may be subjected to seasonal variations such as farm trucks used for the harvest season. These variations are important to consider, especially if they occur at the same time that a subgrade stability problem occurs (for example, freeze-thaw). Other traffic variations, such as weekday versus weekend and night versus day are also important for geometric considerations.

Gasoline Consumption

As with vehicle registrations, gasoline consumption data are an indication only of local growth rates. If no other data are available, some service stations and/or truck service stations located on interstate highway interchanges may serve as an indicator of interstate vehicle fuel consumption. However, this type of data should be considered carefully and may be misleading.

Population Growth

Population growth rates are used to establish traffic growth rates and are good indicators for local conditions. The traffic forecaster should be cautioned against totally relying upon these rates as representing truck growth rates. The population growth rate, total traffic growth rate, and truck traffic growth rate often may be completely different.

Economic Growth

Economic growth rates are a good indicator of truck traffic growth rates. The growth or decline in truck traffic parallels the economic growth/decline. In localized areas, the economic growth of an industry may represent the truck traffic growth. "Through" truck traffic growth rates are dependent upon a regional, not local, economic growth rate. Studies should be conducted to establish the relationship between economic growth and truck traffic growth.

TIME FRAME FOR DATA

The above listed input data are valuable only for the time period the data represents. Extrapolations of data may be made to other time periods, but only with close scrutinization.

Historical Data

Truck loading history (accumulated ESAL's) has a great value when forecasting future loadings. As much historical data as can be assembled should be used. A minimum of 10 years is preferred. Irregularities in the loading history should be documented so future loading trends do not reflect these discontinuities.

Current Data

Data should be as current as possible. Some data, such as lane distributions, directional splits, etc., may be up to two to three years old as long as conditions have not changed significantly. Other data, such as vehicle classifications, ESAL equivalency factors, etc., should be obtained as recently as possible.

Forecast Data

Most pavement designs are prepared to accommodate a number of ESAL repetitions. These ESAL's are calculated based upon a design period, e.g., 10, 20, or 30 years. Therefore, the average daily truck traffic data (ADTT) are expanded or forecast for 10, 20, or 30 years. It should be noted that the longer the forecast period, the greater the possible error due to any assumptions in extrapolating existing data.

NON-TRAFFIC INPUTS

In new pavement design, soil characteristic information is a significant part of the input design data. In overlay design, the current condition of the existing pavement is a significant piece of information. Both of these pieces of information are routinely collected as part of the design process.

The experiences of some States indicate that another piece of information that should be included in overlay design is the past pavement history of that section of roadway. Most States now have in place or are implementing a pavement management system that could provide such inputs. Such systems have the ability to track the pavement performance of particular sections of road. Such histories provide valuable information that should be used to improve the design process for overlays.

Pavement histories indicate whether pavements reached the end of their design life before requiring significant rehabilitation or reconstruction. In those cases where pavements deteriorated before they were intended to, additional steps can be taken in subsequent overlay designs to ensure that the new pavement comes closer to meeting its design criteria. For example, if a roadway deteriorates in three years when it was designed to last seven years, some phenomenon may be at work that was not accounted for in the original design. Such phenomena might include the following:

- The soil is not as strong as test sites indicate.
- The freeze/thaw problem at that location is worse than expected.
- Higher or heavier truck volumes are occurring than accounted for in the design data.
- Tire contact pressures may be increasing more than anticipated.

In addition, many other causes for such deterioration could exist. The presence of information on previous performance can serve to point out highways on which such factors are operative. Subsequent pavement designs then may be adjusted to account for the additional deterioration occurring at those locations.

Pavement management systems also may point out where a pavement is in good condition beyond its expected life. Such information may be used in designing roads; it may allow a reduction in materials to be used for future work at those and other similar locations.

CURRENT TRAFFIC DATA

The initial starting point of any pavement design is the estimation of traffic that will use that facility during the first year after the project's completion. This estimate is often called the "base year" (for new construction) or "current year" (for overlay construction). For the purpose of this document, this initial year will be called "current" year, because of the preponderance of pavement rehabilitation work over new construction in most States.

DATA ITEMS

While considerable amounts of current data are required for geometric and pavement designs for any roadway design, three basic pieces of traffic information control the pavement thickness design (in conjunction with soil and/or existing pavement condition information) and much of the geometric design. These three data items include the following:

- Traffic volumes (AADT).
- Travel by vehicle type.
- Damage factors for each vehicle type.

AADT is used directly and with K (peak hour) and D (directional) factors in the capacity analysis for a new road. However, total volume has only a minor role in the determination of pavement thickness. More importantly to pavement design, AADT is used in conjunction with estimates of the percentages of traffic by vehicle types to estimate the amount of heavy vehicle travel on a road section.

The critical pavement design information is the <u>number</u> of heavy vehicles on an average day during the year. In some instances, this estimate is simply expressed as the expected number of trucks. Where more complete information exists and a more sophisticated analysis can be performed, this may be broken down into truck-style categories. Table 2 shows an example of some of these truck-style categories.

The truck volume information above combined with an average damage estimate per vehicle (usually expressed in ESAL's or EWL's) provides the pavement loading condition information used in the design process. The current year pavement loading estimates are expanded through the forecasting techniques described in the next section on Forecasting to result in the total expected loads throughout the design life of the project.

The importance of the current loadings is hard to overstate in that they serve as the basis for the forecast loadings. Essentially, the more accurate the volume (by truck style) and load equivalency factors, the more accurate the pavement design, and the more likely the pavement will perform as expected over its design life.

SOURCES OF INFORMATION

Current year traffic design data is normally obtained from one of three types of sources, depending on the nature of the project and the sophistication of the agency estimating the traffic. These three sources include the following:

- Actual traffic counts (including vehicle classification counts and weighings) from either historical files or special count sessions done specifically for that project.
- Special transportation studies.
- Computer network assignments.

Often data from two or all three of these sources are used for any one project.

Traffic Data

Actual traffic counts are the most commonly used source of current year data for overlay design and other reconstruction and maintenance functions of existing pavements. Actual counts also supply many of the defaults used in new pavement design. These counts include the following:

- Special traffic volume and/or vehicle classification counts done especially for the project.
- Previously existing, site-specific traffic information collected on a routine basis and maintained in databases of highway agencies.
- Regional, statewide, or other default or average data maintained by the State.

The ideal current data for a project would include 365 days of truck data providing the following information:

- The number of vehicles by vehicle type.
- The actual weight loadings experienced by the pavement.

Given the predicted improvements in low-cost WIM technology (i.e., complete sites for $5,000 to $10,000), it may actually be possible in the foreseeable future to collect this type of information on a project basis. To do this, however, projects will need to be identified sufficiently far in advance to allow for the installation of the data-collection equipment.

Given the ability to adjust for seasonal and other causes of variation in traffic data, it may be possible to collect this site-specific type of information for some specified length of time that is less than one year, and still estimate annual average loadings on each pavement section with an accuracy close to that of the ideal case described above. Equipment to perform short-duration counts of vehicle classifications and truck weights are already available on the commercial market. To make necessary seasonal adjustments, however, States will need to install a series of permanent traffic recorders that collect vehicle classification and/or truck weight data throughout the year. These stations would function similarly to existing automatic traffic recorders (ATR's), which are currently used to calculate seasonal adjustment factors for short-duration volume counts.

Highway agencies will have to continue estimating current loadings from available data until necessary technological advances are made, equipment costs decline, administrations come to accept the data collected as being in the interest of the departments, and design lead times can be adjusted to allow for site-specific data collection. Given most States' current traffic monitoring capabilities, a reasonable request for current traffic information for a project should include the following:

- Site-specific volume counts, adjusted for seasonality.
- Site-specific vehicle classification counts (adjusted for seasonality if possible).
- Available truck weight information (i.e., estimates of damage factors) by vehicle classification.

Equipment (and personnel) currently available can collect this information at a cost that is minimal when compared to the cost of the complete design and construction of pavement projects of any size larger than filling potholes. That is, most pavement projects cost in excess of $1,000,000. Compared to such costs, the need for $5,000 in data collection is quite small, and the impact such data can have on the design of the project is quite large (see Appendix C).

Where the above "goals" can not be met, the use of "averages" and "defaults" is necessary. Such averages are the norm for vehicle weights (statewide average ESAL's per vehicle type) and for seasonal correction factors. Unfortunately, these regional or statewide averages are used rather than to collect data at the project site. Better planning would permit the agencies to conduct the survey work to obtain data more directly applicable to the project under consideration. A complete understanding of the impacts of not collecting that information upon the levels of service provided by the design would, in most cases, illustrate the inadequacies of "average" or "typical" input parameters. This is particularly true for vehicle classification data.

It is not possible to provide a general recommendation for the use of particular types of averages over other types (e.g., statewide averages versus averages by functional class versus using a factor from a nearby road). Many variables exist in each State's data collection process, and one recommendation applicable to all cases is not advisable. However, it is desirable to use seasonally adjusted, site-specific data as a preference to defaults or averages whenever possible. When defaults or averages are necessary, the agency using them should make every effort to ensure that those defaults are reasonable for that project and that better data cannot be collected cost-effectively.

Special Transportation Studies

Special studies are most important for new highway projects, where no existing traffic exists. They are also appropriate for those projects that will likely result in significant increases in traffic as a result of the diversion of traffic from other routes or where related development along a highway corridor indicates the potential for increased highway demand.

Special studies include corridor analyses, inter-city travel studies, expected growth of population and employment and their consequential traffic generation along a route, and any of the various impact analyses that might accompany the construction of a new highway or major reconstruction of an existing facility. Such studies will produce estimates of traffic volume data similar to those described above. They should be used to supplement the collection of actual traffic data from existing roadways.

For major rehabilitation or reconstruction projects, a factor in selecting the course of action to follow is typically overlooked. Considering the negative impact of traffic control measures during reconstruction or rehabilitation on traffic flow patterns, the costs of delays and the increase in accidents may justify the expenditure of funds on a new parallel facility rather than on major rehabilitation or reconstruction.

Computer Network Analyses

Computer network analyses are primarily a subset of the special studies described above. They are used in urban areas where transportation modeling takes place on a routine basis as part of the ongoing urban planning process. However, some highway agencies maintain models that describe traffic volumes and travel demands throughout the State.

Computer network analyses have the advantage of being able to describe the demand for travel through particular corridors without regard for existing traffic conditions. This allows an agency to estimate immediate growth in traffic on a particular highway that results from improvements in vehicle carrying capacity. Finally, because highway assignments are done routinely as part of the normal planning process, such volume estimates usually are readily available for use in design procedures.

FORECASTING

While current data is important to the design of pavements, many of the largest errors in the design of pavement thicknesses come from the poor estimation of future traffic over the life of the highway. Commonly, analyses of prematurely failed pavements show that the road actually reached the number of loadings for which it was designed, but the loadings occurred in a much shorter time frame than anticipated by the pavement design.

It should be noted that the ultimate objective of such traffic forecasting is to provide an estimate of the loadings to which the pavement system is to be subjected, as a result of the vehicular traffic, during the design period. It is possible to make these projections of design loadings by expanding and forecasting the ESAL's directly. However, it is recommended that better estimates of the ESAL's may be obtained by disaggregating the traffic stream into the components contributing to ESAL computations and to make predictions or forecasts of the changes of those constituent parts. Because of the nature of historical data and the likely nature of future traffic data, it is felt a more reliable estimate of the design ESAL may be obtained by forecasting these component characteristics of the traffic stream.

Forecasting of traffic information and pavement loadings over the design life of a pavement is an inexact science. This report describes the important aspects of forecasting and provides a brief introduction to what is needed to perform reasonable forecasting of traffic.

The following sections will discuss the different approaches to forecasting traffic information that are available, the types of information that should be forecast, the problems that occur in forecasting pavement loadings, the need for periodic review of the factors being used to forecast traffic, and the periodic analysis of the reasons for forecasting successes and/or failures over time.

LEVELS OF SOPHISTICATION IN FORECASTING

Just as there are levels of sophistication in the data that are collected to estimate current year traffic, so are there levels of sophistication in the forecasting of traffic. As with collecting current year traffic data, being able to disaggregate the different components that make up pavement loadings (volumes, vehicle classifications, and damage factors) usually will allow a better estimate of future growth than if ESAL's as a lumped sum are simply expanded as a whole.

It is recommended that the design agency use disaggregated information (i.e., the number of trucks by vehicle type, not just a percentage of trucks) whenever that information exists and that efforts be made to collect and monitor the types of information that facilitate forecasting at these levels.

Five alternative levels of data forecasting have been identified for use in predicting traffic data for pavement design. These five levels are listed below in the reverse order of their desirability but in the order of probable ease of use:

- Level 1: Forecast simple expansion of current year ESAL's.
- Level 2: Forecast changes in AADT's, percent trucks, and average load equivalency factors per trucks.
- Level 3: Forecast volumes of cars, volumes of trucks, and average load equivalency factors per truck.
- Level 4: Forecast volumes of cars, percentage of trucks by vehicle class, and load equivalency factors per vehicle class.
- Level 5: Forecast volumes of cars, volumes of trucks by vehicle class, and average load equivalency factors per vehicle class.

Levels 2 and 3 above are quite similar as are Levels 4 and 5. To a certain extent, it does not matter whether volumes or percentages are forecast. The reason they are separated is that some States have found that their truck volumes do not fluctuate as significantly throughout the year as do their automobile volumes. Thus, these States find it more desirable to measure and predict average annual truck volumes rather than measure a percentage of trucks at a particular time of the year and then convert that estimate to an average annual figure for use in forecasting.

The primary advantage of disaggregation of traffic information is that it allows engineers to separately account for the different factors that cause pavement deterioration. This means that unexpected changes in one area of traffic data input will not invalidate the entire growth estimate.

For example, if it is known that a road will be affected by the opening of a new concrete plant during the design life of a pavement, the designer can estimate more easily the effect of truck traffic to that plant if the truck traffic estimate is disaggregated by truck type. In this case, only the estimate of three- or four-axle, single-unit trucks grows appreciably in number over the design life of the pavement. In addition, the average ESAL per three- or four-axle vehicle likely would change. This, too, could be simply accounted for, in that the resulting large number of concrete trucks might bring the average ESAL per vehicle for all three- or four-axle single units very close to that of a full concrete truck, which can be readily determined.

If the traffic design in the above example only included an estimate of the percentage of trucks, the analysis should include a review of how the expected increase in trucks would change both the total percentage of traffic comprising trucks and the total average ESAL for all trucks passing that point. While the new estimate of percentage of trucks might not be hard to estimate, determining a new and accurate mean ESAL per vehicle likely would be quite difficult. Such an estimate invariably would be harder to calculate and ultimately be less reliable than an estimate of ESAL per vehicle within a specified vehicle class.

Disaggregating vehicle classification estimates into a number of truck types also allows the explicit treatment of changing patterns of truck usage. In many areas of the country, while the total number of trucks using the highways has been increasing slowly over the years, the mix of trucks has changed significantly, with a considerable growth in large trucks and a decrease in smaller vehicles. When using a simple percentage of trucks and average ESAL per truck estimate, it is difficult to account for such changes without resorting to pure guess work. By assuming that average ESAL's per vehicle type may not change significantly (assuming weight laws remain fairly constant) and by merely increasing the percentage of large vehicles, this type of impact is readily accounted for in the design process.

Finally, disaggregating the traffic inputs forces the forecaster to acknowledge all of the different factors that can affect pavement loadings:

- Automobile volumes may change at a different rate than truck volumes.
- The percentage of trucks may remain constant, but the mix of trucks may change.
- The damage (fatigue) each truck type causes may change due to changing weight laws or continued developments in high-pressure tire technology.

<u>Forecasting Trucks Separately from Autos</u>

Truck volumes (or volumes of particular styles of trucks) may not grow at the same rate as passenger car volumes. A model that assumes the same rate of growth for automobiles and trucks may under- or over-estimate truck volumes. For example, on I 95 in Duval County, Florida, 21.3 percent trucks rural and 10.2 percent trucks urban both describe the same 4,000 trucks per day traveling that highway.

The fact that the forecaster makes a special attempt to estimate changing traffic levels for both autos and trucks is important. While auto volumes (including trucks expressed as passenger car equivalents) usually control the number of lanes a facility may have or the configuration those lanes may take, truck volumes control the thickness of a pavement.

By separating autos from trucks, the forecaster must make a specific effort to address the potential for truck usage to change at a different rate than automobile usage. In addition, this should cause the forecaster to consider the potential for changing vehicle mixes within the percentage of trucks.

Forecasting Changing Truck Mixes

By disaggregating the number of trucks into specific truck types, the forecaster avoids one of the most common mistakes in pavement design traffic data collection. In this error, a statewide or regional ESAL per truck is applied to a simple estimate of percentage of trucks. Unfortunately, ESAL values vary considerably between trucks of different classes, and if the truck mix of that site differs from the statewide or regional norm, the ESAL figure may be significantly in error. By disaggregating the truck mix, the forecaster can readily identify the types of trucks that currently are causing road damage (fatigue) and then determine how those truck volumes will change over time.

In some States, further singling out specific types of trucks for forecasting separately from autos and "standard" trucks is advisable. These special trucks usually contribute exceptionally high degrees of pavement fatigue and include the following:

- Trucks hauling construction materials (brick, aggregate, etc.).
- Ore (including coal) trucks.
- Grain trucks.
- Log trucks.
- Concrete transit-mix trucks.
- Garbage trucks.
- Any other type of truck considered "special" by a particular State.

These vehicles are separated from "standard" trucks for much the same reason it is recommended the separation of trucks from automobiles;

i.e., they contribute so much potential for pavement damage that they warrant being considered separately from the lumped data process.

When using the more sophisticated forecasting strategies described above (Levels 4 and 5), these special trucks would constitute another vehicle category. For the less sophisticated analyses, these truck types would be an additional step in the forecasting process.

<u>Load Equivalency Factors</u>

Historically, the average load equivalency factor per vehicle or vehicle type has changed over time. There is a distinct possibility that this trend will continue.

Load equivalency factors are a function of the weight being applied by any axle or group of axles (i.e., tandems or tridems) and the surface area over which that weight is being applied. Consequently, a weight applied by a single axle will have a higher load equivalency factor than that same weight applied by a tandem axle. Several studies indicate that changes occurring in the truck fleet currently on the highways are causing changes to the load equivalency factor that each vehicle of a particular type and weight will cause to the pavement.

Three major forces are currently causing increases in the ESAL per vehicle of a particular type, and only one of these forces is regularly monitored as part of the normal truck weight data collection and W4 table generation process of most States. These factors include the following:

- Vehicle loads.
- Truck tire pressures.
- Use of single tire axles (as opposed to the "standard" dual tire for trailers and rear axles.)

The standard truck weight monitoring program, if properly designed and executed, will account for increasing vehicle and axleloads as they occur. The conversion of these figures into ESAL's also should be easily accomplished, provided each agency continually updates the ESAL tables it uses for pavement design. However, the other two factors, tire pressure and axle configuration, give significant cause for alarm, because no data collection program exists to routinely monitor these changes or directly account for their effects on ESAL's for those specified axle loads.

Both the increasing tire pressures found on many trucks and the switch to fewer tires per axle are causing existing axle weights to be distributed over smaller surface areas. These changes are advantageous to truckers in that they improve fuel economy, but they are a problem to pavement engineers since they cause unexpectedly high amounts of fatigue compared to a "normally" configured axle of similar weight.

Consequently, it is recommended that States monitor changes such as those listed above and be prepared to adjust load equivalency factors per axle configuration of known weight to account for these changes. Again, such adjustments will be considerably easier if disaggregated truck weight information is used.

TECHNIQUES FOR FORECASTING

Unfortunately, there is no "best" method for forecasting. Many of the better forecasts have come from performing several different forecasts using different techniques and then comparing the results to develop a composite forecast. Selecting a forecasting technique or techniques to use is really a function of matching the available information with the expertise within the forecasting agency, and choosing those procedures likely to provide the most reliable results.

Potential forecasting techniques that might be considered include the following:

- Historical trends (regression analyses).
- Judgmental growth rates and engineering estimates.
- Compound interest equations.
- Straight-line projections.

- Transportation studies.
- Pavement management inputs.

Some of these methods are closely related, and other additional forecasting methods certainly are available to an agency.

Historical Trends

The use of historical data to project future conditions probably is the most common of the available forecasting techniques. It may be used to forecast any of the traffic characteristic variables in pavement design. Essentially, it uses an agency's historical data files to run a regression analysis on the desired variable against time. This produces a regression formula that may be used to extrapolate the historical growth over time. Essentially, this method assumes that growth will continue in the same manner as in the past.

Historical trends are most commonly used to extrapolate volume growth in areas not subject to significant development. Historical trends also should be used to determine on-going changes in the vehicle mix and ESAL per vehicle estimates on existing highways. In some cases, States will need to improve their vehicle classification data collection programs to collect this type of information.

In most cases, historical travel trends are computed on a regional or statewide basis. These estimates then are applied to specific projects and adjusted to account for the effects of growth that are specific to the project site.

Estimates and Judgmental Growth Rates

Judgmental growth rates and estimates are used when historical growth rates do not appear to reflect expected growth at a particular site. Such actions may be necessary to account for such discontinuities as changes in the vehicle weight laws, railroad line abandonments or new service, and where the potential exists for significant changes in industrial output, for example plant openings or closings (e.g., sawmills in the Pacific Northwest or coal fields in the Midwest).

Estimates often are a part of the larger transportation studies described below and should reflect the impact non-traffic variables (e.g., gasoline prices, legislation, etc.) have on truck and automobile volumes. These alterations of historical trends should be based on known quantities, such as the presence of an existing but currently closed plant, or the known desire of a company to shut down operation of an existing facility. They also may be used to test the effect of various possible legislative scenarios pertaining to weight laws and total vehicle usage.

When using estimates that alter the historical trends established through rigorous data collection, the basis for the alterations should be described clearly in project documents to thoroughly explain why such estimates were used and what effect those estimates had on predicted loadings.

Compound Interest Equations

The compound interest equation is normally used in those cases in which a pavement project is expected to generate new economic or residential developments. The compound interest equation indicates that growth in absolute terms is expected to increase over time. This occurs in areas experiencing heavy population and economic growth and is particularly common for new facilities.

Use of the compound interest equation results in a parabolic curve of volume versus time (see Figure 3). The growth curve is relatively flat at the beginning of the project, with an increasing slope in the later portion of the design period. This shows the effects of development being completed after the transportation project has been completed.

Straight-Line Projections

Straight-line projections commonly are used in those cases in which a single forecast of vehicles has been made. This forecast is usually for the final design year of the project. On a graph of traffic versus time, a straight line then is projected between the initial traffic

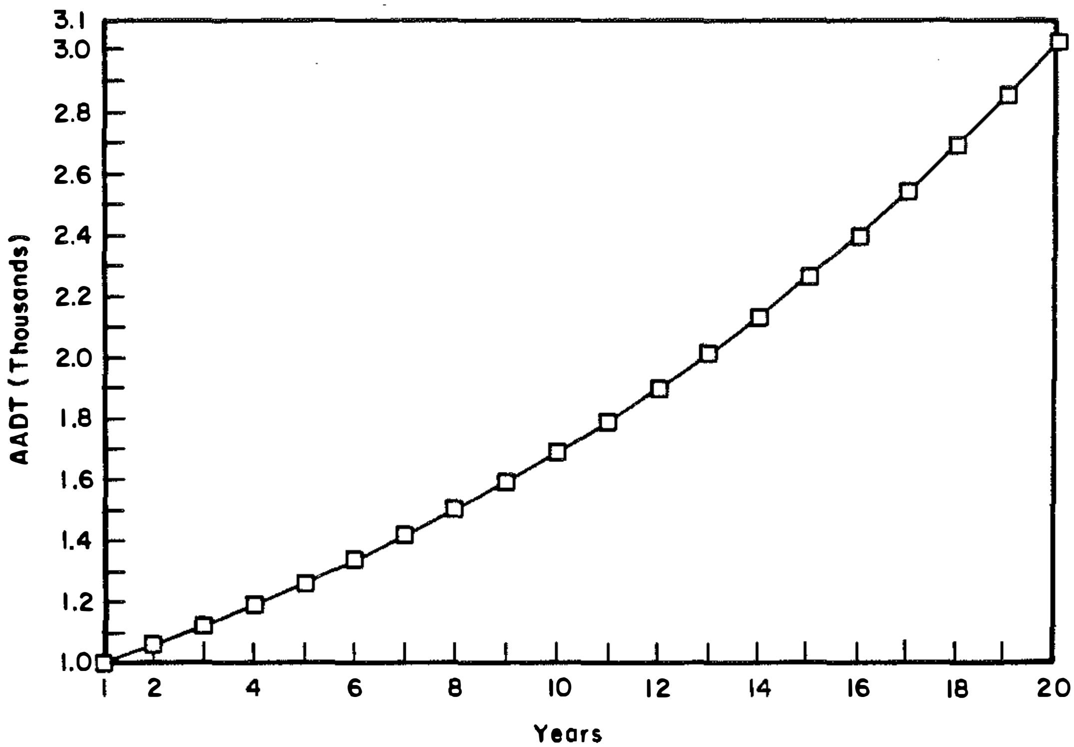


Figure 3. Five percent annual traffic growth.

levels and the expected forecast. This allows for annual estimates of growth without the need to specifically forecast those years.

