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16. Abstract A computerized procedure was developed to make a comparison between the rehabilitation costs associated with the present 60-kip GVW limit and those costs associated with an increase to 80-kip gross weight (or any other specified limit). In order to properly take into consideration the effect of several climatic factors throughout the state, the following activities were conducted before using the computerized procedure: (a) division of the State of Texas into five climatically homogeneous regions; (b) determination of basic rehabilitation/maintenance performance and cost parameters for each region. In summary, the computerized methodology developed for the analysis of the FM system consists of: (a) a procedure that transforms vehicle loadings into 18-kip EASLs; (b) a load shifting procedure that allows the consideration of given traffic distributions under new GVW limits; (c) a cost estimation procedure that computes miles in need of rehabilitation alternatives and costs. Using a highway cost index of 5.5%, an interest rate of 5.5% and an ESAL growth rate of 3.35%, the procedure developed in this study indicates that the average annual rehabilitation cost would increase by approximately \$230 million if all load zones are removed. Similar estimates can be obtained for any specified set of input data.					
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A MODEL FOR ESTIMATING REHABILITATION COSTS ASSOCIATED WITH
THE ELIMINATION OF LOAD ZONES IN THE FM SYSTEM

By

Alberto Garcia-Diaz

Research Report 1132-F
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