This is a reasonable method for forecasting intervening years of traffic growth when resources do not exist to make those forecasts on a year-to-year basis. This type of forecast is used best when significant amounts of new travel are not expected to materialize directly as a result of the pavement project.

Pavement Management Inputs

Pavement management systems normally are not directly used in the forecasting of traffic inputs to the design process. However, as noted in the previous section on Current Traffic Data, pavement management systems may be used to adjust forecast traffic estimates. Monitoring of past pavement performance and previous design vehicle loadings can serve as an important key to examining the reasonability of new traffic forecasts, particularly for overlay design.

Evidence of previously poor pavement performance may be used (and often should) to adjust forecast truck volumes or ESAL's to reflect the propensity of that pavement section to deteriorate, regardless of whether that premature deterioration was actually due to weather, numbers of vehicles, or ESAL's per vehicle (i.e., numbers of overweight trucks). In this manner, additional structural material can be placed on a road section that has shown a tendency to fail earlier than expected, thereby adding structural integrity to the pavement and providing the pavement section with a better chance for reaching its design life.

Transportation Studies

Transportation studies commonly are conducted as part of the environmental impact assessment performed for most projects. Such studies determine the effects of population, land use, and other factors on the amount and composition of traffic expected on a particular road segment. Most transportation studies concentrate on the geographic area immediately affected by the proposed project, but can include studies that detail regional and statewide travel potential.

Transportation studies are very useful in that they directly tie the causes of vehicle travel to the volumes and vehicle mixes that determine pavement thickness. Such studies are dependent on the forecasts of population and employment (e.g., industrial or agricultural activity) that are expected to affect the road during its design life.

INPUT VARIABLES FOR FORECASTING

An agency should not forecast traffic without also looking at related variables. Considering the potential impacts of these outside variables often has a significant impact on the expected level of change during the lifespan of the pavement. Such variables include the following:

- Historical traffic levels.
- Legal load limits.
- Population growth.
- Economic activity.
- Availability of alternative routes.
- Availability of alternative modes (for both passengers and freight).
- Political influences on any or all of the above.

The above variables are almost always taken directly into account in the more formal forecasting procedures as a part of special transportation studies. They also serve as the basis for most forecast decisions done on the basis of engineering judgment.

PITFALLS IN FORECASTING

Numerous pitfalls arise in the forecasting process. The biggest of them is the potential for discontinuities occurring in traffic growth over time. These sudden changes may occur in any of the three basic traffic inputs: volumes, vehicle classifications, or truck weights.

Various happenings (impossible to predict) may occur to cause discontinuities in traffic patterns. Fuel shortages, such as occurred in 1974, may cause drastic and immediate changes. Other causes, such as changes in the legal load limit, vehicle styles, and land use, manifest themselves over a long period of time. Major changes in commodity carried or function performed as well as alternate modes of transportation (air, rail, water) may have immediate effects.

Some discontinuities are site specific; for example, an unexpected development or shopping complex may be built along a road, significantly increasing the amount of traffic using that facility. Other discontinuities may occur on a statewide or national basis. For example, the recent changes in the allowable gross weight of vehicles will likely cause faster deterioration in some pavements than was expected because of higher axleloads. Changes in gasoline prices also may have significant effects on the amount of traffic using facilities, as was shown in the early 1970's.

Changes also may occur in the type of vehicle using a particular road. These changes might result from new vehicle configurations carrying similar goods (note the move to single-tire axles) or to changes in the commodities being carried (the loss of agricultural land to light industry in many areas bordering growing urban centers). Changes in vehicle mix also occur as urban areas mature, and what were previously rural sites begin to carry urban traffic mixes.

Finally, discrepancies may occur as a result of significant changes in mode of carriage. In this era of deregulation, significant changes in the availability of some modes of transport, and even the competitive pricing of various modes of transport, can happen quickly. For example, many communities are losing rail service. Commodities previously shipped by that service often switch to moving by truck for either the entire shipping distance or for at least short hauls to other rail facilities.

Usually, accurately forecasting the time and magnitude of such changes is impossible. However, it may be possible to consider the effects of such changes and to make reasonable estimates of the chance of certain events taking place. These efforts should be made for each project.

USE OF A REVIEW PERIOD

All too often in the design of pavements, once a set of numbers are accepted for use by an agency, those numbers remain in use regardless of changing traffic levels and characteristics. Such is often the case with statewide or regional defaults. Because of the frequent use of such factors and the importance they have in the design of pavements and the expenditure of funds, each agency should continually review the factors it is using and update them as necessary.

Also important is the review of the design data on roads with the actual levels of traffic that utilize those roads. In this manner, the faults of the forecasting process may be determined and, over time, minimized.

When used with a comprehensive pavement management system, this continual review of design information also may improve a State's ability to forecast future pavement needs and defend those needs to State and congressional lawmakers trying to balance scarce funds against competing needs and desires.

EQUIPMENT

Traffic forecasts are based upon historical and current traffic data. Procedures and equipment used in the collection of these data have received increased attention in recent years. The FHWA has addressed this topic with funded research and development contracts intended to fully explore the statistical and engineering base upon which traffic data collection programs should and would be built. The product of these efforts is the Traffic Monitoring Guide (TMG), which was issued in final form in 1985. As indicated in the TMG, it is intended to be a statement of good practice rather than a standard. Nonetheless, the States have generally been advised that they should follow at least the minimum programs described in that document or show that their traffic data collection activities are equally effective.

The TMG recommendations are significant and will have a major impact upon traffic data collection activities immediately and in the future. Major features of these "requirements" are summarized in the following paragraphs to serve as a basis for the discussion of traffic data equipment. Probably the most significant recommendation in the TMG is for a 48-hour continuous monitoring period for temporary volume, classification, and truck-weight monitoring. This single factor mandates automation of all traffic data collection programs for traffic monitoring.

The minimum traffic monitoring programs defined in the TMG include traffic volume counting (including both permanent ATR and temporary counting), vehicle classification, and truck weighing programs. The TMG recommends a minimum of five ATR seasonal groups, with five to eight ATR locations per seasonal group. The result is that at least 25 ATR stations are needed in each State. This recommendation has not caused any major changes in current activities since most States now have at least this number of sites.

The minimum traffic volume sampling program consists of one 48-hour data collection session per year on each of one-third of the Highway

Performance Monitoring System (HPMS) sample sections in each State. Consequently, all HPMS sample sections will be counted during a 3-year cycle. For example, the State of Florida has 2,494 HPMS sample sections. A total of 832 of these would be counted each year. This number is far less than the current number of traffic counts acquired each year under the existing program. Most States, however, are using cumulative traffic counters for these data collection programs so that a 48-hour session will yield only a 48-hour total for the traffic volume. Differences between days will not be measured by these counts.

The minimum vehicle classification recommendation of the TMG is that 300 sessions of 48 hours each be conducted over a 3-year cycle, so that 100 locations would be sampled each year. This number of sessions is in line with current efforts in most states. However, the 48-hour data collection duration makes the usual practice of manual classification impractical. This guideline effectively mandates that all states implement automated classification programs. Those States that have pursued automated vehicle classification have given serious consideration to using classifiers for a larger subset of the traffic counting locations than specified under the minimum TMG vehicle classification recommendations.

The TMG also recommends that truck weight data be collected for a minimum of 90 sessions per 3-year cycle (30 per year) for 48 continuous hours. Both the number and length of these data collection periods are a major departure from current State practices. The implementation of WIM programs is critical to the successful realization of this portion of the TMG.

The following sections will discuss the availability and characteristics of equipment for use in meeting the traffic monitoring needs of traffic forecasting activities.

TRAFFIC COUNTING EQUIPMENT

Traffic counting equipment is generally furthest along in meeting the needs defined in the TMG. Devices exist now for performing all functions that have been defined. Recent advances have been directed toward improvements in sensor technology and compatibility of traffic counting equipment with microcomputers. Prices for field data collection units have dropped significantly in the past five years. Most vendors now offer ATR systems that use a microcomputer as a host device at the State central offices and use telephone lines for data transfer.

VEHICLE CLASSIFICATION EQUIPMENT

Vehicle classification has generally been accomplished using data-collection technicians assigned to specific locations to manually record the number of each type of vehicle passing during each hour of the study. These data collection sessions vary between 6 and 8 hours in length. The specific vehicle classification categories used in these studies are generally those defined in earlier FHWA guidelines. The TMG suggests the use of a classification scheme of 13 vehicle types in place of the previous 24 vehicle types. These 13 types (which include an optional category for motorcycles) are intended to enhance the feasibility of automated vehicle classification equipment.

Equipment available for automatically performing this function has evolved in the past five years in response to the development of the TMG and State needs to more efficiently collect traffic data. Automated vehicle classification devices marketed in the U.S. generally employ one of two classification principles. The first is identification of vehicle type by overall vehicle length. This approach ignores both the number and configuration of axles. It also has the disadvantages of depending upon inductive loop detection of truck length. Modern trucks and trailers are making increased use of aluminum and other materials that do not provide iron alloys throughout the length of the truck and trailer. The result is that a truck of this type is misclassified as either a truck and an automobile or as two automobiles.

The second approach is the identification of vehicle type by the number and configuration of axles. This concept is the basis for the 13 FHWA vehicle types and is derived from research conducted by John Wyman at the Maine Facility.

The pricing of automated vehicle classification has become more competitive. In fact, at least one vendor is offering equipment that can classify vehicles by either length or axles at the cost of traffic counters sold in 1984.

Classification equipment in use in the United Kingdom incorporates both axle and vehicle length data as well as chassis height measurements. This multiple sensor approach has been used only on an experimental basis in this country.

WIM EQUIPMENT

The most significant impacts of the TMG are in the truck weighing element. The use of crews of students and/or technicians to weigh trucks on static scales is no longer feasible. States must use WIM devices to meet the recommendations of the TMG. In addition, even those States now using WIM equipment may have to make major changes to their programs if the sampling of truck weights by this method is to meet the FHWA guidelines. For example, the operation of only a few fixed sites for long periods of time is not acceptable. It is, however, suggested that repeated sessions at the same site are needed to establish the temporal variability of truck weight data. This can be accomplished with permanently installed sensors. The spatial variability can be determined by the use of portable WIM equipment deployed to sample truck weights at randomly selected locations.

As indicated in Table 3, all but 11 of the 50 States now have functioning WIM systems. There are six companies marketing WIM products and most have a significant base of installed systems. WIM has proven to be an effective tool for the transportation profession, but most of the currently deployed WIM systems are permanently installed and cannot meet the truck weight sampling approach recommended in the TM Guide. The following paragraphs briefly describe available WIM systems.

Table 3. WIM equipment experience by State and manufacturer

STATE	MANUFACTURER	STATE	MANUFACTURER
Alabama	RAD	Montana	-------
Alaska	IRD,GR	Nebraska	-------
Arizona	GR	Nevada	RAD
Arkansas	SR	New Hampshire	-------
California	IRD,PAT,SR*	New Jersey	PAT
Colorado	-------	New Mexico	RAD
Connecticut	-------	New York	-------
Delaware	PAT,SR	North Carolina	WW*
Florida	RAD,GR	North Dakota	SRP
Georgia	RAD,PAT,SR	Ohio	BWS
Hawaii	PAT	Oklahoma	RAD*
Idaho	RAD*,PAT*,BWS	Oregon	IRD,BWS
Illinois	SR	Pennsylvania	PAT,SR
Indiana	SR	Rhode Island	-------
Iowa	BWS	South Carolina	-------
Kansas	BWS	South Dakota	**
Kentucky	RAD*	Tennessee	SRP
Louisiana	RAD	Texas	RAD,SRP
Maine	IRD,**	Utah	BWS
Maryland	BWS,SR	Vermont	-------
Massachusetts	PAT	Virginia	RAD
Michigan	WW	Washington	PAT
Minnesota	IRD	West Virginia	SRP
Mississippi	RAD	Wisconsin	BWS
Missouri	GR	Wyoming	RAD

KEY:
- BWS - Bridge Weighing Systems
- GR - Golden River Corporation
- IRD - International Road Dynamics
- PAT - PAT Corporation/Siemens
- * - Removed
- ** - State´s Own Bridge Device
- RAD - Radian Corporation
- SRP - Streeter Richardson Portable
- SR - Streeter Richardson Platform
- WW - WeighWrite/CMI-Dearborn

Bridge Weighing Systems

The Bridge Weighing Systems device was first developed at Case Western Reserve University in research sponsored by the FHWA. The active weight sensing device is a strain transducer clamped or permanently fixed to the longitudinal support beams of a highway bridge. Temporary or permanent axle sensors are placed on the road surface of the approach to the bridge to assist in the classification of vehicle types and to acquire speed data. An optional manual input is provided for detailed manual classification information. Data are recorded in a dedicated microcomputer equipped with the required electronic data-acquisition subsystems. Mobile versions of this WIM system usually have the instrumentation installed in a van, which can be parked under the bridge. Permanently installed versions of the system have an instrumentation cabinet.

In its portable configuration, the bridge WIM system is designed for quick setup and removal. In many cases, calibration need be performed only once at each site and subsequent returns to that site may not require recalibration. However, it is usually recommended that even these locations be recalibrated at least annually. Setup time is usually less than half an hour. Some users of portable versions of this equipment have reported difficulties with using tapeswitches or pneumatic tubes as portable axle sensors. Bridge Weighing Systems has addressed this problem by offering permanently installed axle sensors using piezoelectric cable.

Accuracy of this equipment may be affected by a number of factors, including the horizontal alignment of the roadway approach, the skew of the bridge, the number of lanes of traffic, and the presence of other vehicles on the bridge. These factors affect the interaction of the span and the vehicles and thereby the gross and axle weight readings. Single spans cannot exceed 65 feet in length. As with all WIM systems, the roadway approach to the WIM location must be smooth and free of distress.

Bridge WIM systems are the least noticeable by the traveling public of all of the WIM devices. It can be operated unattended, and generally has very low life-cycle costs.

CMI-Dearborn

CMI-Dearborn now produces and markets a WIM system developed at the University of Saskatchewan and previously offered by International Road Dynamics (IRD). The weight sensor consists of two rectangular weighing platforms measuring 54 inches wide by 21 inches long by 9 inches deep. The platforms rest on a common concrete foundation. Loads applied to a platform are transferred to a central oil-filled piston, which is the active sensing element. One platform is placed in each wheelpath and the electronic subsystems are installed at the roadside. Inductive loops are installed both before and after the weighing platforms to provide speed and presence indications. The CMI-Dearborn system is permanently installed and requires heavy equipment and several days for installation.

Although it is difficult and expensive to install, it is particularly attractive for installation in States located in the "frost belt" and other locations where the environmental conditions are severe and high reliability is needed. This equipment is also very accurate and requires little maintenance.

Streeter Richardson

Streeter Richardson now markets two different WIM systems. The first uses a platform supported on each corner by strain gauge load cells. The platform is made of high strength steel with a "honeycomb" construction to increase its stiffness. Each of the four load cells has a 10,000 pound capacity. It is normally permanently installed, but can be deployed as a portable low-speed WIM device. The weighing platforms are 58 inches wide by 27 inches long by 8 inches deep. One is placed in each wheel path. A height adjustment is provided to allow a smooth transition from the roadway to the platform surface.

Inductive loops, one on either side of the weigh platforms, are used to provide speed and presence indications. The remaining elements of this WIM system include a microprocessor-based data-acquisition, processing, and control unit and a video terminal. A medium-speed version of this eqùipment is designed for use as a sorting scale with trucks travelling at approximately 30 mph. A high-speed (55 mph) version is also produced. An accuracy of ± 5 percent at the 90-percent confidence level is claimed for gross weights with this equipment when operated at speeds of 40 mph or less.

The second WIM product offered by Streeter Richardson is portable and uses a capacitive weighmat as its weight transducer. The weight sensor is 72 inches wide by 20 inches long by 3/8 inch thick. It consists of three parallel sheets of steel separated from each other by a rubber dielectric material. This weighmat acts as a three-plate capacitor within a tuned circuit. When the rubber in the sensor is compressed by a load, the capacitance of the weighmat changes, causing a shift in the oscillating frequency of the tuned circuit. This frequency change is interpreted by a microprocessor-based data-collection system as a weight. The weighmat is fixed to the surface of the highway with adhesive and nails. Normally, it is installed in one wheelpath of a traffic lane. Up to four sensors may be used with the same electronic data-acquisition unit. This part of the system requires 110 volt alternating current electrical power, which can be supplied by a small portable generator. About 30 minutes is required to install or remove the system at a site, exclusive of the traffic control. The sensor should not be installed on wet, damp, or cold pavement surfaces. The weighmat also is subject to damage by dragging vehicle parts.

Radian Corporation

The Radian Corporation offers a WIM system developed by Dr. Clyde Lee at the University of Texas for the Texas Department of Highways and Public Transportation. The weight transducer consists of a steel frame that supports a load-cell assembly and six triangular load plates. The transducer is 54 inches wide by 18 inches long by 3.5 inches deep. One of these weight sensors normally is placed in each wheel path. The load-cell assembly contains eight active load cells and another eight matched load cells, which are used to provide temperature compensation. Data-acquisition and processing circuitry are contained in an IBM XT microcomputer. The Radian system can monitor truck weights in four lanes of traffic simultaneously. The sensors normally are moved from site to site.

PAT/Siemens

The Siemens-Allis Corporation in the United States is marketing a WIM system that incorporates PAT Equipment Corporation WIM sensors with Siemens electronics. The PAT weight transducer is a steel plate either 48 or 72 inches wide by 20 inches long by 1 inch deep. Three of the 4-foot or two of the 6-foot sensors may be installed side by side to cover a 12-foot lane. Each sensor is supported along its longer side at a height of 3/4 inch by a steel frame that has a total depth of 2 inches. As a wheel passes over the steel plate, its bending is monitored by strain gauges located in slots on its under side. The entire plate is then enclosed in vulcanized synthetic rubber.

Siemens recommends placing two weight sensors in each wheel path at high-speed locations. This approach allows comparison of measurements for the same wheel and for comparison of measurements of each end of single axle. With this information, unreasonable readings may be discarded. The two WIM sensors in the same wheelpath also are used in a procedure that provides axle-spacing information. Low-speed weighing often is done by a configuration that uses a pair of WIM transducers, one in each wheelpath, but offset to provide axle spacing information. Electronic data-acquisition subsystems are housed in a weatherproof enclosure or building at the roadside.

Weighwrite

CMI-Dearborn is also the marketing agent in the United States for the low-speed Weighwrite WIM system. This device is not widely used in the U.S.

Golden River Corporation

The Golden River Corporation's WIM system uses the same capacitive weighpad previously described for the Streeter Richardson portable WIM system. The roadside data-collection electronic subsystem operates automatically. The system may be left unattended, although this mode of operation is questionable due to the risk of vandalism to the weighmat. Data may be stored in summary fashion or as individual vehicle data.

The equipment has internal correction for both speed and temperature effects. It is very portable, but the weighmat is not easily installed on damp, wet, or cold pavements. The weighmat also is subject to damage by dragging vehicle parts.

OTHER WIM TECHNOLOGIES

Emerging capacitive-sensor technology includes two major modifications to existing weighmats mounted on the road surface. The first change is the use of a capacitive strip 6 inches wide by 72 inches long rather than the mat, which is 18 inches wide by 72 inches long. Current versions of both the capacitive strip and the capacitive mat use three sheets of steel separated by a rubber dielectric material enclosed in a protective neoprene covering. Work on the capacitive strip has been carried out under a contract entitled "Development of a Low Cost Truck Weighing System" issued by the FHWA.

A further development involves installing the capacitive strip or mat in a shallow excavation in the road surface. Since the capacitive sensor is itself approximately 3/8 inch thick, the excavation will be approximately 3/4 to 1 inch deep.

The second promising WIM technology area is piezoelectric sensing. Research in this field conducted in Europe for the past several years has concentrated on the use of coaxial cables consisting of a copper sheath and central conductor and a dielectric of piezoelectric powder. Further development of this concept in the U.S. is being jointly funded by the States of Iowa and Minnesota and the FHWA. The State of Washington also is initiating a research project using piezoelectric cable technology.

CONCLUDING REMARKS

The individual responsible for preparing traffic forecasts upon which to base ESAL determinations often would like to have more data. However, additional data may not necessarily solve the forecasters problems. To be of value, data that are available and used must be "good" data. This issue presents the need to establish traffic sampling plans so the data obtained are representative of various stratifications that are desired. Most traffic forecasting currently is based on historical data. Such is also likely to be true for the near and intermediate future. Such historical data do need to be representative of those situations that are being forecast. However, projection of historical trends into the future by whatever methodology may be adjusted and changed because of various economical, political, and other circumstances. Here again, it is important to look to previous circumstances in order to evaluate the impact of these potential political and economic perturbations in the future. Such factors as modifications of legal load limits by various legislative bodies and changes in vehicle styles and loading practicers may hve as much impact upon the estimation of a design ESAL as do the future trends indicated by historical data.

There are a number of factors that have recently been recognized as significant in ESAL calculations. Some have only recently been considered and therefore historical data are not typically available to provide a basis for good projections. Such factors include the effects of tire pressures, uneven loading between arious axles within an axle group, and single-wheeled versus dual-wheeled axle configurations. There also is a major effort toward the implementation of weigh-in-motion technology to obtain data with regard to the weight characteristics of the traffic stream. Since many pavement design schemes and technologies are based upon the distributions of static vehicular weights, thre is he question as to whether the design schemes and criteria need to be modified to account for the distributions of vehicular weights obtained by dynamic methodologies. It already is established that weight distributions obtained by static and dynamic technologies are different for the same traffic stream. These differences, however, are not well established.

A statistical basis for traffic sampling that can be implemented easily by various highway agencies of different sizes and complexities is needed. Differences between data collection schemes for high-volume urban areas and low-volume rural areas need to be recognized. The important point is that the data describing the characteristics of traffic streams need to be valid and representative so reliable projections may be obtained.

Additional studies of various models for forecasting traffic stream characteristics are needed. These models should accunt for not only local traffic patterns but the impact of interregional travel desires. The impact of alternate highway routes and the effect of alternate modes of transportation need to be considered in uch forecasting models. Forecasting models that are developed must be suffciently flexible to accommodate various ranges of the amount and reliability of data available to use in the model.

The ultimate design value sought from the process of traffic data collection and forecasting is the ESAL value to be used to design the pavement thickness and components. The importance of the estimation of an appropriate ESAL value may be evaluated by looking to the impact of either overdesign or underdesign. This raises such issues as the potential for stage construction and for the relationship of the upgrading of a particular project within an overall highway network either before or after the remaining portion of the system has been upgraded. Traffic data also have significant importance in relationship to the current trend towards pavement management.

APPENDIX A

TRAFFIC ADJUSTMENT AND GROWTH FACTORS FOR FORECASTING

Florida Department of Transportation

INTRODUCTION

This appendix explains the methodology used by the Florida Department of Transportation to convert seasonal traffic counts into AADT based on adjustment factors developed from ATR programs. It also explains the estimation of K and D factors used in capacity analyses, which often result in restraining traffic volumes to theoretical maximum volumes. Finally, it explains the methods of developing site-specific traffic growth factors and one method of developing a generalized growth factor.

All traffic forecasts for pavement design are predictions of the number of 18-kip equivalent single axleloads (ESAL´s) that a pavement will be subjected to during its design life. Barring the effect of any major changes to the traffic pattern, past performance is the best indicator to future performance.

Typically, a growth rate is applied to a known volume to generate future volumes of traffic. These predicted volumes are then multiplied by a truck percentage to give truck volumes. These truck volumes are multiplied by an average 18-kip ESAL per truck to give numbers of 18-kip ESAL´s. When the 18-kip ESAL´s are summed across the design life of the project, accumulated 18-kip loads are the result. Traffic volumes thus play a very important role in the prediction of 18-kip loadings.

To provide as many traffic counts as possible, a 24-hour counting period was established. Prior to 1982, seasonal 24-hour counts were made from one to four times a year, and the arithmetic average of the counts was assumed to be the AADT for the count site.

A study conducted by the Traffic Counts Office in 1981 using continuous count information verified that AADT could be replicated accurately using one 24-hour seasonal count factored by weekly factors generated from continuous counters.

Continuous counters replicate the traffic patterns within contiguous areas and therefore they have been assigned to individual counties for the purpose of developing monthly or weekly factors for use in factoring a single 24-hour count to a 24-hour Annual Average Daily Traffic.

The factor development process follows:

a) $WADT_L / AADT_L = MF_L$

b) $\Sigma_i^N MF_L / N = MF_i$ or MF_j

c) $(MF_j - MF_i)/\#\ Weeks = AWF_k$

d) $ADT/AWF_k = AADT$

Definitions:

$WADT_L$ = non-directional weekly average daily traffic for a continuous counter

$AADT_L$ = non-directional annual average daily traffic for a continuous counter

MF_L = monthly factor for a continuous counter

MF_i = average monthly factor for a county/area for preceeding month

MF_j = average monthly factor for a county/area for succeeding month

N = number of counters/county

Weeks = number of weeks between mid-month to next mid-month

AWF_k = average weekly factor

ADT = 24-traffic count at a non-continuous count site

AADT = annual average daily traffic for a non-continuous count site

District 1 was used to test this process in 1982. All districts utilized this process for 1983 to the present. Table 4 gives the count year definitions and the factor utilization time by district. Table 5 contains an example of monthly factors that are available for each county in Florida.

CAPACITY RESTRAINED VOLUMES

Pavement design is based upon the number of ESAL's a road will experience in its most heavily loaded lane. To accurately determine these loadings, traffic volumes must be tempered with directional distribution and lane usage factors. Volumes must be checked to insure they do not exceed the theoretical capacity for the roadway or else volumes and loadings will not agree. Department procedure is to allow traffic to grow according to a growth factor until capacity is reached and then restrain the volume to this level for the remainder of the forecast period.

Lane distributions, directional splits, and 30th highest hour factors may be obtained using data collected by permanent traffic counters (ATR devices). Two traffic volume statistics drawn from the traffic count data for use in design are K and D factors. The design-hour K value represents the ratio of the 30th highest hour volume of traffic to the AADT. The design-hour D value represents the highest directional volume as a percentage of the hourly volume for the 30th highest hour. D values are calculated by taking the average of the 28th thru 32nd highest hour volume for data stability.

Accurate measures of K and D factors are generally available only from ATR sites, and a method was needed to provide a statistical technique for applying accurate measures of K and D to all sections of the state highway system. Variables such as geographic, demographic, and roadway characteristics may be used as significant predictors of K and D:

(1) AADT, district location, functional classification, urban/rural distinctions, and divided/undivided roadway distinctions are significant

Table 4. Factor utilization table

COUNT YEAR	PERIOD FROM	PERIOD TO	DISTRICT I	II	III	IV	V	VI
1970-1981	$7/1/Yr_i$	$6/30/Yr_j$						
1982	1/1/82	12/31/82	AWF					
1983	1/1/83	12/31/83	AWF	MF	MF	MF	MF	MF
1984	10/1/83	9/30/84	AWF	AWF	AWF	AWF	AWF	AWF
1985	7/1/84	6/30/85	AWF	AWF	AWF	AWF	AWF	AWF
1986	7/1/85	6/30/86	AWF	AWF	AWF	AWF	AWF	AWF

AWF = Average Weekly Factor
MF = Monthly Factor
Note: A blank indicates that seasonal counts are not factored

Table 5. Example of monthly factors for counting year 1986

FIRST DISTRICT

NOTE: FACTORS FOR COUNTY 1 ARE BASED ON THE STATIONS LISTED BELOW

CO	STA		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	14	MED	0.95	0.95	0.89	0.95	1.03	1.09	1.15	1.32	1.27	1.13	0.91	0.91
7	39	MED	0.90	0.87	0.84	0.92	1.00	1.08	1.10	1.23	1.21	1.10	0.95	0.97
15	86	MED	0.95	0.94	0.96	0.96	0.97	0.99	1.15	1.23	1.24	1.20	1.09	1.03
3	94	MED	0.86	0.87	0.88	0.97	1.06	1.14	1.21	1.27	1.30	1.16	1.00	0.93
3	143	MED	0.81	0.82	0.83	0.89	1.05	1.13	1.06	1.12	1.10	1.18	1.18	0.91
13	146	MED	0.94	0.74	0.80	0.85	0.99	0.98	0.98	1.04	1.11	1.02	1.04	0.93
15	148	MED	0.97	1.00	0.99	1.05	1.07	1.07	1.12	1.18	1.20	1.14	1.03	1.04
7	160	MED	0.90	0.86	0.83	0.95	1.06	1.09	1.06	1.16	1.12	1.09	1.04	0.95
1	AVG	MED	0.91	0.88	0.87	0.94	1.02	1.07	1.10	1.19	1.19	1.12	1.03	0.95

NOTE: FACTORS FOR COUNTY 4 ARE BASED ON THE STATIONS LISTED BELOW

CO	STA		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
4	68	MED	0.88	0.84	0.83	0.87	1.01	1.08	1.01	1.18	1.16	1.09	1.09	1.00
4	145	MED	0.86	0.84	0.84	0.88	1.00	1.06	1.11	1.23	1.24	1.09	0.98	0.96
4	AVG	MED	0.87	0.84	0.83	0.87	1.00	1.07	1.06	1.20	1.20	1.09	1.03	0.98

NOTE: FACTORS FOR COUNTY 5 ARE BASED ON THE STATIONS LISTED BELOW

CO	STA		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
7	39	MED	0.90	0.87	0.84	0.92	1.00	1.08	1.10	1.23	1.21	1.10	0.95	0.97
7	160	MED	0.90	0.86	0.83	0.95	1.06	1.09	1.06	1.16	1.12	1.09	1.04	0.95
5	AVG	MED	0.90	0.86	0.83	0.93	1.03	1.08	1.08	1.19	1.16	1.09	0.99	0.96

NOTE: FACTORS FOR COUNTY 6 ARE BASED ON THE STATIONS LISTED BELOW

CO	STA		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
4	68	MED	0.88	0.84	0.83	0.87	1.01	1.08	1.01	1.18	1.16	1.09	1.09	1.00
4	145	MED	0.86	0.84	0.84	0.88	1.00	1.06	1.11	1.23	1.24	1.09	0.98	0.96
13	146	MED	0.94	0.74	0.80	0.85	0.99	0.98	0.98	1.04	1.11	1.02	1.04	0.93
6	AVG	MED	0.89	0.80	0.82	0.86	1.00	1.04	1.03	1.15	1.17	1.06	1.03	0.96

NOTE: FACTORS FOR COUNTY 7 ARE BASED ON THE STATIONS LISTED BELOW

CO	STA		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
7	39	MED	0.90	0.87	0.84	0.92	1.00	1.08	1.10	1.23	1.21	1.10	0.95	0.97
7	160	MED	0.90	0.86	0.83	0.95	1.06	1.09	1.06	1.16	1.12	1.09	1.04	0.95
7	AVG	MED	0.90	0.86	0.83	0.93	1.03	1.08	1.08	1.19	1.16	1.09	0.99	0.96

NOTE: FACTORS FOR COUNTY 8 ARE BASED ON THE STATIONS LISTED BELOW

CO	STA		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
14	13	MED	0.98	0.97	0.98	1.01	1.02	1.06	1.04	1.10	1.12	1.10	1.05	1.06
2	44	MED	0.95	0.90	0.85	0.89	0.99	0.99	0.92	1.02	1.02	1.00	0.92	0.94
14	79	MED	0.94	0.89	0.90	0.95	1.01	1.04	1.05	1.13	1.16	1.09	1.03	1.03
18	119	MED	0.93	0.86	0.78	0.88	0.95	1.05	0.89	0.98	1.14	1.13	0.93	1.01
8	AVG	MED	0.95	0.90	0.87	0.93	0.99	1.03	0.97	1.05	1.11	1.08	0.98	1.01

NOTE: FACTORS FOR COUNTY 9 ARE BASED ON THE STATIONS LISTED BELOW

CO	STA		JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
7	39	MED	0.90	0.87	0.84	0.92	1.00	1.08	1.10	1.23	1.21	1.10	0.95	0.97
4	68	MED	0.88	0.84	0.83	0.87	1.01	1.08	1.01	1.18	1.16	1.09	1.09	1.00
16	128	MED	0.87	0.82	0.83	0.92	1.02	1.13	1.10	1.24	1.26	1.16	1.02	0.96
7	160	MED	0.90	0.86	0.83	0.95	1.06	1.09	1.06	1.16	1.12	1.09	1.04	0.95
9	AVG	MED	0.86	0.84	0.83	0.91	1.02	1.09	1.06	1.20	1.18	1.11	1.02	0.97

predictors of K.

(2) AADT, district location, functional classification, urban/rural distinctions, divided/undivided roadway distinctions, and roadway width are identified as potentially significant predictors of D.

The prediction model (for Florida highways) for K is represented by the following equation:

$$
\begin{aligned}
K = 11.6 &- 0.000061 \times AADT \\
&+ 0.64 \text{ (if located in District 2)} \\
&+ 0.73 \text{ (if located in District 3)} \\
&+ 0.52 \text{ (if located in District 4)} \\
&+ 3.10 \text{ (if a minor arterial)} \\
&+ 1.25 \text{ (if an interstate)} \\
&- 1.15 \text{ (if a collector)} \\
&- 1.59 \text{ (if in an urban area)} \\
&+ 1.48 \text{ (if an undivided roadway)} \\
&+ 0.0024 \times AADT \text{ (if a minor arterial)} \\
&+ 0.000038 \times AADT \text{ (if in an urban area)} \\
&- 0.00015 \times AADT \text{ (if an undivided roadway)} \\
&+ 1.18 \text{ (if in an urban area and undivided)}
\end{aligned}
$$

The prediction model (for Florida highways) for D is represented by the following equation:

$$
\begin{aligned}
D = 56.46 &+ 0.00011 \times AADT \\
&- 1.52 \text{ (if located in District 1)} \\
&- 2.21 \text{ (if located in District 4)} \\
&- 1.44 \text{ (if a minor arterial)} \\
&- 0.58 \text{ (if an interstate)} \\
&+ 0.0225 \times \text{Roadway Width} \\
&+ 0.000045 \times AADT \text{ (if an interstate)} \\
&- 0.00011 \times AADT \text{ (if in an urban area)} \\
&+ 2.23 \text{ (if in an urban area and undivided)}
\end{aligned}
$$

SITE-SPECIFIC GROWTH FACTORS

Traffic volumes are the one data element used in forecasting loadings for which State highway agencies have a sufficient history. In an area of stable traffic patterns, historical volumes may be used to generate traffic growth factors. The following methods may be used:

- Linear regression for projects that do not add lanes (i.e., resurfacing).
- Compound growth for projects that add lanes.
- Network assignmnt volumes.

Linear Regression Technique

A simple linear regression technique is used to fit a straight line through historical traffic volumes on roads containing projects that do not add lanes. A straight line has proven to be the best fit for predicting future volumes for these types of projects. The data are plotted on graph paper and examined for evidence of stability. A straight line is then fitted to the stable portion and the slope is determined. A mathematical process using a hand-held calculator is usually used to determine the form of the line, but a purely graphical technique may be used. The following example (Figure 4) illustrates this method:

YEAR	AADT	
1960	7,945	
1961	7,908	
1962	6,136	
1963	5,553	
1964	6,506	
1965	7,860	
1966	7,907	
1967	8,743	
1968	8,494	
1969	8,952	
1970	9,658	Stable
1971	9,834	Growth
1972	11,252	Period
1973	11,980	
1974	12,068	
1975	13,503	
1976	13,265	
1977	14,066	
1978	14,880	
1979	15,414	
1980	16,200	
1981	14,051	
1982	13,634	
1983	14,152	
1984	14,942	
1985	16,842	

(Stable Growth Period: 1963–1980)

Equation of line through stable growth period is

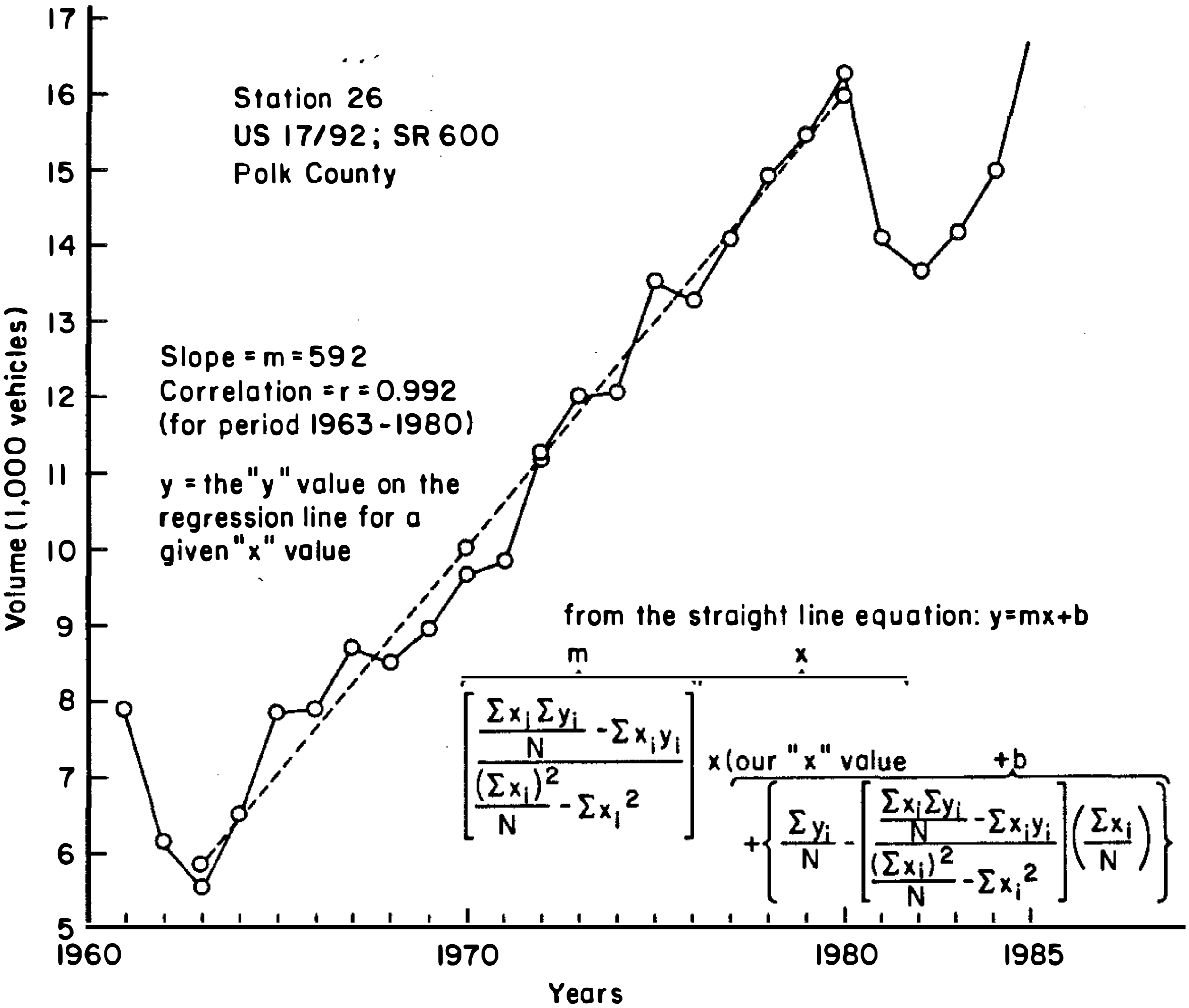
$$Y = 592 X + 5,868$$

in which Y = AADT and

X = age (in years)

Slope = 592

Correlation (r) = 0.99



$$y = \left[\frac{\frac{\Sigma x_i \Sigma y_i}{N} - \Sigma x_i y_i}{\frac{(\Sigma x_i)^2}{N} - \Sigma x_i^2}\right] x + \left\{\frac{\Sigma y_i}{N} - \left[\frac{\frac{\Sigma x_i \Sigma y_i}{N} - \Sigma x_i y_i}{\frac{(\Sigma x_i)^2}{N} - \Sigma x_i^2}\right]\left(\frac{\Sigma x_i}{N}\right)\right\}$$

Figure 4. Linear regression technique.

Compound Growth Technique

In 1968, the Florida Department of Transportation (FDOT) conducted a comprehensive study of traffic trends at 500 stations, each having fourteen years of annual traffic count records for the period 1955 through 1968. The study revealed that the traffic growth trend during the first ten years was best represented by a family of compound growth curves. In extending these compound growth curves ahead for four years and checking the projected volumes against the actual 1968 traffic counts, it was found that, at about the tenth year, the growth trends flattened somewhat from a compound to a linear growth pattern. Based on this finding, it has become FDOT policy to use a compound growth rate for the first ten years of a traffic projection and a linear growth rate thereafter on projects that increase the number of lanes on existing roads and on new construction or reconstruction.

Historical traffic data are plotted on graph paper to depict the growth trend at that traffic station. On most highways, traffic growth remains steady. At some locations, the steady growth is followed by an abrupt rise or fall in traffic volume (due to the effect of significant highway changes or major land use changes) and is then followed by another stable growth period. It is these stable growth periods that are examined in establishing the historic growth trend. If the data plot is a relatively straight line, a linear historic growth pattern is indicated; if an upward curve, then a compound historic growth rate. If the data plot is of some other form, the trend is determined using the most recent years of steady growth.

The growth rate so determined is applied to the current traffic volume to obtain future traffic volumes. To facilitate that operation, tables have been prepared to show traffic growth factors that are based on a compound growth rate for ten years and a linear rate thereafter. Given a percentage of compound growth, the growth factor for any future year (up to 40 years) is found from the table (see Figure 5 for graphical representations of growth factors). The appropriate growth factor is then multiplied by the current traffic volume to obtain the basic traffic forecast for the desired year.

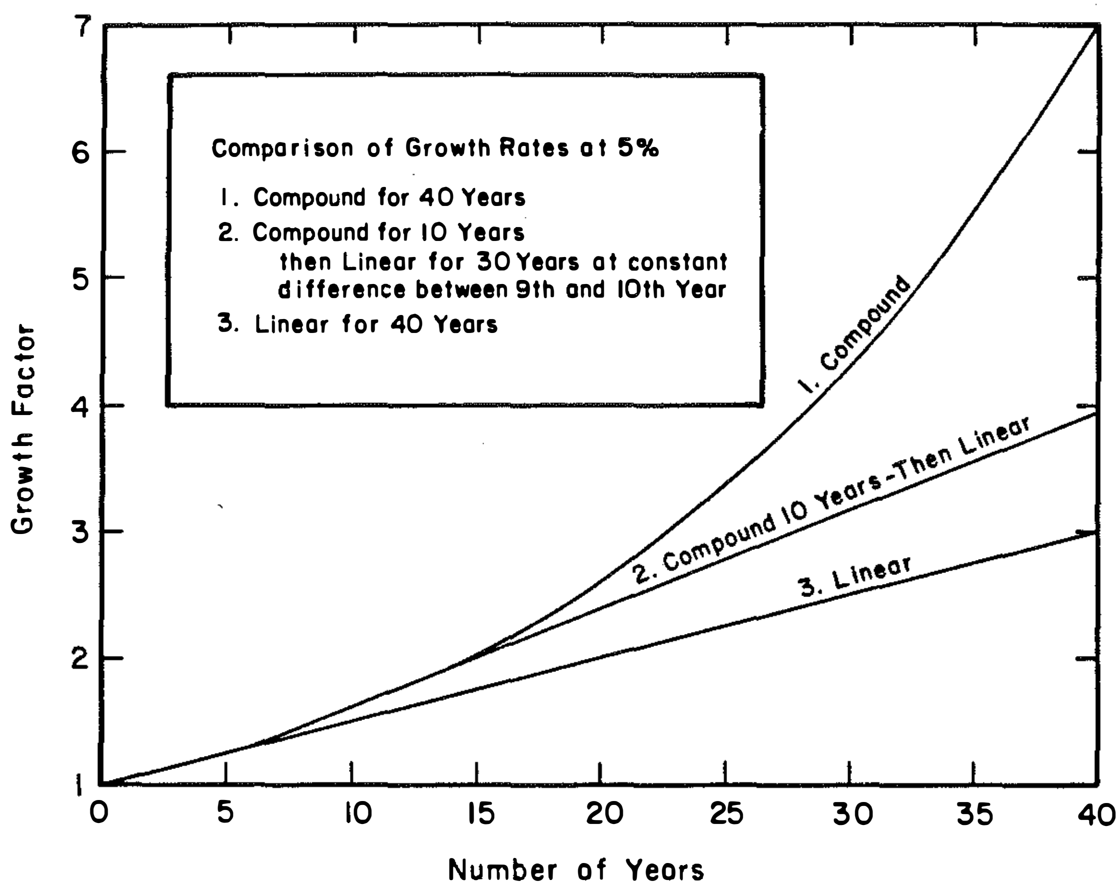


Figure 5. Comparison of growth rates at five percent.

The following example covers the compound-rate technique used to derive a growth factor using historical data.

Given:

1. ADT History (use the last 10 to 12 years of history)
2. Compound-linear Rates Table

Find:

1. Factors to be used for estimating future traffic volumes
2. Traffic volumes for selected years

First, plot the ADT history on semi-log paper (volume on log scale) (see Figure 6). Then plot the average of the first three years and the average of the last three years, and connect these two average points with a straight line.

Example (Station 72-605)

1955 - 5,070	Average = 5,753	1963 - 9,502	
1956 - 6,010		1964 - 9,942	
1957 - 6,180		1965 - 10,406	
1958 - 6,880		1966 - 11,275	
1959 - 7,175		1967 - 11,483	Average = 12,367
1960 - 7,748		1968 - 12,183	
1961 - 7,996		1969 - 13,436	
1962 - 8,593			

If the line through the average points also passes through the historical ADT points with approximately as many points above as below the line, the station has a regular growth pattern.

The following method of determining historical growth rate applies directly to stations having <u>regular growth patterns</u> by calculating the least squares line (Y = log AADT and X = Year - 1954) for only the stable part of the history. To find the compound rate of growth for historical data:

a. Average the last three counts to obtain an equivalent 1968

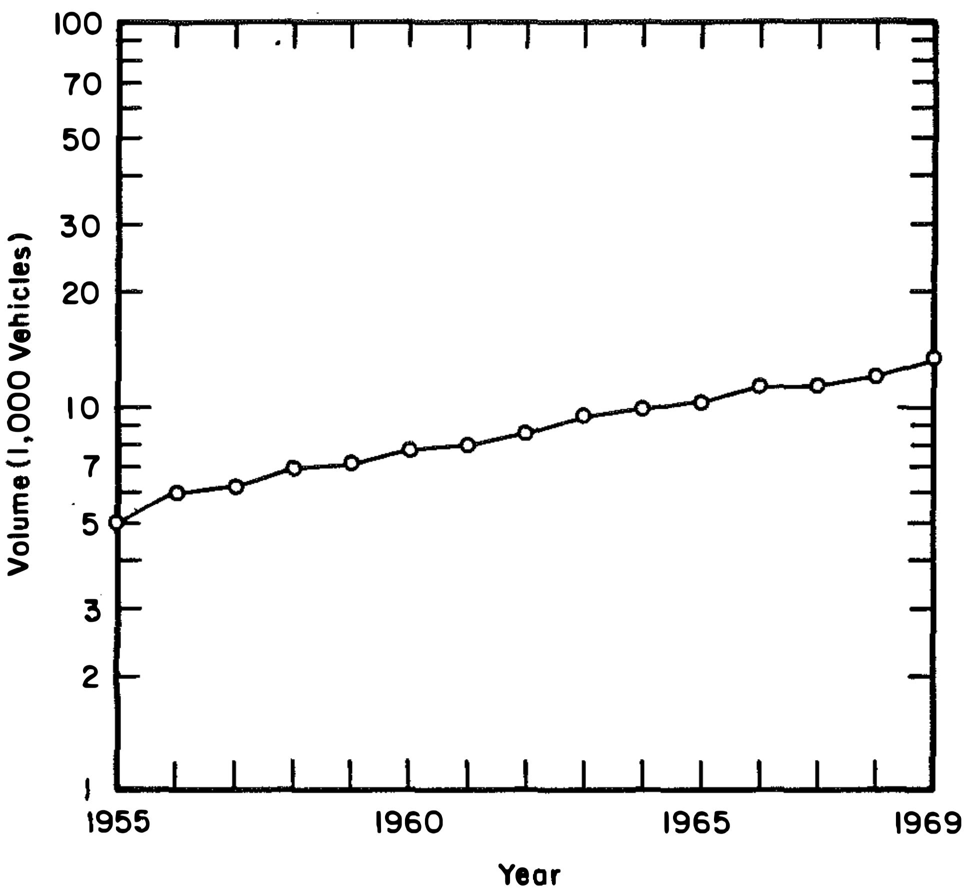


Figure 6. Historical growth at station 72-605.

volume (12,367).

b. Average the first three counts to obtain an equivalent 1956 volume (5,753).

c. Divide the 1968 volume by the 1956 volume (12,367 ÷ 5,753 = 2.1496).

d. Determine the number of years over which the growth has occurred by subtracting the year of the earlier average from the year of the later average (1968 - 1956 = 12 years).

e. In column one of a compound linear rate table (Table 6), locate this number of years (12). On the line for Year 12, find the figure nearest 2.1496. The figure 2.153, the closest figure on Line 12, is in the column headed 6.7 percent. This is the annual compound rate of growth.

<u>Network Assignment Technique</u>

In major urban areas, future volumes may be obtained using network assignment models. The volumes obtained from those models are based on current traffic, predicted land use patterns, expected improvements/additions to the highway system, and the public's desire to travel from one place to another. This travel desire is based on local knowledge and can be verified by origin-and-destination studies conducted in the urban area. However, it is prudent to take traffic volumes from the network assignment models with care -- rezoning may change land use, expected improvements may not be built -- as the volumes may easily exceed capacity. If the volumes from the network assignment appear reasonable, then a compound or linear growth rate can be fitted between the current and future volumes, depending on whether or not the project will add lanes.

For example, if a road carries a volume of 10,000 AADT in 1985, and the year 2000 network assignment for that road is 40,000 AADT, then a growth rate can be determined between the two points (providing the network assignment volume appears reasonable).

The linear model (used for resurfacing projects) simply determines the slope of the line between the two end points:

Table 6. Example from table of percentage rates of growth

ANS EVALUATION SECTION
FLORIDA DEPARTMENT OF TRANSPORTATION
PERCENTAGE RATES OF GROWTH
COMPOUND 10 YEARS * LINEAR THEREAFTER

YEAR	6.4%	6.5%	6.6%	6.7%	6.8%
1	1.064	1.065	1.066	1.067	1.068
2	1.132	1.134	1.136	1.138	1.141
3	1.205	1.208	1.211	1.215	1.218
4	1.282	1.286	1.291	1.296	1.301
5	1.364	1.370	1.377	1.383	1.389
6	1.451	1.450	1.467	1.476	1.484
7	1.544	1.554	1.564	1.575	1.585
8	1.643	1.655	1.667	1.680	1.693
9	1.748	1.763	1.778	1.793	1.808
10	1.860	1.877	1.895	1.913	1.931
11	1.971	1.992	2.012	2.033	2.054
12	2.083	2.106	2.129	2.153	2.177
13	2.195	2.221	2.247	2.273	2.299
14	2.307	2.335	2.364	2.393	2.422
15	2.419	2.450	2.481	2.513	2.545
16	2.531	2.565	2.599	2.633	2.668
17	2.643	2.679	2.716	2.753	2.791
18	2.754	2.794	2.833	2.874	2.914
19	2.866	2.908	2.951	2.994	3.037
20	2.978	3.023	3.068	3.114	3.160

$$M = (40{,}000 - 10{,}000)/(2000 - 1985) = 2{,}000.$$

Traffic will increase by 2,000 AADT each year.

The compound model (used for projects that add lanes) determines the annual percent growth between the beginning and ending years. Using Florida's method, a 15-year factor of 4.0 (i.e., 40,000/10,000) yields an annual growth rate of 10.5 percent.

GENERAL GROWTH FACTORS

Alternately, growth rates may be derived from analyses of historical data of such attributes as vehicle registrations, gasoline consumption, and population. If this latter method is used to derive a growth factor, it is important to derive a growth factor from several data bases and compare the results for reasonableness. For example, vehicle registration and population may both show a positive growth while gasoline consumption shows a decline. This can be attributed to more fuel efficient cars or the residents of one area buying their gasoline in another place. Gasoline companies sometimes centralize their credit card billing in one location, and report all gasoline sales from that location. Just make sure that the figures pass the test of common sense.

Growth factors for Florida counties are based on several indices. Many factors were considered (population, vehicle-miles traveled, autos registered, gasoline sold, area, State-maintained centerline miles, total centerline miles, State-maintained lane miles, total lane miles) but population, gasoline consumption, and daily vehicle-miles traveled offered the best correlation while maintaining a degree of independence.

Three independent factors are chosen to minimize abnormalities that may unduly affect growth rates. For example, gasoline consumption may show a decline even though passenger car travel is on the increase. This may be attributed to increased fuel efficiency of vehicles or incorrect base data. A self-imposed county gas tax will cause residents of that county to buy gasoline in a neighboring county that does not have the additional tax.

To reduce the effects of any unusual year in the analysis, 10 years of data are analyzed for each variable. Too few years of data are subject to the influence of one year of inconsistent data, and too many years of data dilute the present-day growth rate. In Florida, a 10-year period provided the optimum performance.

Compound growth rates are fitted through the ten years of data for each variable using a regression technique. If the growth rate for all three indices are similar, then its fair to assume that it is the proper rate. When the three rates differ, engineering judgment is used to determine the growth rate for that county. The process is repeated each year for the newly accumulated data. The earliest year is dropped and the newest is added to the data -- a sliding 10-year window.

As an example, Clay County (CO 71) population has increased from 41,436 in 1973 to 74,524 in 1983. This indicates approximately six percent compounded growth for each year of the last 10 years. Gasoline consumption indicated about six percent growth per year and daily vehicle-miles traveled (DVMT) indicated about five percent growth per year. Since all these indicators show similar growth, the traffic growth factor for Clay County is recommended to be six percent. Because of the accuracy level of the data, it is recommended to round off to the nearest whole percent.

HEAVY TRUCKS AND 18-KIP LOADINGS

Many agencies do not keep separate records of truck volumes, but instead estimate them. Manual vehicle classification surveys taken at selected locations several times a year are used to derive a truck percentage of the total traffic volume. When a truck percentage is multiplied by a traffic volume, an estimated truck volume is produced. Since almost all 18-kip loads applied to a pavement are a result of heavy trucks, it is important that the numbers of trucks be estimated as closely as possible.

An analysis of vehicle classifications over a long time period will reveal a change in the composition of the truck fleet utilizing the nation's highways. The predominant type of heavy truck on the road in 1968 was a 2S2, tractor-trailer whereas in 1986 it is a 3S2 tractor-trailer. In the future, it well may be that double bottoms (2S1-2, 3S1-2) will be the most common trucks. Classifications are important because the same load carried on different styles of trucks can produce drastically different 18-kip ESALs. For example, on a flexible pavement with SN = 3 and PT = 2.5, the following may occur:

TYPE OF VEHICLE	AXLELOAD DISTRIBUTION (pounds)					TOTAL LOAD (pounds)	18-KIP ESAL
3S2	10,000	36,000	34,000			80,000	2.604
2S1-2	10,000	18,000	18,000	17,000	17,000	80,000	3.733

As illustrated above, the same 80,000-pound load can exert 43 percent more 18-kip ESAL's on the same pavement simply due to a different axle configurations.

Further refinements of accumulated 18-kip loadings may be derived through consideration of such elements as axleload distributions, truck tire pressures, lane distributions, and directional splits. Very little data are available about the first two, but the few studies that exist show the effects to be considerable.

The <u>1985 Traffic Monitoring Guide</u> from FHWA provides an excellent treatise on traffic variations and sampling procedures. For a rapidly growing State, such as Florida, it is important to provide coverage counts yearly, instead of a one-third sample as recommended by the Guide.

LACK OR SHORTAGE OF DATA ELEMENTS

Seldom, if ever, does the design traffic engineer have all the data required for an accurate traffic forecast. Consequently, compromises must be made. Available data are used to the fullest extent and statewide averages or defaults are used when necessary.

Traffic volume is the single most important variable in traffic forecasting. Without a volume as a starting point, the rest of the procedure is pointless. If sufficient volume history exists (approximately 10 years), then a growth factor can be derived from that history. If the volume history does not exist, use county-wide growth factors; lacking that, use statewide factors.

Next most important is the heavy truck volume. If the data are available, use it. Otherwise a vehicle classification somewhere on the road in question may be used to generate a truck percentage to multiply against the traffic volume and generate an estimated truck volume. If a road specific classification is unavailable, then classification from a similar type facility may be used. However, a county-wide truck percentage <u>is not</u> recommended -- it is too gross a number to yield respectable estimates.

Site specific truck weights provide the best estimate of 18-kip ESALs, but usually are unavailable. Statewide average truck equivalency factors are commonly available. If possible, subdivide these factors into rural/urban and functional class for better estimates.

If studies have been performed on unequal axleload distributions or high truck tire inflation pressures, use the results to factor up the 18-kip equivalency factors. Otherwise ignore it -- there are no accepted defaults for these values.

Directional factors play no role in the development of accumulated 18-kip axleloads -- the assumption is made that a road will experience even traffic distribution over a 10-20 year life. However, known anomalies can be accounted for by assuming 100 percent of the loads will occur in one direction. The prime example is a road leading from a mine -- all trucks will be loaded traveling from the mine and empty returning. If the directional distribution factor is desired for capacity analysis, use the factor from an ATR site, or a default of 0.55.

18-KIP ESTIMATES USING VARYING QUALITY DATA

The following example (Figure 7 and Tables 7 through 10) is typical of a rural resurfacing project in Florida. Estimates of accumulated 18-kip ESAL's are made for the same project using increasing amounts of site-specific data. Each successive load estimate provides a more accurate estimate of accumulated 18-kip ESAL's than the previous estimate. The last (Case 4, Table 10) provides the best estimate of loads for a resurfacing project on this road.

Interestingly, the four estimates only result in two different payment design overlays, but this cannot be expected to always occur. The best estimate of loadings will be based on detailed site-specific data.

Cases 1 through 4 are arranged in ascending order of most generalized information to most site-specific data:

- Case 1 (Table 7) has no field data from the project location (Available data from the nearest locations are used).
- Case 2 (Table 8) has ADT volumes and historical counts on the project location, and uses estimated K, D, and T factors and estimated 18-kip ESAL data.
- Case 3 (Table 9) has ADT volumes; historical counts; and K, D, and T factors on the project, and uses estimated 18-kip ESAL data.
- Case 4 (Table 10) has all site-specific project data.

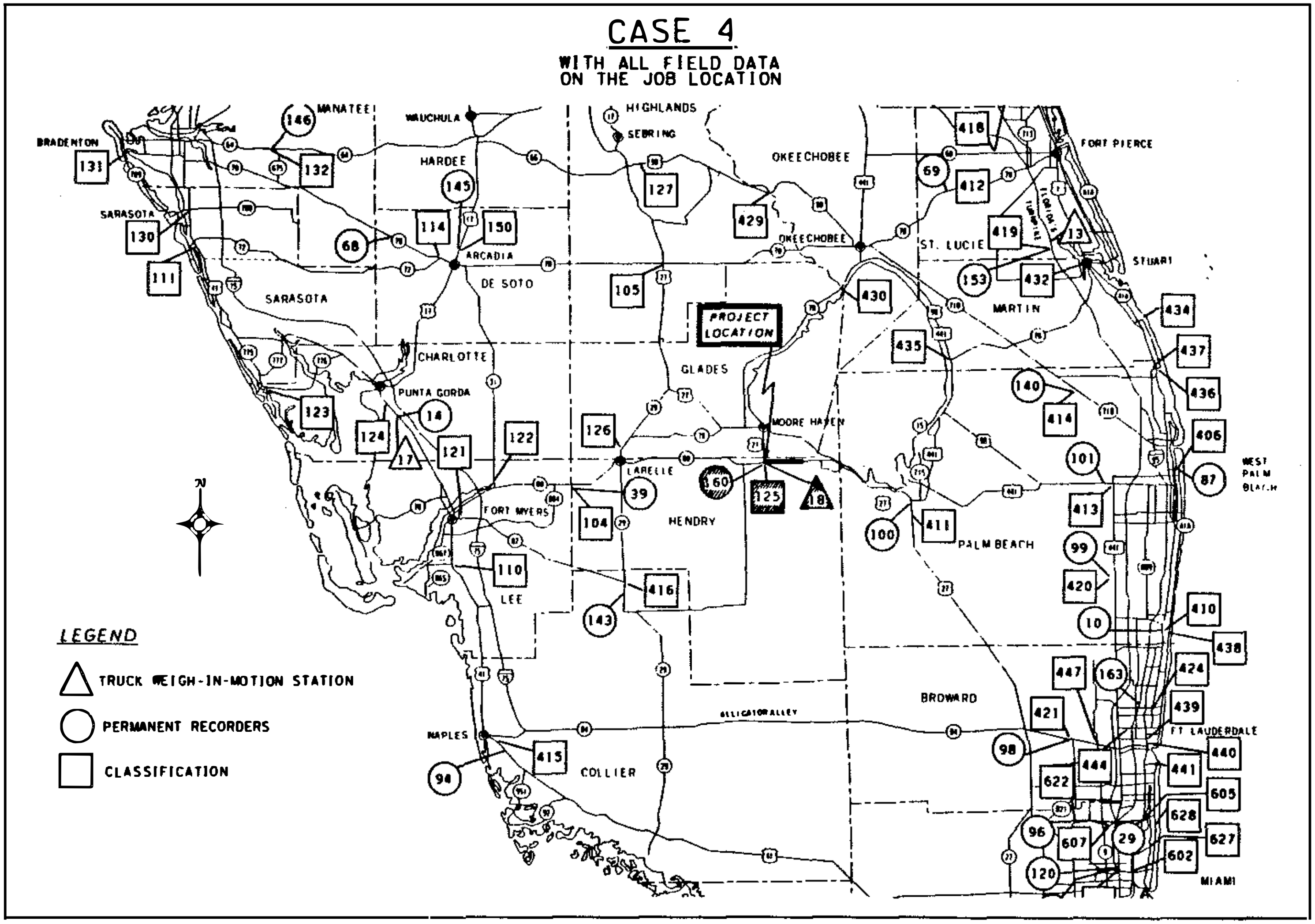


Figure 7. Map of portion of Florida showing resurfacing project location and locations of count stations.

Table 7. Case 1 (no field data for project location)

```
**** TSO FOREGROUND HARDCOPY ****
*** PRINTOFF, 15 MAY 86, 13:07:38.THURSDAY ***
DSNAME=PL934.H.ESAL.OUTPUT                              (K1        )

                    STATE OF FLORIDA
               DEPARTMENT OF TRANSPORTATION
                  DIVISION OF PLANNING
            BUREAU OF TRANSPORTATION STATISTICS

        18-KIP EQUIVALENT SINGLE AXLE LOADS FOR PAVEMENT DESIGN

     PREP. BY:   CLEMONS                 DATE:   5-14-86

     BUDGET  NO.:  0000000        PROJECT NAME:
  STATE PROJ. NO.:  07030-0000           ON:   SR 25/US1
    F.A.PROJ.NO.:                      FROM:  JUNCTION OF SR 80
          COUNTY:  HENDRY                TO:  SR 720
       TYPE WORK:  WIDENING,RESURFACING
        COMMENTS:  ASSUMES TWO LANES  TWO WAY FLEXIBLE PAVEMENT
                   SN=3,PT=2.5   K=11% D=54% T=15%
       TAPE FILE:  A:07 KIP,R-0000-00 CASE #1(NO DATA ON JOB)
```

		18-KIP ESAL(1000)					
YEAR	AADT	ANNUAL	ACCUM.	T	D	LF	EF
1986	12587.	406.	406.	0.15	0.50	0.9	1.3100
1987	12763.	412.	818.				
1988	12939.	418.	1236.				
1989	13115.	423.	1659.				
1990	13291.	429.	2088.				
1991	13467.	435.	2523.				
1992	13642.	440.	2963.				
1993	13818.	446.	3409.				
1994	13994.	452.	3861.				
1995	14170.	457.	4318.				
1996	14346.	463.	4781.				
1997	14522.	469.	5250.				
1998	14698.	474.	5724.				
1999	14874.	480.	6204.				
2000	15050.	486.	6690.				
2001	15226.	491.	7181.				
2002	15401.	497.	7678.				
2003	15577.	503.	8181.				
2004	15753.	508.	8689.				
2005	15929.	514.	9204.				
2006	16105.	520.	9723.	0.15	0.50	0.9	1.3100

Table 8. Case 2 (ADT and historical counts for project location)

```
**** TSO FOREGROUND HARDCOPY ****
*** PRINTOFF, 15 MAY 86, 13:16:03, THURSDAY ***
DSNAME=PL934?1.ESAL.OUTPUT                              (K1        )

                         STATE OF FLORIDA
                   DEPARTMENT OF TRANSPORTATION
                       DIVISION OF PLANNING
               BUREAU OF TRANSPORTATION STATISTICS

        18-KIP EQUIVALENT SINGLE AXLE LOADS FOR PAVEMENT DESIGN

           PREP. BY:  CLEMONS                  DATE:  5-14-86

         BUDGET NO.:  0000000      PROJECT NAME:
     STATE PROJ. NO.:  07030-0000              ON:  SR 25/US1
        F.A.PROJ.NO.:                        FROM:  JUNCTION OF SR 80
             COUNTY:  HENDRY                   TO:  SR 720
          TYPE WORK:  WIDENING,RESURFACING.
           COMMENTS:  ASSUMES TWO LANES  TWO WAY FLEXIBLE PAVEMENT
                      SN=3,PT=2.5   K=11% D=54% T=15%
          TAGF FILE:  A:07 KIP,R-0000-00 CASE #2(GOOD ADT,HISTORY--
                      ESTIMATED KDT,ESTIMATED 18KIP ESAL
```

YEAR	AADT	18-KIP ESAL(1000) ANNUAL	ACCUM.	T	D	LF	EF
1986	9616.	310.	310.	0.15	0.50	0.9	1.3100
1987	9724.	314.	624.				
1988	9832.	317.	942.				
1989	9940.	321.	1262.				
1990	10048.	324.	1587.				
1991	10156.	328.	1914.				
1992	10263.	331.	2246.				
1993	10371.	335.	2580.				
1994	10479.	338.	2919.				
1995	10587.	342.	3260.				
1996	10695.	345.	3605.				
1997	10803.	349.	3954.				
1998	10911.	352.	4306.				
1999	11019.	356.	4662.				
2000	11127.	359.	5021.				
2001	11235.	363.	5384.				
2002	11342.	366.	5750.				
2003	11450.	370.	6119.				
2004	11558.	373.	6492.				
2005	11666.	377.	6869.				
2006	11774.	380.	7249.	0.15	0.50	0.9	1.3100

Table 9. Case 3 (ADT; historical counts; K, D, and T factors for project location)

```
**** TSO FOREGROUND HARDCOPY ****
*** PRINTOFF. 15 MAY 86, 13:29:50. THURSDAY ***
DSNAME=PL934RH.ESAL.OUTPUT                                  (K1        )

                         STATE OF FLORIDA
                  DEPARTMENT OF TRANSPORTATION
                      DIVISION OF PLANNING
               BUREAU OF TRANSPORTATION STATISTICS

      18-KIP EQUIVALENT SINGLE AXLE LOADS FOR PAVEMENT DESIGN

         PREP. BY:  CLEMONS                    DATE:  5-14-86

       BUDGET NO.:  0000000        PROJECT NAME:
   STATE PROJ. NO.:  07030-0000                  ON:  SR 25/US1
     F.A.PROJ.NO.:                             FROM:  JUNCTION OF SR 80
          COUNTY:  HENDRY                        TO:  SR 720
        TYPE WORK:  WIDENING,RESURFACING
         COMMENTS:  ASSUMES TWO LANES  TWO WAY FLEXIBLE PAVEMENT
                    SN=3,PT=2.5   K=11% D=54% T=27%
        TA&F FILE:  A:07 KIP.R-0000-00 CASE #3(GOOD ADT.HISTORY--
                    GOOD KDT.ESTIMATED 18KIP ESAL
```

YEAR	AADT	18-KIP ESAL(1000) ANNUAL	ACCUM.	T	D	LF	EF
1986	9616.	559.	559.	0.27	0.50	0.9	1.3100
1987	9724.	565.	1124.				
1988	9832.	571.	1695.				
1989	9940.	577.	2272.				
1990	10048.	584.	2856.				
1991	10156.	590.	3446.				
1992	10263.	596.	4042.				
1993	10371.	603.	4645.				
1994	10479.	609.	5253.				
1995	10587.	615.	5869.				
1996	10695.	621.	6490.				
1997	10803.	628.	7117.				
1998	10911.	634.	7751.				
1999	11019.	640.	8391.				
2000	11127.	646.	9038.				
2001	11235.	653.	9690.				
2002	11342.	659.	10349.				
2003	11450.	665.	11015.				
2004	11558.	671.	11686.				
2005	11666.	678.	12364.				
2006	11774.	684.	13048.	0.27	0.50	0.9	1.3100

Table 10. Case 4 (all data are site specific)

```
**** TSO FOREGROUND HARDCOPY ****
*** PRINTOFF. 24 APR 86. 13:09:18. THURSDAY ***
DSNAME=PL934101.K1.DATA

                    STATE OF FLORIDA
              DEPARTMENT OF TRANSPORTATION
                  DIVISION OF PLANNING
          BUREAU OF TRANSPORTATION STATISTICS

    18-KIP EQUIVALENT SINGLE AXLE LOADS FOR PAVEMENT DESIGN

       PREP. BY:  CLEMONS                 DATE:  4-24-86

     BUDGET  NO.:  0000000        PROJECT NAME:
 STATE PROJ. NO.:  07030 0000               ON:  SR 25/US27
   F.A.PROJ.NO.:                          FROM:  JUNCTION OF SR80
        COUNTY:  HENDRY                     TO:  SR 720
     TYPE WORK:  RESURFACING              CASE #4 (ALL GOOD DATA)
      COMMENTS:  ASSUMES FOUR LANES-TWO WAY FLEXIBLE PAVEMENT
                 SN=3,PT=2.5     K=11% D=57% T=27/14
     TAGF FILE:  A:07 KIP.R-0000
```

YEAR	AADT	18-KIP ESAL(1000) ANNUAL	ACCUM.	T	D	LF	EF
1986	9616.	525.	525.	0.27	0.50	0.9	1.2300
1987	9724.	530.	1055.				
1988	9832.	536.	1591.				
1989	9940.	542.	2133.				
1990	10048.	548.	2681.				
1991	10156.	554.	3235.				
1992	10263.	560.	3795.				
1993	10371.	566.	4361.				
1994	10479.	572.	4933.				
1995	10587.	577.	5510.				
1996	10695.	583.	6094.				
1997	10803.	589.	6683.				
1998	10911.	595.	7278.				
1999	11019.	601.	7879.				
2000	11127.	607.	8486.				
2001	11235.	613.	9099.				
2002	11342.	619.	9717.				
2003	11450.	625.	10342.				
2004	11558.	630.	10972.				
2005	11666.	636.	11609.				
2006	11774.	642.	12251.	0.27	0.50	0.9	1.2300

APPENDIX B

HISTORICAL TRAFFIC DATA USED TO ESTIMATE ACCUMULATED PAVEMENT FATIGUE (AN EXAMPLE)

A section of I 65 in Kentucky failed after only seven months of service. Investigation of the properties of the constituent materials indicated that all had met minimum specification limits. Initial analyses revealed that the original estimation of traffic was low and that the estimated design strength of the subgrade was high. This combination led to an inadequate thickness design. A minimal thickness design, materials meeting minimum specifications, and high levels of existing traffic created a combination of conditions that compounded to cause a premature failure. To completely evaluate the failure, it was necessary to estimate the accumulated fatigue history for that section of interstate pavement. Estimating an accumulated fatigue requires such information as:

- Quantification of factors influencing load equivalency factors.
- Vehicle volumes.
- Classification of the traffic stream.

LOAD EQUIVALENCY FACTORS

Flexible pavement designs are primarily a function of traffic volume, material characteristics, and the relative damage (fatigue) caused by various axleloads and their configurations. If material characteristics and traffic volumes are assumed to have been determined, variations in thicknesses would be a function of relative load equivalency factors, i.e., the loading conditions.

ANALYSES OF AXLE CONFIGURATIONS

Uniform Loading

The Chevron N-layer computer program was used to analyze the effects on highway pavement performance of tire and axle configurations where all tires in a configuration were equally loaded. An 18-kip four-tired single axleload was used as the reference load. Figure 8 shows the relationships between damage factor (or load equivalency factor) and total load on axle groups when the load is uniformly distributed among the axles of the group. The curves shown in Figure 8 may be approximated by

$$\log(DF) = a + b(\log(Load)) + c(\log(Load))^2, \qquad (2)$$

in which DF = load equivalency factor of total load on axle configuration relative to an 18-kip four-tired axleload,

Load = axleload in kips, and

a, b, c = regression coefficients (Table 11).

Uneven Loads on Tandems

Analyses of the effects of uneven load distributions on the axles of a 36-kip tandem group revealed that the damage factor for the load distributed evenly on the tandem should be adjusted by a multiplying factor (MF) illustrated in Figure 9 to account for uneven load distributions. Analyses of 1980 W-4 tables for Kentucky revealed a 40-percent increase in the calculated fatigue when the uneven load distribution was considered.

Uneven Loads on Tridems

The increased use of tridem axle groups suggested an investigation of actual load distributions. Inspection of the W-4 tables revealed that the majority of tridems had uneven load distributions. Adjustment factors to account for those uneven loadings were developed. The following definitions were used:

M = the heaviest axleload of the three axles,

L = the least axleload of the three axles,

I = the intermediate axleload between the maximum and minimum axleloads, and

E = the axleload is equal to an axleload on at least one other axle.

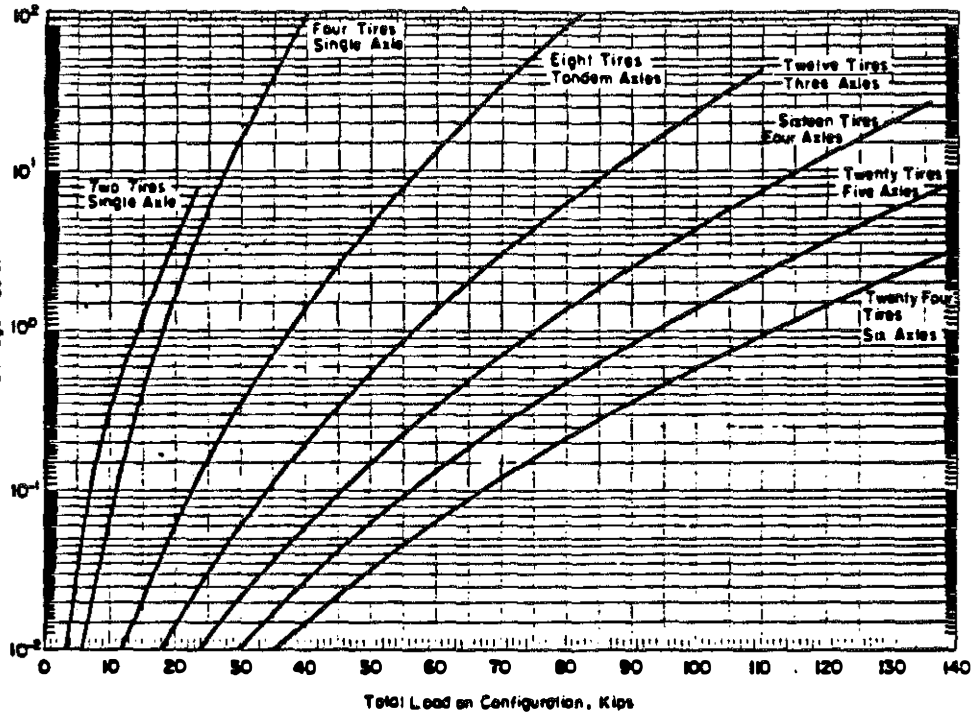


Figure 8. Relationship between load equivalency and total load on the axle group, evenly distributed on all axles.

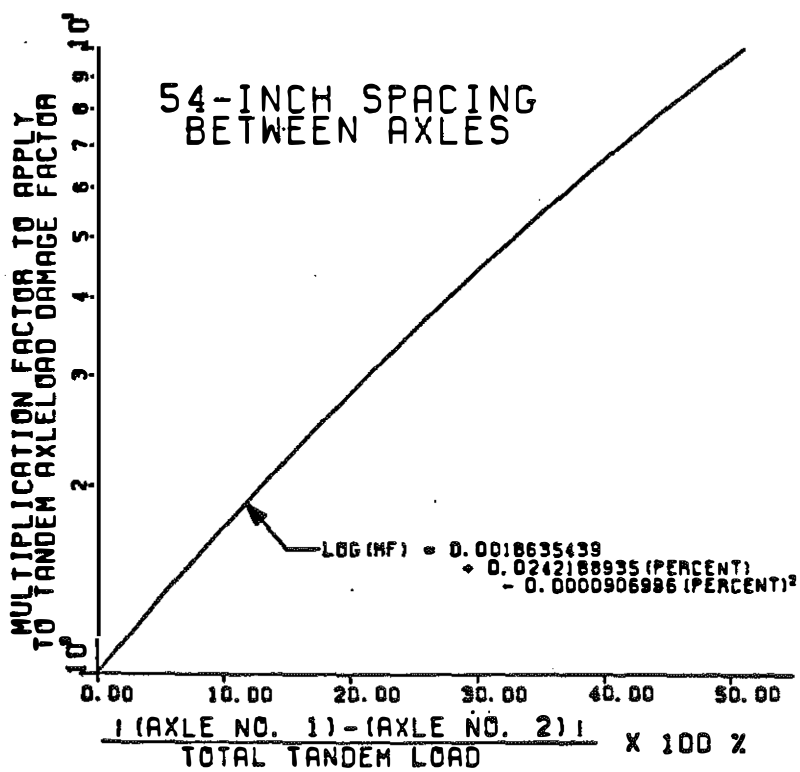


Figure 9. Multiplying factor to account for uneven load distribution on the two axles of a tandem.

Table 11. Regression coefficients to calculate load equivalency for various axle configurations

$$\log(\text{Damage Factor}) = a + b(\log(\text{Load})) + c(\log(\text{Load}))^2$$

AXLE CONFIGURATION	COEFFICIENTS a	b	c
Two-Tired Single Front Axle	-3.540112	2.728860	0.289133
Four-Tired Single Rear Axle	-3.439501	0.423747	1.846657
Eight-Tired Tandem Axle	-2.979479	-1.265144	2.007989
Twelve-Tired Tridem Axle	-2.740987	-1.873428	1.964442
Sixteen-Tired Quad Axle	-2.589482	-2.224981	1.923512
Twenty-Tired Quint Axle	-2.264324	-2.666882	1.937472
Twenty-four Tired Sextet Axle	-2.084883	-2.900445	1.913994

Note: Load is in kips (1 kip = 1,000 pounds)

The allowable repetitions associated with 54 kips uniformly distributed on the tridem were determined for comparison to various uneven load patterns. Table 12 summarizes the coefficients and regression statistics of the analysis. The influence of pavement structure upon the scatter of data was very significant for tridems, but structure was not nearly so influential for an uneven load distribution within a tandem. For 670 tandems, the accumulated adjusted ESAL was 1.4 times that of an evenly distributed load. For 1,951 tridems, the accumulated adjusted ESAL was 2.3 times that of evenly distributed loads.

FLOTATION VERSUS DUAL TIRES

In recent years, wide flotation tires have been utilized on steering axles and, more recently, to replace dual tires on rear axles. Ready-mix transit trucks that once had ten tires on three axles, or fourteen tires on four axles, now may have a total of six or eight tires, respectively, with all tires being the same size. The effects of single flotation versus "standard" dual tires are illustrated in Figure 10. There is a larger difference in damage factors between flotation tires and dual tires at lesser loads, and the damage factors approach equality at the higher loads. Contact areas for flotation tires at higher loads approach the total area of standard dual tires. Analyses have not been made for unequal load distributions on single flotation tires.

EFFECTS OF AXLE SPACING

To determine the sensitivity of damage factor to the distance between axles of a tandem group, the appropriate relationship between axle spacing and an adjustment factor is defined as

$$\log(adj) = -1.589746 + 1.505263(\log(sp)) - 0.337357(\log(sp))^2 \quad (3)$$

in which adj = adjustment for axle spacing greater than 54 inches and
sp = spacing between two axles of the tandem, inches.

Table 12. Coefficients from regression analyses of unequal load distribution on individual axles of tridem axle group

log(Multiplying Factor) = a + b(Ratio) + c(Ratio)^2
in which Ratio = (M - L) / I
M = Maximum Axleload, kips,
I = Intermediate Axleload, kips,
L = Least Axleload, kips, and
a,b,c = coefficients

Load Pattern: 1. L,I,M 2. M,I,L 3. M,E,E 4. E,E,M	
Constant a	0.468782731
Coefficient b	1.093207072
Coefficient c	-0.1503124207
Standard Error of Estimate	0.073149
Correlation Coefficient, R	0.96024
F Ratio	1183.4
Sample Size	648
Load Pattern: 1. I,L,M 2. M,L,I 3. E,L,E	
Constant a	-0.1161216122
Coefficient b	1.507954095
Coefficient c	0.377814882
Standard Error of Estimate	0.069341
Correlation Coefficient, R	0.92765
F Ratio	326.9
Sample Number	343
Load Pattern: 1. L,M,I 2. I,M,L 3. E,M,E	
Constant a	-0.0235937584
Coefficient b	1.283412872
Coefficient c	-0.2187655038
Standard Error of Estimate	0.088165
Correlation Coefficient, R	0.92395
F Ratio	710.7
Sample Size	478
Load Pattern: 1. L,E,E 2. E,E,L	
Constant a	0.0004399421
Coefficient b	0.8053052125
Coefficient c	0.2363591702
Standard Error of Estimate	0.05634
Correlation Coefficient, R	0.96827
F Ratio	1037.4
Sample Size	282
Load Pattern: All Patterns Above	
Constant a	-0.198429071
Coefficient b	1.20191282
Coefficient c	-0.1746353238
Standard Error of Estimate	0.09792
Correlation Coefficient, R	0.9240
F Ratio	2085.4
Sample Size	1951

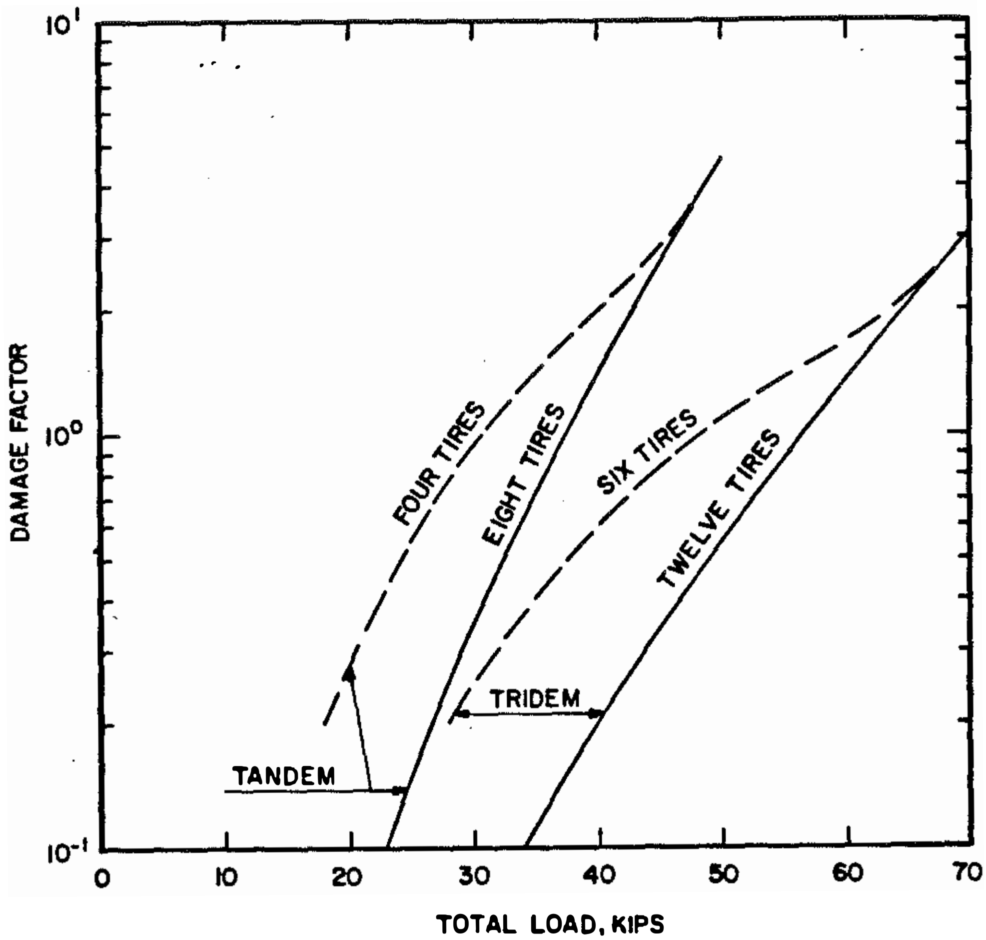


Figure 10. Load-equivalency relationships for four-tired and eight-tired tandem axles and for six-tired and twelve-tired tridem axles.

KINGPIN LOCATION

The kingpin location, the connection between a trailer and the tractor, may be varied by the trucker up to as much as 24 or 30 inches from its desirable location. Displacements of the kingpin by as much as 18 inches is not uncommon. Such a displacement may shift a portion of the trailer load to the steering axle where small increases in load are proportionately more damaging to the pavement as well as creating a safety problem by increasing the difficulty of steering.

An increase from 9 kips to 10.7 kips on the front axle causes the load equivalency factor for that axle to increase from 0.2 to 0.4. However, a 1.7-kip increase of the tandem axleload of 34 kips causes an increase in the load equivalency factor of only 0.18. Moving the kingpin assembly back to the center of the tandem on the tractor will not increase the pavement life significantly. Thus, no adjustment factor for location of the kingpin is utilized because any shift in position is directly reflected in the axleloads.

EFFECTS OF TIRE PRESSURES

A small sample of axleloads, tire contact lengths, tread widths, types of tire construction (radial or bias ply), tire pressures, and axle spacings were utilized to evaluate the impact of tire pressures. Figure 11 is a histogram summarizing tire pressure data in 5-psi intervals. In summary, the following observations are made:

- Seventy-four percent of all tires were radials.
- Pressures in seven percent of all tires ranged between 120 and 129 psi.
- The average tire pressure for all tires was 102 psi.
- The average tire pressure for all tires on the steering axle was 105 psi.
- The average tire pressure for all tires on rear axles was 101.4 psi.
- Pressures for radial tires:
  a. The average for all tires was 105 psi.
  b. The average for the steering axle was 108 psi.

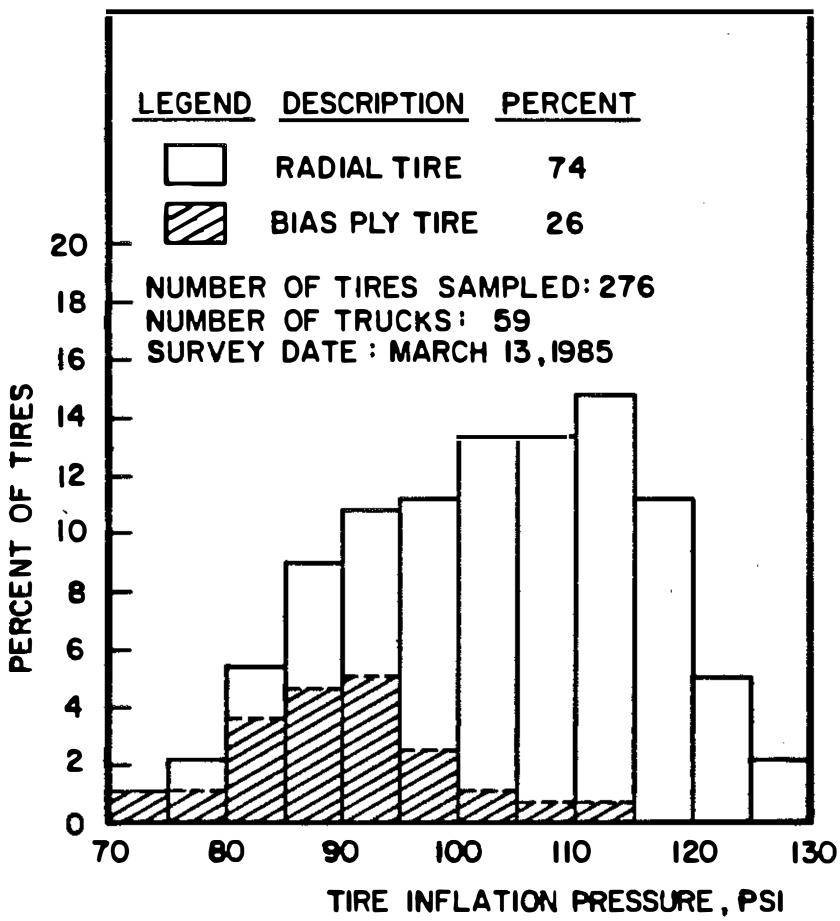


Figure 11. Histogram of measured tire pressures.

c. The average for tires on rear axles was 104 psi.

- Pressures for bias-ply tires:
  a. The average for all tires was 90 psi.
  b. There was only 0.3-psi difference in pressure between the steering and rear axle tires.
- The average pressure in radial tires was 15.3 psi higher than that for bias-ply tires.
- As much as a 40-psi differential was detected between tires within the same tandem group.

At the AASHO Road Test, most tires were inflated to 75 psi, resulting in a contact pressure of 67.5 psi. Increased tire pressures decrease the length (and thus area) of the tire in contact with the pavement. The reduced area causes an increased punching effect.

All load equivalency factors associated with loads and adjustment factors for variations in load distribution between axles and distance between axles of a tandem have been determined to be relatively insensitive to pavement thickness. However, the adjustment factors for variations in tire pressures for four-tired single axles are dependent upon the thickness of the asphaltic concrete. Substituting the terms "adjustment factor" for "damage factor" and "tire pressure" for "load", Equation 2 also describes the adjustment factor as a function of tire pressure for a constant thickness of asphaltic concrete. Values for the regression coefficients are given in Table 13.

An analysis was made for axle groupings using flotation tires instead of dual tires. Fatigue effects of tire-pressure variations for flotation tires are much more severe (as much as four to five times) as for the same pressure in groups using dual tires.

CASE HISTORY

For the section of I 65 in Kentucky constructed in 1984 mentioned at the beginning of this appendix, available data to approximate the accumulated fatigue included the following:

Table 13. Regression coefficients to calculate adjustment factors for varying tire pressures and axle configurations for equally distributed tire loads

log(Factor) = A + B log(TCP) + C (log(TCP))^2
in which TCP = Tire Contact Pressure

THICKNESS OF ASPHALTIC CONCRETE (inches)	COEFFICIENTS A	B	C
	TWO-TIRED SINGLE AXLE		
3	-11.423641	8.452615	-1.206807
4	-9.718723	7.272744	-1.071370
5	-8.667064	6.604668	-1.020443
6	-7.983404	6.219065	-1.013936
7	-7.528589	6.005482	-1.033063
8	-7.225865	5.903743	-1.067872
9	-7.029159	5.878171	-1.112632
10	-6.909049	5.906263	-1.163835
	FOUR-TIRED TANDEM AXLE		
3	-11.983535	8.850933	-1.257276
4	-10.133166	7.527803	-1.086909
5	-9.191001	6.946769	-1.050864
6	-8.721212	6.741902	-1.079290
7	-8.540266	6.763541	-1.145226
8	-8.543689	6.926599	-1.233377
9	-8.670125	7.181627	-1.335045
10	-8.881250	7.498079	-1.444985
	SIX-TIRED TRIDEM AXLE		
3	-12.227565	9.069919	-1.304090
4	-10.347085	7.708593	-1.121828
5	-9.423848	7.141287	-1.087605
6	-9.016720	6.994653	-1.129134
7	-8.913110	7.093011	-1.213003
8	-9.009383	7.342882	-1.321764
9	-9.230684	7.690169	-1.445523
10	-9.539068	8.101609	-1.578329
	FOUR-TIRED SINGLE AXLE		
3	-2.464465	0.576804	0.420942
4	-1.962926	0.591450	0.263080
5	-1.637979	0.612273	0.154626
6	-1.414034	0.635424	0.075089
7	-1.253849	0.659304	0.014209
8	-1.136684	0.683179	-0.033811
9	-1.049978	0.706696	-0.072534
10	-0.985633	0.729684	-0.104286
	EIGHT-TIRED TANDEM AXLE		
3	-2.573477	0.647141	0.414958
4	-2.221248	0.803333	0.224419
5	-1.889261	0.818996	0.116696
6	-1.579889	0.763381	0.054667
7	-1.291573	0.668360	0.020454
8	-1.022015	0.550498	0.004322
9	-0.768984	0.419143	0.000498
10	-0.530517	-0.279885	0.005342
	TWELVE-TIRED TRIDEM AXLE		
3	-2.640784	0.686070	0.413835
4	-2.224371	0.777724	0.239410
5	-1.829865	0.730261	0.147497
6	-1.461152	0.614593	0.100533
7	-1.116870	0.462852	0.080565
8	-0.794540	0.291453	0.077889
9	-0.491654	0.109482	0.086793
10	-0.205964	-0.077749	0.103706

- Hourly vehicle volume counts obtained with automatic recorders at a nearby site.
- Quarterly manual vehicle classification counts (Table 14 is a typical example).
- Loadometer data obtained over two consecutive days while the pavement was opened to traffic.

Inspection of the quarterly manual counts revealed there were no continuous 24-hour counts and that counts were conducted for a fixed group of hours on the same day of each week, i.e., 6 pm - 10 pm on Mondays, 10 am - 6 pm on Tuesdays, 6 am - 10 am on Wednesdays, and 10 pm - 6 am on Thursdays as marked by the horizontal lines in Table 14. No vehicle classification data were available for Fridays, Saturdays, and Sundays. Special 24-hour counts were made on a Saturday and Sunday to obtain some estimate of vehicle classifications on weekends. Another 24-hour count was made on a Wednesday to verify the validity of an estimation procedure used herein to distribute daily volumes among classifications and to estimate daily traffic volume data for missing hours and/or days. Table 15 is an example giving the sum of the counted vehicles for Mondays through Fridays (from Table 14) and expressed as percentages. Table 16 (a Saturday count) and Table 17 (a Sunday count) correspond to Table 15. The percentage of trucks for Monday through Friday (32 percent) was much higher than for Saturday (18 percent) and Sunday (12 percent). Analyses of vehicle classification counts showed large variations in the percentages for some classifications during a 24-hour period and during the calendar year.

A 24-hour count was made in March 1985 to answer the question, "Is the distribution of vehicle classifications for a group of hours taken during any weekday approximately the same as distribution for the same group of hours during a 24-hour count?" Hourly classification counts taken during the special 24-hour count on a Wednesday were grouped identically to that shown in Table 14. Percentages were calculated and compared to the count taken in April 1984 (the same season of the year) and found to be nearly the same. Thus, the classification counts were converted to percentages corresponding to the groups of hours shown in

Table 14. Typical manual vehicle classification count

KENTUCKY TRANSPORTATION CABINET, DEPARTMENT OF HIGHWAYS
DIVISION OF PLANNING, TRAFFIC SURVEY AND ANALYSIS SECTION
VEHICLE CLASSIFICATION COUNT
COUNTY: HARDIN 1984 STATION: L54 N
DISTRICT: 4 ROUTE: I 65
MILEPOST: 89.400
ROAD DESIGNATION: R
LOCATION INFORMATION: 1.5 MILES SOUTH OF THE KY-61 INTERCHANGE, SOUTH OF ELIZABETHTOWN

							SINGLE UNIT TRUCKS			SINGLE TRAILER TRUCKS			MULTI-TRAILER TRUCKS				
				OTHER 2 AXLE 4 TIRE	BUSSES												
TIME PERIOD	DATE	MOTOR CYCLES	PASSENGER CARS	VEHICLES	SCHOOL	OTHER	2 AXLE 6 TIRE	3 AXLE	4 OR MORE AXLE	4 OR LESS AXLE	5 AXLE	6 OR MORE AXLE	5 OR LESS AXLE	6 AXLE	7 OR MORE AXLE	COAL TRUCKS	TOTAL VEHICLES
06-07AM	6/20/84	1	153	42	0	1	8	0	0	0	73	0	0	2	0	0	280
07-08AM	6/20/84	0	273	57	0	2	15	0	0	0	97	0	0	1	0	0	445
08-09AM	6/20/84	2	142	36	0	3	11	0	0	2	93	0	6	0	0	0	295
09-10AM	6/20/84	0	174	33	0	1	13	0	0	4	85	1	0	1	0	1	312
10-11AM	6/19/84	2	402	123	1	3	26	5	10	13	108	0	7	0	0	11	700
11-12AM	6/19/84	1	358	110	0	2	20	2	22	30	115	0	14	0	0	11	674
12-01PM	6/19/84	2	418	109	1	1	22	3	4	10	165	0	12	2	0	0	749
01-02PM	6/19/84	3	532	248	0	0	98	10	0	40	214	0	17	0	0	0	1162
02-03PM	6/19/84	2	472	188	0	2	76	12	0	38	202	0	19	1	0	0	1012
03-04PM	6/19/84	3	313	101	0	3	72	11	0	31	139	2	10	0	0	0	685
04-05PM	6/19/84	3	306	79	0	1	12	1	2	13	76	0	1	0	0	0	494
05-06PM	6/19/84	2	270	61	0	0	42	7	0	6	95	0	1	0	0	0	484
06-07PM	6/18/84	6	411	89	0	2	41	8	3	4	145	5	3	2	0	0	719
07-08PM	6/18/84	3	351	72	0	0	33	9	8	1	141	4	3	1	0	0	626
08-09PM	6/18/84	1	218	64	1	1	13	0	0	5	87	0	2	0	0	0	392
09-10PM	6/18/84	3	163	33	0	3	10	1	0	3	74	0	4	0	0	0	294
10-11PM	7/02/84	3	167	34	0	1	17	0	0	19	96	0	2	0	0	0	339
11-12PM	7/02/84	1	152	24	0	0	8	0	0	11	86	1	0	2	0	0	285
12-01AM	7/03/84	0	148	30	0	2	6	0	0	4	72	0	4	0	0	0	266
01-02AM	7/03/84	2	176	42	0	2	18	0	0	10	81	0	3	0	0	0	334
02-03AM	7/03/84	0	151	44	0	0	14	0	0	11	73	0	4	0	0	0	297
03-04AM	7/03/84	0	122	14	0	0	7	0	0	19	78	0	3	0	0	0	243
04-05AM	7/03/84	0	143	11	0	0	9	0	0	10	64	0	2	0	0	0	239
05-06AM	7/03/84	0	160	15	0	0	8	0	0	9	75	0	10	0	0	0	277
TOTAL VEHICLES		40	6175	1659	3	30	599	69	49	293	2534	13	127	12	0	23*	11603
PERCENT OF TOTAL		0.3	53.2	14.3	0.0	0.3	5.2	0.6	0.4	2.5	21.8	0.1	1.1	0.1	0.0	0.2	

% HEAVY TRUCKS = 3729/11603 = 32.1%
AXLES / TRUCK = 16294/ 3729 = 4.370
TOTAL HOURS = 24

AXLE CORRECTION FACTOR = 0.72

WEIGHT LIMIT: 80000
LATEST ADT COUNT: 19583 IN 1983

* NOTE: COAL TRUCKS HAVE BEEN INCLUDED WITH OTHER TRUCK TYPES (ACCORDING TO APPROPRIATE VEHICLE TYPE) FOR COMPUTATION OF TOTAL TRUCKS, PERCENT TRUCKS, AXLES PER TRUCK, AND AXLE CORRECTION FACTOR.

HIGHWAY SYSTEMS
FEDERAL : 1
STATE : 1
FUNCTIONAL: 1

Table 15. Sum of hourly counts from Table 14 for Monday through Friday

VEHICLE CLASSIFICATION	DATE/TIME 6/20/84 6AM-10AM NO.	%	DATE/TIME 6/19/84 10AM-6PM NO.	%	DATE/TIME 6/18/84 6PM-10PM NO.	%	DATE/TIME 7/2-3/84 10PM-6AM NO.	%	TOTAL NO.	%
Auto + Others	920	60.1	4122	69.2	1421	70.0	1444	63.3	7907	68.2
22	47	3.5	368	6.2	97	4.8	87	3.8	599	5.2
23	0	0.0	51	0.9	18	0.9	0	0.0	69	0.6
24	0	0.0	38	0.6	11	0.5	0	0.0	49	0.4
321/322/331	6	0.5	181	3.0	13	0.6	93	4.1	293	2.5
332	348	26.1	1114	18.7	447	22.0	625	27.4	2534	21.8
333	1	0.1	2	0.0	9	0.4	1	0.0	13	0.1
5212	6	0.5	81	1.4	12	0.6	28	1.2	127	1.1
6312	4	0.3	3	0.1	3	0.1	2	0.1	12	0.1

Table 16. Sum of hourly counts for Saturdays

VEHICLE CLASSIFICATION	DATE/TIME 6/20/84 6AM-10AM NO.	%	DATE/TIME 6/19/84 10AM-6PM NO.	%	DATE/TIME 6/18/84 6PM-10PM NO.	%	DATE/TIME 7/2-3/84 10PM-6AM NO.	%	TOTAL NO.	%
Auto + Others	38178	79.4	156098	86.4	55020	85.2	47626	70.6	296922	82.3
22	1023	2.1	3738	2.1	1477	2.3	1195	1.8	7433	2.1
23	76	0.1	312	0.2	31	0.1	254	0.4	673	0.2
24	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
321/322/331	230	0.5	991	0.5	492	0.8	507	0.8	2220	0.6
332	7978	11.8	18185	10.1	7354	11.4	16805	24.9	50322	13.9
333	128	0.3	56	0.1	0	0.0	72	0.1	256	0.1
5212	435	0.9	1190	0.7	215	0.3	1050	1.6	2890	0.8
6312	51	0.1	29	0.1	0	0.0	0	0.0	80	0.1

Table 17. Sum of hourly counts for Sundays

VEHICLE CLASSIFICATION	DATE/TIME 6/20/84 6AM-10AM NO.	%	DATE/TIME 6/19/84 10AM-6PM NO.	%	DATE/TIME 6/18/84 6PM-10PM NO.	%	DATE/TIME 7/2-3/84 10PM-6AM NO.	%	TOTAL NO.	%
Auto + Others	27828	73.5	202855	90.8	87379	89.0	41187	83.8	359249	87.9
22	364	1.0	1030	0.5	1469	1.5	852	1.7	3715	0.9
23	42	0.1	0	0.0	202	0.2	164	0.3	408	0.1
24	154	0.4	103	0.1	10	0.0	0	0.0	267	0.1
321/322/331	406	1.1	825	0.4	319	0.3	194	0.4	1744	0.4
332	8650	22.8	16578	7.4	8426	8.6	6558	13.3	40212	9.8
333	280	0.7	308	0.1	31	0.0	75	0.2	694	0.2
5212	84	0.2	1441	0.6	394	0.4	119	0.2	2038	0.5
6312	70	1.2	308	0.1	0	0.0	0	0.0	378	0.1

Table 14. Figure 12 is an example illustrating the variations in percentages over the year (determined from seasonal counts) for cars and five-axle semitrailer trucks for the hours from 10 pm to 6 am for weekdays.

To utilize the hourly recorded traffic volumes and the vehicle classification distributions required an interpolation procedure assumed to be that shown in Figure 12. Wednesdays were assumed to be the middle of the week. Straight-line segments were used to connect the data points in Figure 12. The total volume for a group of hours (Table 14) was obtained by summing the volumes for those hours for Monday through Friday. Volumes for Saturdays and Sundays also were summed according to the same groups of hours shown in Table 14 and distributed according to the percentages shown in Tables 16 and 17, respectively. The total weekly sum was distributed for each vehicle classification according to the percentage factor appropriate to that week (Figure 12 is an example for two classifications). Summing all weekly volumes for each vehicle classification produces the total volume distribution as shown in Table 18.

Only one loadometer study had been conducted during the time the distressed pavement was open to traffic (April 29, 1984, to November 21, 1984). Data were sorted by vehicle classification. For a given vehicle classification, damage factors for each vehicle were calculated for each axleload according to tire and axle configurations corresponding to the relationships given in Table 11, adjusted for uneven load distributions when appropriate, and then summed for that vehicle. After calculating and summing the ESAL for each vehicle within a given classification, the total ESAL for all vehicles in that classification was the sum of the total ESAL for each vehicle. An average damage factor for each vehicle classification was calculated by dividing the total calculated ESAL by the number of vehicles in that classification (Table 19). Corresponding values from Tables 18 and 19 were multiplied and the products summed, yielding the resulting ESAL shown in Table 20.

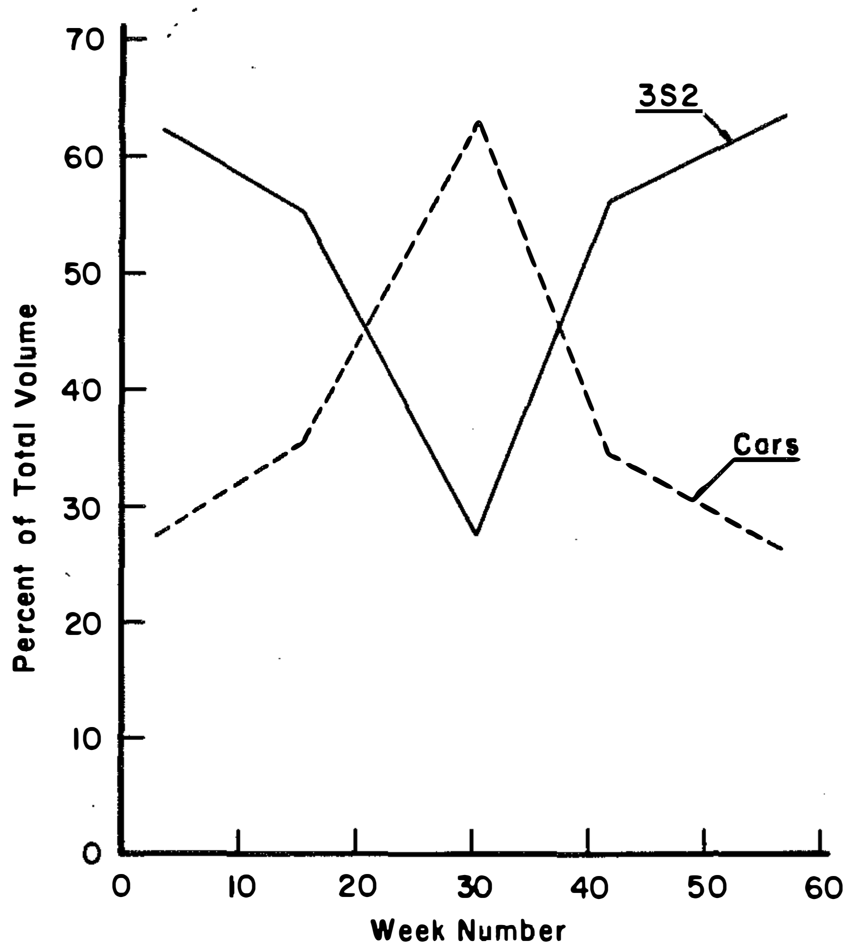


Figure 12. Percentage of total volume versus week number for cars and Five-Axle Semitrailer Trucks.

Table 18. Estimated total volume of vehicles by classification

VEHICLE CLASSIFICATION	VOLUME 6AM-10AM NO.	10AM-6PM NO.	6PM-10PM NO.	10PM-6AM NO.	SATURDAY NO.	SUNDAY NO.	TOTAL NO.
Auto + Others	141406	140690	537943	183736	296922	359249	1659946
22	11356	9140	38408	12685	7433	3715	82737
23	544	339	4965	1755	673	408	8684
24	0	636	2648	693	0	257	4284
321/322/331	10623	3632	16562	3269	2220	1744	38050
332	131594	62135	146629	75738	50322	40212	506630
333	87	263	958	704	256	694	2962
5212	5227	2124	8302	1909	2890	2033	22490
6312	4	4	3	2	80	373	466

Table 19. Estimated accumulated fatigue

VEHICLE CLASSIFICATION	AVERAGE LOAD EQUIVALENCY
Auto + Others	0.0050
22	0.2081
23	0.4362
24	0.4362
321/322/331	0.4851
332	0.9608
333	0.7402
5212	1.8784
6312	1.6960

Table 20. Estimated accumulated fatigue adjusted for increased truck tire inflation pressures and radial tire usage

VEHICLE CLASSIFICATION	TOTAL VOLUME	AVERAGE LOAD EQUIVALENCY	UNADJUSTED 18-KIP EAL (COL 2 x COL 3)	EAL ADJUSTED FOR TIRE PRESSURE AND TYPE (1.2912 x COL 4)
Auto + Others	1659946	0.0050	8299.7	8299.7
22	82737	0.2081	17217.6	17217.6
23	8684	0.4362	3788.0	4890.6
24	4284	0.4362	1868.7	2412.7
321/322/331	38050	0.4851	18458.1	23831.3
332	506630	0.9608	486770.1	628468.9
333	2962	0.7402	2192.5	2830.7
5212	22490	1.8784	42245.2	54542.8
6312	466	1.6960	975.2	1259.1
Total	2326249		581815.1	743753.4

The distressed pavement consisted of 7 inches of asphaltic concrete over 16 inches of a dense-graded aggregate base placed on a CBR 3 subgrade. Bias ply truck tires accounted for 26 percent of the tires, and the average tire pressure resulted in a required multiplying factor of 1.192 to adjust the calculated ESAL. Radial tires accounted for the remaining 74 percent, and the increased tire inflation (and corresponding contact) pressure resulted in a correction factor of 1.326 to adjust the calculated ESAL. The estimated ESAL for each truck style was adjusted by

$$\begin{aligned} TESAL &= (0.26 \times 1.192 + 0.74 \times 1.326)\ ESAL \\ &= 1.2912 \times ESAL \end{aligned}$$

in which TESAL = the adjusted ESAL accounting for tire construction and contact pressure.

Adjusted ESAL´s are shown in Table 20 by vehicle classification and as a total.

To verify the accuracy of the estimated ESAL´s, cores were obtained from the pavement. Resilient modulus tests were run on some of the cores and extraction tests were performed on the remainder. The modulus of elasticity adjusted for percent asphalt content and voids content in the mix was within the range of moduli obtained from the resilient modulus tests. Because the pavement had failed, an estimate of the in-place modulus could be made theoretically as a function of the estimated fatigue. The modulus was adjusted to an equivalent value to match the temperature conditions used during the resilient modulus tests on the cores. The modulus associated with traffic fatigue and adjusted for temperature also fell in the range of values obtained from the resilient modulus tests. Thus, approximately the same modulus was obtained from three different analyses. Therefore, it may be concluded that the procedure used to fill gaps in data was adequate. The factors used to adjust the estimated fatigue for changes in load patterns, tire inflation pressures, and tire construction are valid and needed to obtain a closer estimate of fatigue caused by traffic versus the original design assumptions. This particular example illustrates the vast difference between assumed design parameters and actuality. Fatigue is a function of the traffic using the pavement and the combination of physical properties of the in-place materials and not of the number of years chosen for the original design.

APPENDIX C

OVERLAY SENSITIVITY TO DESIGN INPUTS USING THE ASPHALT INSTITUTE'S DESIGN PROCEDURES

The following sensitivity analysis shows that pavement overlay design is significantly influenced by the traffic inputs used to estimate design loadings. It points out the monetary consequences of using poor estimates of traffic in pavement design calculations. The main body of this document points out the types of data that should be collected and forecast for pavement design; this analysis underscores the need for such data and the consequences of not collecting and using the appropriate data.

The example presented below also demonstrates the need for using site-specific data whenever possible. Statewide and regional averages are necessary in many cases due to limitations in the ability of most states to collect information at project locations, but such average data may cause significant errors in the estimation of design traffic.

Furthermore, when making site-specific traffic estimates, the design agency should be aware of changing seasonal traffic characteristics. In many locations, truck traffic varies both in number and loading characteristics throughout the year. These changes also tend to be different than the seasonal changes in total volume used to estimate AADT. By taking only one vehicle classification count, not seasonally adjusting that count to represent average annual conditions for each type of vehicle, and then applying statewide damage factors, the chance for providing a significantly bad estimate of traffic conditions approaches that of simply using statewide averages. As shown below, the use of statewide averages may cause substantial errors in the design of pavements at specific locations.

INTRODUCTION

This appendix discusses the effects of variation in the design inputs on the results of pavement overlay design. The design procedure used in the analysis is that described in the Asphalt Institute's Pavement Overlay Design Manual (MS-17).

The basic design parameters input into the analysis procedure are:

- The traffic parameters:
  - AADT (current year).
  - Vehicle Classification Percentage for each vehicle type.
  - ESAL for each vehicle type.
- The growth expected within the design period (this can be expressed as simply growth in AADT, or as changes in vehicle classification and EAL per truck estimates).
- An estimate of the remaining structural integrity of the existing pavement.

While all of these parameters affect the final estimate of pavement overlay depth, this analysis concentrates primarily on the traffic inputs. In the examples presented later, it assumes that errors from estimating pavement deterioration (pavement quality) and from forecasting traffic levels and composition are consistent regardless of the traffic inputs used and that the better the initial traffic estimates, the better the final analysis. The effects of errors in forecasting and pavement quality estimation are discussed only briefly.

DESCRIPTION OF DESIGN PROCEDURE

The Asphalt Institute's procedure takes the specified traffic estimates and computes a Design Equivalent Axle Load (DEAL). This represents the loadings the proposed pavement will experience during its design life. It includes estimated growth during the life of the project. This design value is then used as an input to empirical curves relating pavement quality to DEAL to estimate the appropriate amount of new pavement to be added to an existing roadway to achieve the design objectives.

Given that the pavement condition is correctly selected (and thus the correct curve on the design charts), variation in the traffic data inputs directly affects the pavement depth calculation. For example, if truck weights (ESAL per truck type) are underestimated due to insufficient data collection, or some other reason, then the pavement depth is underestimated. Unfortunately, the relationship between traffic and pavement depth is not linear, nor is it simple.

Essentially, errors in traffic estimates, whether they are due to poor estimates of initial traffic, poor volume-growth estimates, or poorly estimated changes in vehicle mix or damage factors over time, cause errors in the DEAL calculation. These errors in the DEAL estimate cause errors in the pavement depth calculation, resulting either in premature failure of pavements or overdesigns. Neither of these two transformations (traffic to DEAL or DEAL to pavement depth) is a simple linear function.

DEAL is calculated as follows:

$$DEAL = \Sigma_Y (Volume_Y * \Sigma_T (PVC_t * EAL/VC_t)) \qquad (4)$$

in which Σ_Y = the sum over Y years,

$Volume_Y$ = the AADT for the section of road for each year "Y",

Sum_T = the sum for all vehicle types "T",

PVC_t = the percentage of each of the vehicle types "t", and

EAL/VC_t = the equivalent axleload for each vehicle of type "t".

An analysis of this equation shows that an error of a given percentage, X percent in volume (assumed consistent over the Y years), results in an error of similar magnitude (X percent) in the DEAL estimate. A similarly sized error (X percent of the estimate used) for either vehicle classification percentage or for ESAL per truck type has a slightly smaller effect on the DEAL estimate. Errors in the latter two inputs cause errors in the DEAL estimate equal to the percentage error times the ratio of ESAL's contributed by that vehicle type over total ESAL's. These DEAL errors may be calculated as

$$Error = X\% * (PVC_i * EAL/VC_i)/\Sigma_T (PVC_t * EAL/VC_t) \qquad (5)$$

in which Error = the error in the DEAL estimate and

X% = the percentage error in either the PVC_i or the EAL/VC_i estimate, where "i" indicates the particular vehicle classification that contains the error.

The above analysis may be a little misleading, however, as it suggests that errors in volume estimates cause higher errors in the DEAL calculation than do errors in other traffic inputs. Actually, because it is usually possible to estimate the volume of a road with considerably higher accuracy than either the vehicle classification percentages or the ESAL/vehicle estimate, the errors in the last two estimates are usually responsible for the majority of error in the DEAL estimate and consequently in the pavement (overlay) design depth.

For example, in Washington, the HPMS Vehicle Classification Case Study indicated that the percentage of five-axle combination vehicles on rural principal arterials fluctuated between two percent and twelve percent, depending on when and where the specific counts were taken. The difference between these two estimates is 600 percent ((12 - 2)/2). This 600-percent difference would have a tremendous effect on a pavement overlay design. An overlay design using these as alternative inputs is described in detail later in this appendix.

It would be of great help if errors in DEAL could be consistently related to errors in pavement depth calculations. Unfortunately, the relationship of error in the DEAL estimate to error in the pavement depth analysis is not as simple as determining error in DEAL based on errors in the input traffic values.

Figure 13 shows an example of four curves of DEAL versus overlay depth. (DEAL is expressed as the Design Traffic Number (DTN) where DTN = DEAL / 7300.) Each curve represents the overlay needed for a given quality of existing pavement, as determined by the deflection of the pavement (x) during a Benkelman beam deflection test, and a specified DEAL.

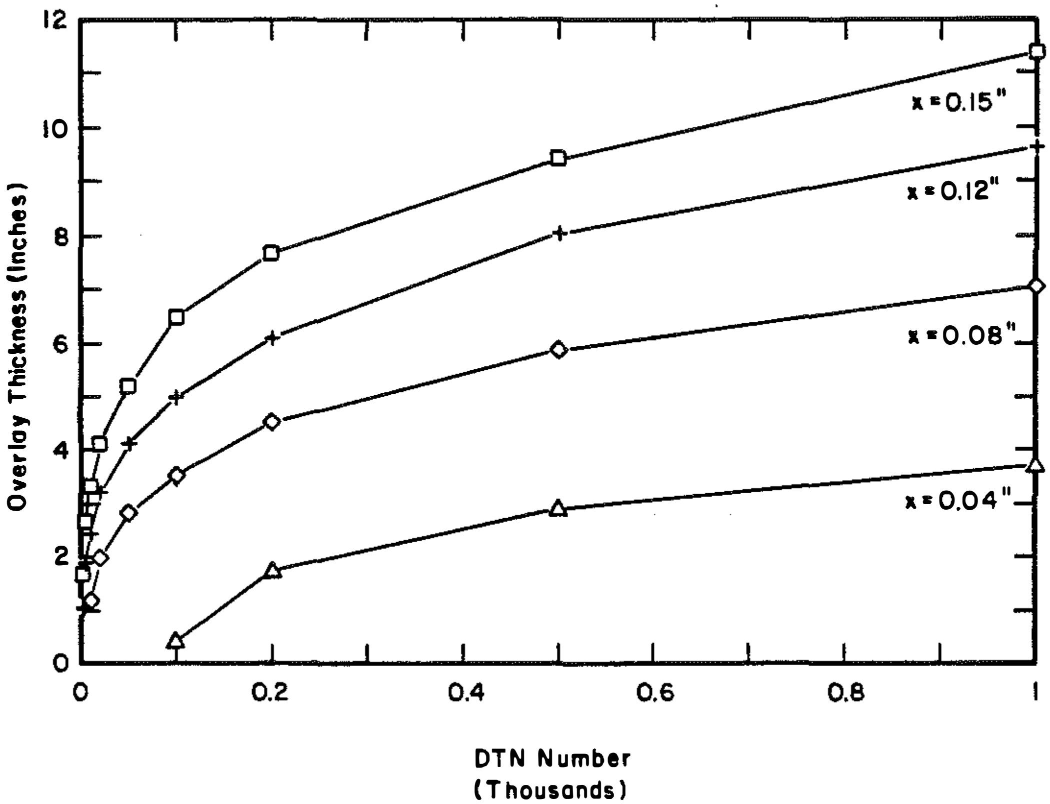


Figure 13. Sensitivity of overlay thickness to estimates of vehicular loadings.

Careful observation of these curves results in the following conclusions, some of them obvious, and some not so obvious:

- The relationship between DEAL and pavement depth is not consistent over the range of DEAL values (i.e., they are not straight line curves).
- The relationship between DEAL and pavement depth is not consistent between curves for equivalent ranges of DEAL (i.e., a change in DEAL from 75 to 100 has significantly different effects on inches of pavement needed depending on whether the curve used is for $x = 0.04$ inch, $x = 0.08$ inch, or $x = 0.12$ inch (This is true for both absolute and percentage changes in DEAL and pavement depth.).
- The relationship between curves ($x = 0.04$, $x = 0.08$, and $x = 0.12$) is not consistent over the range of DEAL (At the lowest levels of DEAL (below 75), the $x = 0.04$ curve is equal to zero. With $75 < \text{DEAL} < 150$, the rate of change in pavement depth is greater for the $x = 0.04$ curve than for either of the other curves. For $\text{DEAL} > 150$, the opposite is true.).
- The effect of error in the DEAL estimate in either percentage or absolute terms is significantly affected by the magnitude of the DEAL estimate, the magnitude of the error, and the existing pavement condition.
- This makes it extremely difficult to specify statewide levels of data collection precision based on the effects of errors, since this relationship is not consistent over the range of statewide overlay needs.
- The lower the truck volumes on a road (and thus the lower the DEAL), the more significant the effect of error in the DEAL estimate in both percentage and absolute terms.

For any one pavement quality curve, the relationship of error in the DEAL estimate to error in the pavement depth is somewhat more consistent. Figure 14 shows the errors in pavement depth calculations that occur for different levels of DEAL estimates and given percentage error ranges (i.e., 10, 15, 20, and 50 percent errors in DEAL estimates), given a Benkelman beam test result of $x = 0.08$ inch. From

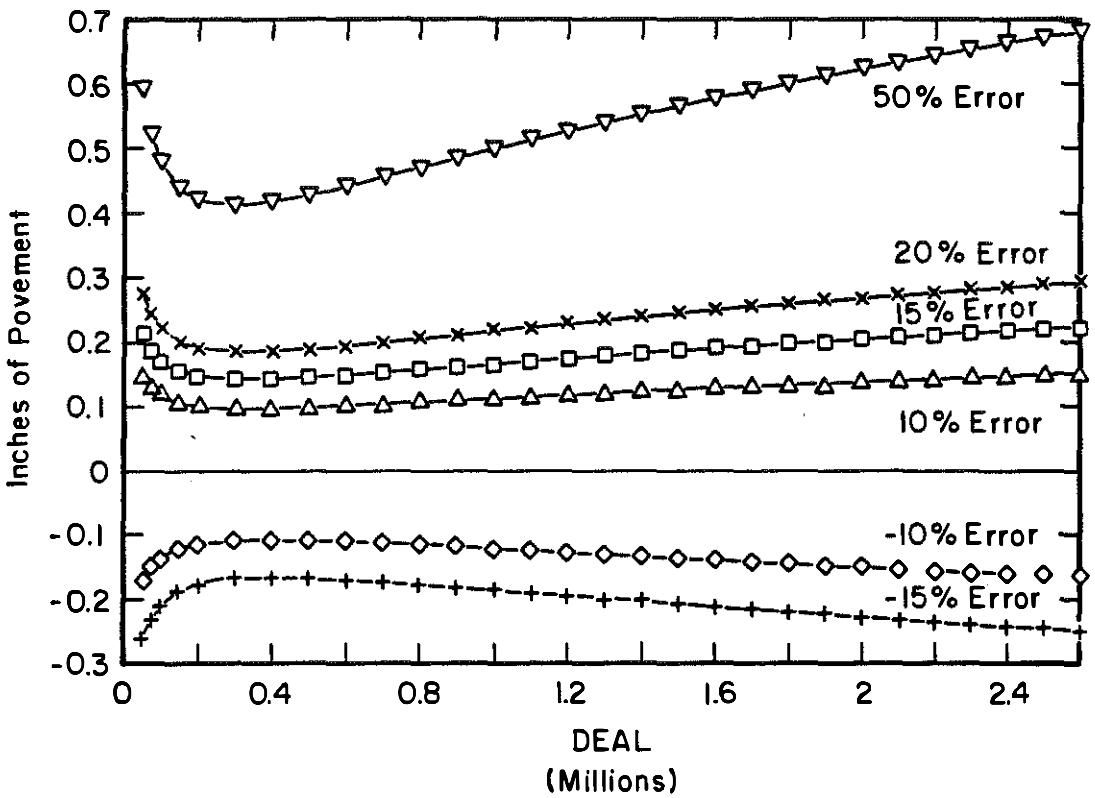


Figure 14. DEAL versus change in overlay thickness.

this graph, it is possible to determine that errors of modest size, (i.e., under 20 percent) in DEAL predictions will have a moderate effect on the amount of truck traffic or its related damage factor is significantly above this error level.

How easily errors greater than 20 percent may be made is demonstrated by the following example. This example examines the effect of variation of only one of the traffic inputs used in the overlay design calculation (the percentage of five-axle trucks in the traffic stream). Note that variations between the actual and estimated values of the other inputs to the design process also will cause errors in the design calculation.

This example looks at the effect on overlay design of using one standard deviation (estimated from available data) above and below the mean value of the percentage of five-axle trucks on principal rural arterials in Washington State. Three designs are performed. Each of the designs uses the same input assumptions with the exception of the percentage of traffic assumed to be five-axle trucks.

The conditions presented represent a range of conditions common on the Washington State highway system. This example also shows the range of errors that may be incurred easily if adequate steps are not taken to seasonally adjust truck travel estimates, or determine the loads being carried by vehicles of each "type" on project roads.

From an existing WSDOT data base, the mean percentage of five-axle trucks on the rural primary arterial system is estimated as 7.10 percent of traffic. One standard deviation about this mean is estimated to range from 12.27 to 1.93 percent. These numbers were calculated from data collected as part of the 1982 HPMS Vehicle Classification Case Study for rural primary arterials.

DESIGN ASSUMPTIONS

The assumptions used in the calculation of both pavement designs are shown below:

Design Volume Per Lane	5,000 vehicles per day
Percent 2-axle Trucks	3.44
Percent 3-axle Trucks	0.71
Percent 4-axle Trucks	0.07
Percent 5-axle Trucks	(Varies, see above)
Percent 6-or-more-axle Trucks	0.18
ESAL per truck	
2-axle trucks	0.11
3-axle trucks	0.47
4-axle trucks	0.66
5-axle trucks	0.98
6-or-more-axle trucks	1.63
Existing Pavement Quality	
Benkelman Beam Deflection Test	
Mean Plus 2 Sigma	0.08 inch

The percentage of trucks within each axle grouping was taken from the HPMS data base for rural primary arterials described earlier. The ESAL per truck estimate was taken from a national HPMS data base for rural interstates. These estimates are approximate, and may or may not be representative of any specific site in Washington State, but they are sufficiently accurate for use in this example.

The total equivalent axleload for each truck type for each day is computed as

Volume * (Percent Type of Truck/100) * (EAL/Truck of that Type).

These values are as follows:

	Design 1	Design 2	Design 3
Total ESAL 2-axle trucks	18.92	18.92	18.92
Total ESAL 3-axle trucks	16.69	16.69	16.69
Total ESAL 4-axle trucks	2.31	2.31	2.31
Total ESAL 5-axle trucks	601.23	94.57	348.57
Total ESAL 6-axle trucks	14.67	14.67	14.67
Total ESAL per day	653.82	147.16	401.16

Design 1 is the mean plus one deviation, Design 2 is the mean minus one deviation, and Design 3 is the mean value of the estimated truck percentage. With a design life of seven years, the total Design ESAL's are

$DEAL_1$ = 7 * Total ESAL per Day * 365 = 1,670,510,
$DEAL_2$ = 7 * Total ESAL per Day * 365 = 375,990, and
$DEAL_3$ = 7 * Total ESAL per Day * 365 = 1,024,954.

This may be equated to the Design Traffic Number (DTN) used in the 1977 version of the Overlay Design Manual by the following formula:

DTN = DEAL/7,300.

So DTN_1 = 228.8, DTN_2 = 51.5, and DTN_3 = 140.4.
Using the graph in Figure 11, the overlay depth may be calculated:

Overlay depth 1 = 4.7 inches,
Overlay depth 2 = 3.0 inches, and
Overlay depth 3 = 4.1 inches.

In this example, the DEAL estimate for the low truck percentage route is 300 percent less than the DEAL estimate for the mean truck condition. Consequently, its corresponding pavement thickness is more than one inch smaller than the design based on mean values. Because pavement thickness is less sensitive to changes in DEAL at higher ranges of DEAL, the overestimation of traffic (Case 1) only results in a 0.6-inch error in pavement depth. Still, such an error would result in significantly different pavement performance. Assuming constant traffic (i.e., no growth), a road operating under Condition 1 (high truck percentage), if designed under Condition 3, would suffer pavement failure in 4.3 years instead of the designed 7 years.

SUMMARY

To a certain extent, the above example illustrates some extreme cases. However, errors of even moderate size in DEAL estimates cause errors in pavement depth of close to 1/4 inch (see Figure 14). Such errors, when multiplied by the number of lane-miles of highway being overlaid each year by a State, cause very significant misallocation of pavement rehabilitation funds.

In Washington, 1,200 miles of overlays are to be placed during the next biennium. If a 1/4-inch error in pavement thickness is made on all of those projects, the state would misallocate $6,600,000. Of this misallocation, some pavements would be overdesigned and some would be underdesigned, but both of these cases represent poor expenditures of limited funds. (Note: The dollar figure above is based on an average of 2.2 lanes per overlay and a material cost of $10,000 per inch of asphalt. Only material costs are included in the above estimate. No labor charges or design costs are used.)

APPENDIX D

TRAFFIC FORECASTING FOR PAVEMENT DESIGN AND ANALYSIS

Oregon Department of Transportation

As part of this multistate study, a written description of the existing vehicle monitoring and forecasting procedures used in the State of Oregon has been prepared. The outline includes two sections, Data Collection and Data Uses. "Section A -- Data Collection" addresses the responsibility, number of sites, equipment, collection methods, site operation, and availability of data. As part of "Section B -- Data Uses", data use, methods of forecasting, estimating and forecasting for non-data highway sections, availability of state economic data, and legislative changes in truck loadings are addressed.

SECTION A. DATA COLLECTION

1. The Highway Division, Oregon Department of Transportation, is responsible for data collection.

2. SITES

a. Truck Weighing

Truck Weighing	Number of Sites
Scale Houses	62
Port-of-Entry (four sites)	
Semi-Portable Scales	5
Pits	25
County, City, Agency, Private Firms	Unknown
Weigh-in-Motion	3

b. Vehicle Classification

Automatic Traffic Recorder (ATR) Stations	115
Project Count Stations	120
Special and Short Period	60
Highway Performance Monitoring System	
Interstate & Federal-Aid Secondary Routes (1050)	90

Federal-Aid Urban and Off System (950)	10
Miscellaneous Count Stations	20
Weigh-in-Motion	3

c. Traffic Counting

ATR Stations	115
Preselected Primary and Secondary	6,140
Primary Interstate Ramps	1,652
Secondary Interstate Ramps	127
Federal-Aid County Highways	4,290
Project Count Stations	120
Special and Short Period	120
HPMS - Interstate and FAS Routes	1,050
Federal-Aid Urban and Off System	950
Miscellaneous Count Stations	40
Weigh-in-Motion Count Stations	3

3. EQUIPMENT

a. Truck Weighing

Weigh Stations

Fairbanks-Morse-Toledo-Masstron-Weightronics

Portable Equipment

General Electronic Dynamic, Model MD-500

Semi-Portable Weighing Planks - LODEC-ELDEC

Weigh-in-Motion Equipment

Jefferson (I 5), DC300 (one scale in each of two northbound lanes)

Woodburn (northbound I 5), CMI Dearborn, Model SS-2001DC

Woodburn (southbound I 5), CMI Dearborn, Model SS-2001A

Portable Weigh-in-Motion

Bridge Weighing Systems Incorporated

b. Vehicle Classification

Manual Tally Board Counters

Weigh-in-Motion Equipment (Same as listed in 3a)

c. Traffic Counting

Tally Board Counters

Inductive Loop Detectors

Loop Detector Counters

Streeter Amet "206" PSC Recorders (Permanent)

MR 101 (Road Tube only -- Portable, Battery)

MR 102 (Loop Detector -- Portable, Battery)

MR 103 (Road Tube or Loop Detector -- Portable, Battery)

MR 121 (MR 202) (Permanent Loop Detector)

Count Summators (Various Brands)

K-Hill Recorders (Road Tube only -- Portable, Battery)

Golden River (Road Tube or Loop Detector)

Weigh-in-Motion Equipment (Same as listed in 3a)

4. COLLECTION METHOD

a. Truck Weighing

Permanent Scales

Port-of-Entry Scales	Four locations, 24 hours per day
Non-Port-of-Entry Scales	Random schedule operation
Portable Scales	Twelve random operations -- axleloads and wheel loads

Weigh-in-Motion -- Observed, recorded, and transmitted

Permanent

Automatic Collection and Summarizing of Data

Truck weight -- observed gross weight and cumulative

Axleload (observed gross weight)

Portable

Same as above

b. Vehicle Classification

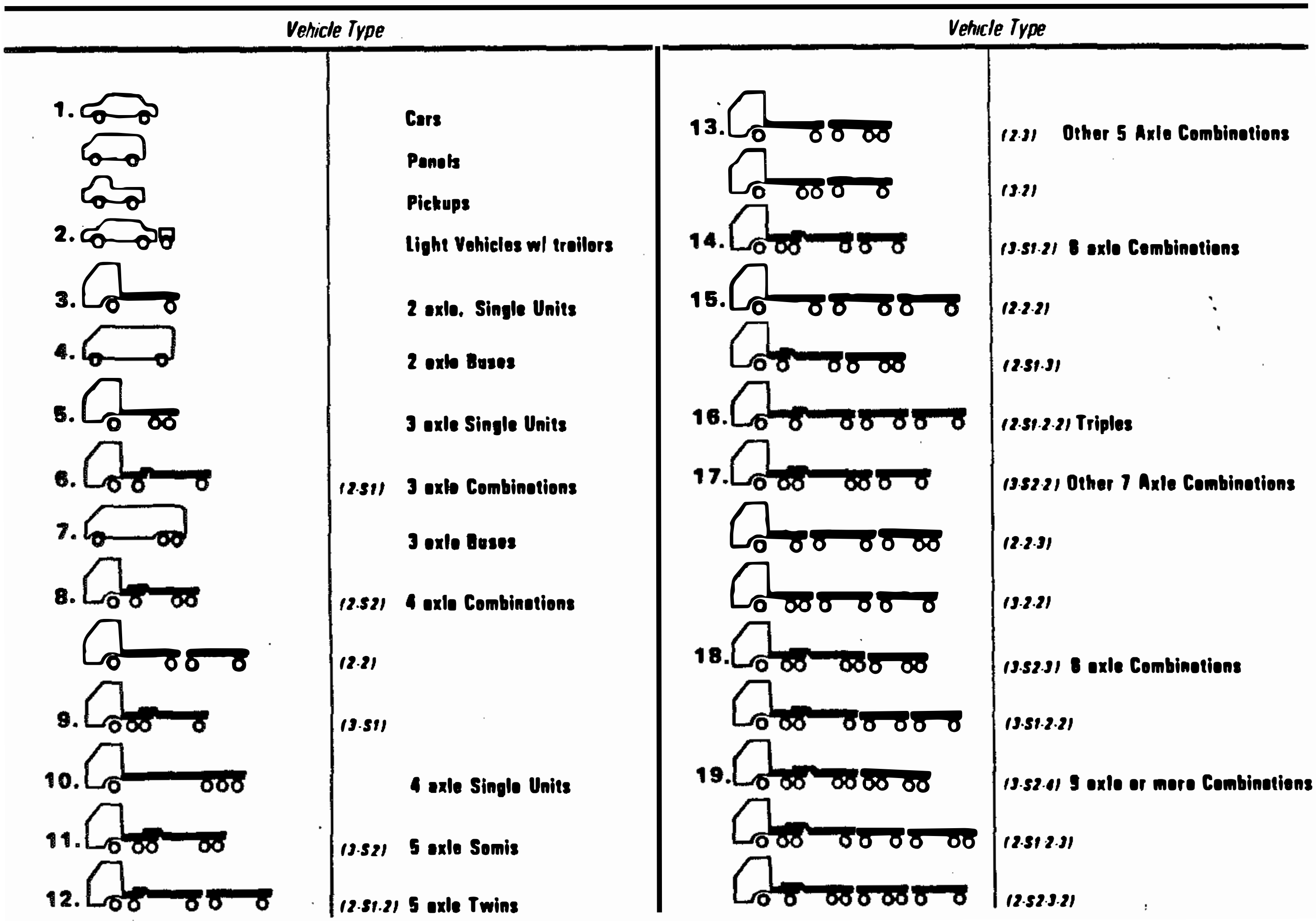
Vehicle classification collected manually (See Table 21 for types of vehicles).

Weigh-in-Motion

Nineteen Truck Classifications (See Figure 15)

Table 21. Vehicle classifications

Oregon Passenger Cars
Out-of-State Passenger Cars
Panels and Pickups
Light Vehicles w/Trailer
Motorcycle and Scooters
Total Light Vehicles
Campers and Light Trucks
Trucks, 2-Axle
Trucks, 3-Axle
Trucks, 4-Axle
Trucks, 5-Axle
Trucks, 6-Axle
Buses



These are examples of configurations; there are other possible combinations not illustrated.

Figure 15. Vehicle classifications used in Oregon's weigh-in-motion Study.

c. Traffic Counting

Manual Counts:

Counts are taken manually using a tally board counter and recording the number of vehicles making each movement with a mechanical button counter or hash marks.

Mechanical Counters:

Counts are recorded on paper tapes or accumulative counters.

Permanent counters are used with inductive loop detectors.

Portable counters or accumulative counters are used with inductive loop detectors or road tube detectors.

Weigh-in-Motion Equipment:

Permanent counters recording total vehicle counts at an adjacent data storage terminal for local pick up and telemetered into the central computer.

County, city, agency, or consultant personnel as may be available.

Individual queries made as needed.

5. SITE OPERATION

a. Truck Weighing

Scale Houses (58) on Random Schedule	190 days/yr
Port-of-Entry (4) on Continuous Schedule	363 days/yr
Semi-Portable (12) on Random Schedule	
Pits (25) on Random Schedule	
County, City, Agency, Private	Unknown
Weigh-in-Motion	
Jefferson (2)	365 days/yr
Woodburn (1)	363 days/yr

b. Vehicle Classification

ATR Stations (115)	1 fall weekday every 3 yrs
85 Stations, 16-hour count	
30 Stations, 24-hour count	
Project Count Stations (120)	
96 Stations, 16-hour count	
24 Stations, 24-hour count	

Special and Short Period Count Stations (60)	Varies between 4- to 24-hour counts
HPMS Count Stations (100)	Varies between 4- to 24-hour counts
Miscellaneous Count Stations (20)	Varies between 4- to 24-hour counts
Weigh-in-Motion	
Permanent	Same as 5a
Portable	Unknown

c. <u>Traffic Counting</u>

ATR Stations (115)	365 day/yr
Preselected Primary and Secondary (6,140)	24 hours on even years
Primary Interstate Ramps (1,652)	24 hours on even years
Secondary Interstate Ramps (127)	24 hours on even years
Federal Aid County Highways (4,290)	24 hours on odd years
Project Count Stations (120)	Varies
Special and Short Period (120)	Varies
HPMS 300 Stations @ 100/Year	8 hours
950 Stations @ every 2 Years	24 hours
Miscellaneous Count Stations (40)	Varies
Weigh-in-Motion Count Stations (3)	Same as 5a

6. AVAILABILITY OF DATA

a. <u>Truck Weighing</u>

Scale Houses (58)

Monthly reports of overweights by axle

Periodic reports of selected trucks by Public Utility Commissioner (PUC) classification

Port-of-Entry (4)

Monthly reports of overweights by axles

All trucks greater than 8,000 lbs gross weight by PUC classification

Semi-Portable (12)

Monthly reports of overweights by axles

Pits -- Included in monthly reports as described for semi-portable

County, City, Agency, Private -- Included in monthly reports as described for semi-portable

Weigh-in-Motion -- Truck weights and axleloads by axle

Data are not available for previous years

b. Vehicle Classification

ATR Stations (115)

85 Stations, 16-hour manual counts with vehicle classification

30 Stations, 24-hour manual counts with vehicle classification

Project Count Stations (120)

96 Stations, 16-hour manual counts with vehicle classification

24 Stations, 14-hour manual counts with vehicle classification

Special and Short Period Count Stations (60)

60 Stations, 4-hour manual counts with vehicle classification

HPMS Count Stations (100)

100 Stations, 8-hour manual counts with vehicle classification

Miscellaneous Counts (20)

20 Stations, 4-hour manual counts with vehicle classification

Weigh-in-Motion (3)

3 Stations, 24-hour recorders telemetering vehicle classifications

Portable Bridge Weighing System (Data not available at this time)

c. Traffic Counting (each calendar year)

ATR Stations (115)

85 Stations, 16-hour manual counts

30 Stations, 24-hour manual counts

115 Stations, Hourly counts each 24 hours by automatic recorders

Project Count Stations (120)

96 Stations, 16-hour manual counts

24 Stations, 14-hour manual counts

Special and Short Period Count Stations (120)

60 Stations, 4-hour manual counts

60 Stations, 4 to 24-hour road rube counts

HPMS Count Stations (2,000)

100 Stations, 8-hour manual counts

950 Stations, 24-hour road tube counts every other year

Miscellaneous Count Stations (40)

20 Stations, 4-hour manual counts

20 Stations, 4 to 24-hour road tube counts

Weigh-in-Motion Count Stations (3)

3 Stations, 24-hour recorders telemetering counts

7. AVAILABLE DATA SETS

a. Truck Weighing

Weigh Stations

Port-of-Entry --	Gross vehicle weight and number of axles
Semi-Portable --	Overweight trucks and number of axles (Primarily for enforcement)
Weigh-in-Motion -- Stations	Gross vehicle weight and axleloads by classification (Not available for past years)

Portable Bridge

Weighing system not available at this time

b. Vehicle Classification

ATR Stations	Hourly vehicle classification counts Weekday vehicle classification counts Annual percentage vehicle classification
Project Count Stations	Hourly vehicle classification counts Weekday vehicle classification counts
Special and Short Period Count Stations	Hourly vehicle classification counts
HPMS Count Stations	Hourly vehicle classification counts
Miscellaneous Counts	Hourly vehicle classification counts
Weigh-in-Motion	Hourly vehicle classification counts Not available for past years Daily vehicle classification counts Annual vehicle classification counts

c. Traffic Counting

(1) ATR Stations (Only)	Hourly Traffic Daily Traffic Weekday Traffic Monthly Traffic Annual Traffic -- once every 3 years Average Annual Daily Traffic

		Average Daily Traffic (Monthly)
		Average Weekday Traffic (AWT)(Monthly)
		Average Saturday Traffic (Monthly)
		Average Sunday Traffic (Monthly)
		Maximum Hourly Traffic (Monthly)
		Maximum Daily Traffic (Monthly)
		Percent Monthly ADT to AADT
		Percent Monthly AWT to AADT
		60 Highest Hourly Traffic by date, hour and weekday -- Each Year
		1st, 10th, 20th, 30th, 40th, and 50th highest daily traffic by date -- Each Year
		Highest daily traffic by date -- Each Year
		Ten Years -- AADT, maximum daily, maximum percent hourly
(2)	Project Counts	Hourly traffic for 14- and 16-hour periods -- 6 am to 8 pm and 6 am to 10 pm
(3)	Special Counts	Hourly traffic for various periods
(4)	HPMS Counts	Hourly Traffic -- Minimum of 8 hours, from 10 am to 6 pm (usually) or 24-hour road tube counts
(5)	Miscellaneous Counts	Hourly traffic for various periods or 24-hour road tube counts
(6)	Weigh-in-Motion	Data not available for past years

SECTION B. DATA USE

8. DATA USE -- GENERAL

a. Truck Weighing

(1) Port-of-Entry -- Weight Stations

All data sent PUC

(2) Truck Scales

All data sent to PUC

Sample axleloads taken at selected stations for short periods

periods to estimate 1979 truck study ESAL's

(3) Weigh-in-Motion

Data not available for past years

b. Vehicle Classification

(1) Port-of-Entry -- Weight Stations

Records sent to PUC

(2) Truck Scales

Records sent to PUC

(3) Manual Counts

Traffic is counted and classified manually, completing a hard copy field form

a. Vehicle classification counts taken every three years at the ATR stations are published in the Annual Volume Tables.

b. Special and project manual vehicle classification counts are taken as needed and processed into a hard copy form.

This data together with seasonal factors and projection factors are used to determine number of axle groups for surface and base design traffic coefficients for highway sections as may be required for projects and traffic reports.

c. Traffic Counting

(1) ATR Station Data

Continuous data are automatically recorded on paper tape and collected manually twice a month. Tapes are edited and sent to Data Processing for keypunch data entry. Monthly preliminary computer printout listings are edited for errors. Corrections are sent to Data Processing for final entry. Final corrected data are stored on computer reel tape and in hard copy files. Monthly data are used to prepare the Monthly Trend Report.

(2) Project, Special, and Miscellaneous Manual Counts

Counts are taken as needed and summarized and filed in hard copy form. Counts are seasonally adjusted and factored for application to each project and for future needs.

(3) Special and Miscellaneous Road Tube Counts

Counts are adjusted for seasonal variation and axle count correction. These factored data are used and adjusted annually to provide continuous values of ADT on state highways included in the Traffic Volume Tables.

9a. HOW DATA ARE USED IN PLANNING

(1) Truck Weighing

For needs (a) through (j) listed below

(2) Vehicle Classification

For needs (a) through (j) listed below

(3) Traffic Counting

(a) To determine urban traffic and projections -- excluding Metro

(b) To review Environmental Impact Study (EIS) reports

(c) To update computer models of area transportation studies

(d) To perform future project traffic studies

(e) For State Pavement Preservation Program

(f) For Six-Year Highway Improvement Program for structural overlay funding distributions

(g) Important factors for determining pavement needs for the long-range "Highway Plan"

(h) For HPMS -- Travel activity by vehicle type and functional class of highway (transmitted to FHWA)

(i) Heavy truck data for HPMS sample stations (transmitted to FHWA)

(j) To determine capacity deficiencies for the long-range "Highway Plan"

9b. HOW DATA ARE USED IN DESIGN

(1) Truck Weighing

Weigh-station data are requested from Permit Section

Weigh-in-Motion data requested beginning January 1986

(Data not currently being used in design)

(2) Vehicle Classification

For pavement design

For geometric design -- passing lanes and climbing lanes

(3) Traffic Counting

To review EIS reports

To determine base and surface designs

To determine work restrictions

To determine traffic capacities, levels of service, and geometrics for preliminary and final designs

10. METHOD OF FORECASTING

a. Traffic Volume (AADT)

AADT figures (listed by mile post) are taken from the current Annual Traffic Volume Tables. These tabulated traffic volumes are multiplied by the growth factor listed in Tables 22 or 23 and prorated for the projected year of interest.

Where traffic counts have been taken that are more recent than those available in the Traffic Volume Tables or closer to the roadway section than the listed mile posts, the current AADT is further refined. This modified AADT is then projected using the projection factors in Tables 22 or 23 and prorated according to the forecast year.

b. Vehicle Classification (Percent Trucks)

The classification count for the nearest similar ATR station is used to determine a base of percentages for each truck classification to the total of heavy trucks. Manual counts also are used to further refine the truck classification distribution nearer to the roadway section under study. Using the AADT profile through the roadway section from the Traffic Volume Tables, the current estimated truck classification breakdown may be determined throughout a roadway section. The vehicle classification count is projected using factors in Tables 22 or 23 and prorated according to the forecast year.

c. Truck Weights (Average ESAL per Truck) Forecast

The last truck weight study was made in 1979 and the same factors are used today. A study is currently underway with the Weigh-in-Motion

Table 22. Urban area VMT growth rate and growth factor forecast

CITY	FORECAST AVERAGE ANNUAL VMT GROWTH RATE 1982-2005 (%)	GROWTH FACTOR 1982-2005
Albany	2.4	1.73
Ashland	2.6	1.80
Astoria	1.1	1.29
Baker	1.4	1.37
Bend	3.0	1.96
Canby	1.1	1.30
Coos Bay	1.8	1.50
Corvallis	2.4	1.73
Cottage Grove	2.1	1.61
Dallas	2.7	1.83
Eugene/Springfield	2.0	1.58
Grants Pass	2.7	1.86
Hermiston	3.2	2.06
Klamath Falls	1.6	1.46
LaGrande	1.7	1.48
Lebanon	2.2	1.64
Lincoln City	2.8	1.87
McMinnville	2.8	1.89
Medford	2.3	1.70
Milton-Freewater	1.2	1.33
Monmonth	1.8	1.52
Newberg	2.9	1.93
Newport	2.7	1.85
Ontario	1.5	1.40
Pendelton	1.5	1.40
Portland	1.5	1.42
Prineville	2.3	1.69
Rainier	2.0	1.59
Redmond	3.2	2.08
Roseburg	1.9	1.53
Salem	2.3	1.69
Seaside	1.7	1.47
Silverton	2.5	1.77
St. Helens	2.4	1.71
Sweet Home	2.0	1.57
The Dalles	1.3	1.36
Woodburn	2.7	1.85

Table 23. County VMT growth rate and growth factor forecasts

COUNTY	ACTUAL 1982 VMT (000)	FORECASTED AVERAGE ANNUAL VMT GROWTH RATE 1982-2005 (%)	GROWTH FACTOR 1982-2005
Baker	150,333	1.7	1.48
Benton	160,982	2.3	1.69
Clackamas	826,377	2.8	1.90
Clatsop	193,022	1.7	1.46
Columbia	144,689	2.3	1.69
Coos	289,796	1.7	1.47
Crook	54,032	2.1	1.62
Curry	109,852	2.1	1.61
Deschutes	291,248	3.2	2.06
Douglas	701,227	1.7	1.47
Gilliam	87,303	1.6	1.44
Grant	58,135	1.4	1.38
Harney	69,356	1.6	1.44
Hood River	149,496	1.8	1.51
Jackson	586,534	2.4	1.73
Jefferson	108,612	2.5	1.76
Josephine	302,210	2.7	1.85
Klamath	350,685	1.9	1.54
Lake	56,759	1.3	1.34
Lane	999,713	2.2	1.66
Lincoln	238,977	2.5	1.77
Linn	585,412	2.3	1.69
Malheur	201,339	1.8	1.50
Marion	819,307	2.5	1.76
Morrow	91,352	2.4	1.72
Multnomah	1,732,274	1.5	1.41
Polk	212,621	2.4	1.73
Sherman	66,919	1.5	1.40
Tillamook	161,077	1.8	1.51
Umatilla	357,288	2.3	1.70
Union	135,613	1.9	1.54
Wallowa	31,112	1.2	1.32
Wasco	205,578	1.8	1.51
Washington	966,329	3.0	1.96
Wheeler	18,504	1.5	1.41
Yamhill	221,772	2.6	1.82
State Total	11,735,835	2.2	1.65

equipment and special weights at selected scale houses to update these factors.

d. Growth Rates

Growth rates are developed using the following information. The approach is subjective and judgmental, and as many relevant factors as possible should be considered.

(1) POPULATION FORECASTING

A. Statewide (Table 24)

1. Portland State University (PSU) Estimates
2. Bonneville Power Administration (BPA) Estimates
3. Executive Department and Department of Transportation (DOT) Revenue Forecast Estimates

B. Countywide (Table 25)

1. PSU Estimates
2. BPA Estimates

C. Cities* (Larger than 3,000 population)

1. Associated County Population Forecasts
2. Historical Growth Trends
3. County-Related Growth
4. Statewide Growth

*These population forecasts are used to determine the growth of urban area traffic.

(2) TRAFFIC FORECASTING

A. Statewide Vehicle-Miles of Travel

1. Previous Growth Rate Periods of Record
2. Historical Factors
   a. Fuel Costs
   b. State Economic Growth
3. DOT Revenue Forecast Estimates

B. State Highway System Vehicle-Miles of Travel

1. State Highway System Vehicle-Miles of Travel
2. Assuming the State Highway System travel remains a constant percentage of the statewide vehicle-miles of travel (Table 22)

Table 24. Comparison of population forecasts

	STATE POPULATION (000)				
	ACTUAL		FORECAST	AVERAGE ANNUAL GROWTH RATES (%)	
FORECAST	1980	July 1, 1983	2000	1980-2000	1983-2000
PSU (Dec 1983)	2,633.1	2,635.0	3,293.7	1.12	1.32
BPA (Aug 1983)	2,633.1	2,635.0	3,555.9	1.51	1.78
DOT (Apr 1984)	2,633.1	2,635.0	3,425.0	1.32	1.55

Table 25. County population forecasts

COUNTY	ACTUAL 1980 POPULATION	FORECASTED 2000 POPULATION PSU	FORECASTED 2000 POPULATION BPA	AVERAGE ANNUAL GROWTH RATES (%) - 1980-2000 PSU	AVERAGE ANNUAL GROWTH RATES (%) - 1980-2000 BPA
Baker	16,134	18,400	17,743	0.7	0.5
Benton	68,211	87,091	96,573	1.2	1.8
Clackamas	241,919	332,628	365,276	1.6	2.1
Clatsop	32,489	38,418	39,985	0.8	1.0
Columbia	35,646	45,704	45,461	1.3	1.2
Coos	64,047	66,218	73,740	0.2	0.7
Crook	13,091	16,144	15,333	1.1	0.8
Curry	16,992	20,486	20,920	0.9	1.0
Deschutes	62,142	100,670	101,726	2.4	2.5
Douglas	93,748	112,263	97,288	0.9	0.2
Gilliam	2,057	2,050	2,122	0.0	0.2
Grant	8,210	8,632	8,373	0.3	0.1
Harney	8,314	7,511	8,592	-0.5	0.2
Hood River	15,835	18,487	19,434	0.8	1.0
Jackson	132,456	173,031	180,851	1.3	1.6
Jefferson	11,599	16,961	13,897	1.9	0.9
Josephine	58,855	81,363	82,901	1.6	1.7
Klamath	59,117	70,086	74,398	0.9	1.2
Lake	7,532	9,113	7,917	1.0	0.2
Lane	275,226	333,925	364,174	1.0	1.4
Lincoln	35,264	46,292	46,684	1.4	1.4
Linn	89,495	108,482	120,052	1.0	1.5
Malheur	26,896	34,061	29,755	1.2	0.5
Marion	204,692	273,454	320,553	1.5	2.3
Morrow	7,519	11,502	8,206	2.1	0.4
Multnomah	562,640	581,519	677,812	0.2	0.9
Polk	45,203	56,076	62,283	1.1	1.6
Sherman	2,172	2,115	1,922	-0.1	-0.6
Tillamook	21,164	24,115	26,668	0.7	1.2
Umatilla	58,861	75,539	84,025	1.3	1.8
Union	23,921	30,386	28,241	1.2	0.8
Wallowa	7,273	9,240	7,556	1.2	0.2
Wasco	21,732	25,884	27,401	0.9	1.2
Washington	245,808	377,188	399,397	2.2	2.5
Wheeler	1,513	1,526	1,368	0.0	-0.5
Yamhill	55,332	77,096	77,320	1.7	1.7
State Total	2,633,105	3,293,656	3,555,947	1.1	1.5

C. County Vehicle-Miles of Travel (Table 23)

1. County Population for current year as provided by BPA and PSU separately.
2. County Population for forecast year as provided by BPA and PSU separately.
3. Current and Historical County Vehicle-Miles of Travel (VMT)
4. Current and Historical State Highway System Vehicle-Miles of Travel
5. Each county's percentage share of the State Highway System Vehicle-Miles of Travel (VMT) for the forecast year:

$$\frac{\%\ \text{VMT (Current Year)}}{\%\text{Population (Current Year)}} = \frac{\%\ \text{VMT (Forecast Year)}}{\%\ \text{Population (Forecast Year)}}$$

in which % VMT = each county's percentage share of State Highway System VMT in the year indicated and

% Population = each county's percentage share of total state population in the year indicated.

The equation is solved twice using PSU population figures and again using the BPA forecasts. These two sets of % VMT's for each county are multiplied by the total state highway VMT figure for the forecast year.

Average annual growth rates are then determined for the period between the current and forecast year for each county.

6. Other Factors
   a. Historical growth of the State Highway System VMT
   b. Population growth in each county
   c. Relationships between each county's historical and forecast population growth
   d. Traffic growth patterns of the "Highway Plan Project"
   e. Latest employment projections from BPA.

7. Final growth rate figures may vary anywhere between the BPA (Population Rates) and the PSU (Population Rates) utilizing the best judgmental value as the final growth rate for the specific period and geographical area

D. State System Urban Areas Vehicle-Miles of Travel (Tables 26 and 27)

Traffic growth forecasts for individual urban areas are developed considering and using several factors:

1. Relationship of population growth for the urban area and the county
2. County population forecasts from BPA and PSU
3. City population forecasts from the "Highway Plan" project
4. 1981 urban area traffic growth study forecasts developed by Andre Kimboko, April 24, 1981
5. County VMT growth rate forecasts estimated under Section C -- County Vehicle-Miles of Travel
6. Weighted average of the "Highway Plan" growth rates for the state highway sections within each urban area.

*There are, as of 1983, 37 urban areas. Thirty-two cities are classified as small urban areas under HPMS plus the five urbanized areas of Portland, Eugene, Salem, Rainier (Longview), and Medford.

E. Non-State System Rural Vehicle-Miles of Travel

1. Relationships of State Highway System Vehicle-Miles of Travel to total state Vehicle-Miles Traveled for current year and historically (Table 27)
2. Relative growth rates of the state highway system and total state VMT
3. Adjust and refine from any reliable non-state traffic data

*In the absence of any other information, it is assumed that vehicle-miles traveled on non-state system rural roads will continue to grow at about the same rate as the total state

Table 26. Total state and state highway system VMT forecasts (billions of miles)

	ACTUAL 1982 VMT	FORECASTED VMT 2000	FORECASTED VMT 2005
Total State VMT	19.385	28.600	31.900
State Highway System VMT	11.736	17.400	19.400

Table 27. State highway system and total state VMT 1960-1982 (millions of miles)

YEAR	STATE HIGHWAY SYSTEM VMT	ANNUAL PERCENT CHANGE	TOTAL STATE VMT	ANNUAL PERCENT CHANGE	RATIO OF STATE HIGHWAY SYSTEM VMT TO TOTAL STATE VMT
1960	4,893	-	7,981	-	0.613
1961	5,167	5.6	8,408	5.4	0.615
1962	5,494	6.3	8,953	6.5	0.614
1963	5,671	3.2	9,353	4.5	0.606
1964	5,982	5.5	9,940	6.3	0.602
1965	6,389	6.8	10,519	5.8	0.607
1966	6,717	5.1	11,055	5.1	0.608
1967	7,097	5.7	11,489	3.9	0.618
1968	7,418	4.5	12,034	4.7	0.616
1969	7,739	4.3	12,700	5.5	0.609
1970	8,267	6.8	13,527	6.5	0.611
1971	8,666	4.8	14,380	6.3	0.603
1972	9,153	5.6	15,236	6.0	0.601
1973	9,460	3.4	15,962	4.8	0.593
1974	9,243	-2.3	15,233	-4.6	0.607
1975	9,671	4.6	15,938	4.6	0.607
1976	10,497	8.5	17,097	7.3	0.614
1977	11,035	5.1	18,148	6.1	0.608
1978	11,819	7.1	19,837	9.3	0.596
1979	11,546	-2.3	19,537	-1.5	0.591
1980	11,748	1.7	19,513	-0.1	0.602
1981	11,962	1.8	19,517	0.0	0.613
1982	11,736	-1.9	19,385	-0.7	0.605

vehicle-miles traveled.

11a. NON-DATA HIGHWAY SECTIONS -- ESTIMATING

(1) Average Annual Daily Traffic

Special manual or road tube counts may be requested. Contracts and requests for available traffic data also are directed to cities, counties, the Forest Service, the Bureau of Land Management, and the Metropolitan Service Districts. Previous studies, traffic generators, aerial photographs, etc also assist in estimating AADT.

(2) Percent Trucks

Same information sources as above

(3) Truck Weights (Average ESAL per Truck)

Same information sources as above

11b. NON-DATA HIGHWAY SECTIONS -- FORECASTING

(1) AADT

Since the rate of increased traffic on the non-data highway sections is approximately the same as the data measured sections, the same factors are used as described under 10(a). The current year non-data highway information is secured from sources described under 11(a).

(2) Percent Trucks

Same forecasting methods as described above

(3) Truck Weights (Average ESAL per Truck)

Same forecasting methods as described above

12. STATE ECONOMIC DATA AVAILABLE

a. Gross State Product

Gross State Product (GSP) = Gross National Product (GNP) x Oregon Personal Income / United States Personal Income

b. State Product by Economy

There are limited data on manufacturing industries such as forest products

c. Labor Force Statistics

Monthly survey sheet

d. Annual Survey and Census of Manufacturers

State/Counties/Standard Metro Statistical Areas (SMSA)

e. Commodity Transportation Survey — 1977

By commodities and destinations -- by states

f. Truck Inventory Use Survey — 1982

13. LEGISLATIVE CHANGES AFFECTING TRUCK LOADINGS SINCE 1975.

a. Federal Legislation

(1) Deregulation of Trucks

1980 Motor Carriers Act

Encourages more truckers to operate than permitted under previous regulations

(2) Relaxation of procedures required for the abandonment of existing railroads

1980 Stieger Act

The Governor by Executive Order established a Task Force, whereby, a preliminary report is to be prepared for the next legislative session indicating the economic impact from the abandonment of certain railroad lines.

Abandoned railroads could conceivably increase truck traffic beyond the design capacity of existing highways.

b. State Legislation

(1) The increased axleload of a truck from 550 pounds to 600 pounds x the sum in inches of tire widths

1985 Legislature, Chapter 172, Paragraph 6a

Increased axleloads will increase design thicknesses for the same truck classification groups.

(2) Changed definition of tandem axles from a maximum of 48 inches to 96 inches apart

1985 Legislature, Chapter 172, Paragraph 3

The change in spacing will have an effect on design thickness constants for the same truck classification groups.

(3) Table of maximum allowable gross weights under Provision 818.010 of the 1985-86 Oregon Vehicle Code were changed for the three-axle through five- or more axle truck groups to three axles through a six-or-more axles.

1985 Legislature, Chapter 172, Paragraph 6a

These changes will have an effect on design thickness constants for the three-, five-, and six-or-more axle truck classification groups.

(4) Motor Vehicles Division has been given authority to set standards for truck weighing devices, heretofore under Federal jurisdiction
1985 Legislature, Chapter 172, Paragraph 1

This may have only a minor effect on truck loading or logistics in the repair, maintenance, operation, and periodic testing.

(5) A legislative committee has been set up to study the transportation and handling of hazardous materials on Oregon highways
1985 Legislature, House Bill 3005.

The effects of this type of study may alter truck loadings due to requirements of specific highway routes, time of travel, maximum loads, separation of synergistic substances, permitted truck classifications, check points, spills, types of hazardous material permitted, and alternate transportation, such as railroads, air, etc.

APPENDIX E

STATE CONTACT PERSONS

The following is a list of the State highway agency contact persons in three technical areas -- flexible pavement design, rigid pavement design, and traffic forecasting for pavement design purposes. Anyone desiring details about specific State procedures should contact the appropriate individual(s).

STATE	FLEXIBLE PAVEMENT DESIGN	RIGID PAVEMENT DESIGN	TRAFFIC FORECASTING FOR PAVEMENT DESIGN
Alabama	William Page Materials and Test Engineer (205)261-5794	William Page Materials and Test Engineer (205)261-5794	George Ray Planning Engineer (205)261-6438
Alaska	Eric Johnson Soils Engineer, Statewide Engineering and Operations (907)338-2121	Eric Johnson Soils Engineer, Statewide Engineering and Operations (907)338-2121	Eric Johnson Soils Engineer, Statewide Engineering and Operations (907)338-2121
Arizona	George Way Pavement Management Engineer (602)255-8094	Charles Eaton Urban Engineering (602)255-7545	Ed Green Supervisor, Travel and Facilities (602)255-7893
Arkansas	Robert Walters Roadway Design Engineer (501)569-2336	Robert Walters Roadway Design Engineer (501)569-2336	Jim Gilbert Chief, Technical Services (501)569-2111
California	Kenneth Mori Pavement Design Engineer (916)445-3882	Kenneth Mori Pavement Design Engineer (916)445-3882	Kenneth Mori Pavement Design Engineer (916)445-3882
Colorado	Peter Hinkley Squad Leader, Design Staff (303)757-9394	Peter Hinkley Squad Leader, Design Staff (303)757-9394	Chuck Peterson Planning Division (303)757-9261

Connecticut	Robert Isabelle Chief, Division of Soils and Foundations (203)529-3330	Robert Isabelle Chief, Division of Soils and Foundations (203)529-3330	Lembit Vahur Director, Office of Inventory and Forecasting (203)566-4034
Delaware	Al Donofrio Chief, Materials Section (302)736-4852	Al Donofrio Chief, Materials Section (302)736-4852	Robert Parke Assistant Highway Director (302)736-4346
Florida	W. N. Lofroos State Pavement Design Engineer (904)487-1700	W. N. Lofroos State Pavement Design Engineer (904)487-1700	H. R. Desai Administrator, System Management Statistics (904)488-4111
Georgia	Donald Emery Transportation Engineer V (404)656-5390	William Moskal Transportation Engineer III (404)656-5445	Joe Long Transportation Planner III (404)696-4634
Hawaii	Walter Kuroiwa Soils and Pavement Design Engineer (808)841-2876	Walter Kuroiwa Soils and Pavement Design Engineer (808)841-2876	Kenneth Miyazono Planning Survey Engineer (808)548-3228
Idaho	Gary Males Pavement Engineer (208)334-5256	Gary Males Pavement Engineer (208)334-5256	John Hamrick Traffic Survey Engineer (208)334-2578
Illinois	W. Emmitt Chastain Technical Services Engineer (217)782-6732	John Ebers Policy and Procedures Engineer (217)782-2245	William Barrows Chief of Planning Services (217)785-2998
Indiana	Eugene Mason Design Services Manager (317)232-5342	Eugene Mason Design Services Manager (317)232-5342	Donald Houterloot Planning Services Manager (317)232-5460
Iowa	Brian McWaters Pavement Engineer (515)239-1510	Brian McWaters Pavement Engineer (515)239-1510	Don Ward Director, Office of Advanced Planning (515)239-1137

Kansas	Andrew Gisi Pavement Engineer (913)296-3008	Andrew Gisi Pavement Engineer (913)296-3008	Clarence Startz Traffic and Field Operations Engineer (913)296-3470
Kentucky	E. B. Drake Transportation Engineer Branch Manager (502)564-3280	E. B. Drake Transportation Engineer Branch Manager (502)564-3280	Donald Ecton Director, Division of Planning (502)564-7183
Louisiana	J. B. Esnard Pavement Design Engineer (504)379-1305	J. B. Esnard Pavement Design Engineer (504)379-1305	J. M. Bankston Head Transport Engineer (504)342-7552
Maine	Allan Smith Highway Design Engineer (207)289-3171	Charles Valley Assistant Highway Design Engineer (207)289-3171	Carl Croce Assistant Director, Bureau of Planning (207)289-2942
Maryland	Ronald Balcer Chief, Evaluation and Pavement Design (301)321-3558	Ronald Balcer Chief, Evaluation and Pavement Design (301)321-3558	Barbara Ostrom Chief, Traffic Forecasting Section (301)659-1121
Massachusetts	Ross Dindio Pavement Design Engineer (617)973-7726	Ross Dindio Pavement Design Engineer (617)973-7726	Phil Hughes Assistant Director of Planning (617)973-7330
Michigan	Fred Copple Supervising Engineer, Bituminous Technical Services, Materials and Technology (517)322-0207	Gene Cudney Assistant Engineer, Research, Materials and Technology (517)322-5695	Norman Farnum Manager, Systems Development and Analysis Section, Urban Planning Division, Bureau of Transportation Planning (517)373-9355

Minnesota	George Cochran Subgrade and Base Design Engineer (612)296-7134	George Cochran Subgrade and Base Design Engineer (612)296-7134	Richard Stehr Director, Transportation Data, Research and Analysis (612)296-7968
Mississippi	Wendel Ruff Assistant Roadway Design Engineer (601)395-1185	Wendel Ruff Assistant Roadway Design Engineer (601)395-1185	Bill Sheffield Transportation Planning Statistician (601)354-7172
Missouri	Danny Davidson Pavement Type Determination Engineer (314)751-3759	Danny Davidson Pavement Type Determination Engineer (314)751-3759	Clifton Jett Planning Traffic Engineer (314)751-4658
Montana	Earl Murphy Manager of Surfacing Design Unit (406)444-6295	Earl Murphy Manager of Surfacing Design Unit (406)444-6295	Phil Colbert Traffic Supervisor (406)444-6122
Nebraska	Roger Henrichson Bituminous Materials Engineer, Materials and Tests Division (402)479-4677	Don Swing Materials and Tests Engineer (402)479-4750	Charles Stalder Traffic Analysis Supervisor (402)479-4520
Nevada	Ledo Quilici Design and Field Engineer (702)885-5520	Ledo Quilici Design and Field Engineer (702)885-5520	Andy Mathiesen Traffic Inventory Coordinator (702)885-3443
New Hampshire	Philip McIntyre Administrator, Bureau of Materials and Research (603)271-3151	Philip McIntyre Administrator, Bureau of Materials and Research (603)271-3151	Robert Lee Traffic Research Engineer (603)271-3344

New Jersey	Nicolai Nicu Chief, Bureau of Geotechnical Engineering (609)984-5003	Nicolai Nicu Chief, Bureau of Geotechnical Engineering (609)984-5003	George Thomas Chief, Bureau of Travel Projections (609)530-3518
New Mexico	Douglas Hanson Chief, Materials Laboratory Bureau (505)982-0955 Ext. 351	Douglas Hanson Chief, Materials Laboratory Bureau (505)982-0955 Ext. 351	Ron Forte Assistant Chief, Planning Bureau (505)982-0955 Ext. 272
New York	D. N. Geoffroy Director, Technical Services Division (518)457-4445	D. N. Geoffroy Director, Technical Services Division (518)457-4445	E. W. Campbell Director, Planning Division (518)457-1965
North Carolina	Shie Shin Wu State Pavement Design Engineer (919)733-7838	Shie Shin Wu State Pavement Design Engineer (919)733-7838	E. R. Shuller Head of Traffic Surveys Section (919)733-3141
North Dakota	David Leer Design Engineer (701)224-2552	David Leer Design Engineer (701)224-2552	Gary Berreth Planning Engineer (701)224-4408
Ohio	Roger Green Pavement Design Engineer (614)462-6953	Gene Geiger Pavement Design Engineer (614)462-6953	David Melick Assistant Engineer of Pavement and Soils (614)462-7203
Oklahoma	Eddie Cuadeves Pavement Design Engineer (405)521-2601	Eddie Cuadeves Pavement Design Engineer (405)521-2601	Leon Reiuke Supervisor, Traffic Analysis (405)521-2575
Oregon	Ronald Noble Surfacing Design Engineer (503)378-2580	Ronald Noble Surfacing Design Engineer (503)378-2580	Vernon Tabery Traffic Analysis Supervisor (503)373-7098

Pennsylvania	Wade Gramling Chief, Roadway Management Division (717)787-1199	Wade Gramling Chief, Roadway Management Division (717)787-1199	Neil Shope Manager, Performance Reporting Division (717)787-3200
Rhode Island	James Capaldi Chief Design Engineer (401)277-2023	James Capaldi Chief Design Engineer (401)277-2023	James Capaldi Chief Design Engineer (401)277-2023
South Carolina	Noel Yobs Director of Preconstruction (803)758-3414	Noel Yobs Director of Preconstruction (803)758-3414	Noel Yobs Director of Preconstruction (803)758-3414
South Dakota	Rusty Leach Pavement Design (605)773-3401	Don Anderson Pavement Design (605)773-3401	Larry Schoenhard Traffic Forecasting (605)773-3278
Tennessee	Jerry Hughes CE Manager 2 (615)741-2806	Jerry Hughes CE Manager 2 (615)741-2806	Richard Warpoole CE Manager 1 (615)741-6741
Texas	James Brown Design Engineer (512)465-6108	James Brown Design Engineer (512)465-6108	Terry Cearley Director of Traffic Analysis (512)465-7412
Utah	Wade Betenson Pavement Design Engineer (801)965-4303	Wade Betenson Pavement Design Engineer (801)965-4303	Clinton Dopham Highway Planning Engineer (801)965-4158
Vermont	Robert Murphy Design Services Engineer (802)828-2645	Robert Murphy Design Services Engineer (802)828-2645	Larry Willey Traffic Research Engineer (802)828-2685
Virginia	John Bassett Materials Division (804)737-7731	John Bassett Materials Division (804)737-7731	Don Wells Transportation Planning Division (804)786-2961

Washington	Newt Jackson Pavement Design Engineer (206)753-7110	Newt Jackson Pavement Design Engineer (206)753-7110	Mark Hallenbeck Research Engineer (206)543-6261
West Virginia	Gary Reed Pavement Design (304)348-2990	Gary Reed Pavement Design (304)348-2990	Jerry Legg Chief, Traffic Analysis Section (304)348-2870
Wisconsin	Gerald Burns Pavement Design Engineer (608)266-1897	Gerald Burns Pavement Design Engineer (608)266-1897	Don Revello Traffic Forecasting Engineer (608)266-1010
Wyoming	Robert Warburton State Materials Engineer (307)777-4070	Robert Warburton State Materials Engineer (307)777-4070	Jack Warburton State Planning Engineer (307)777-7552

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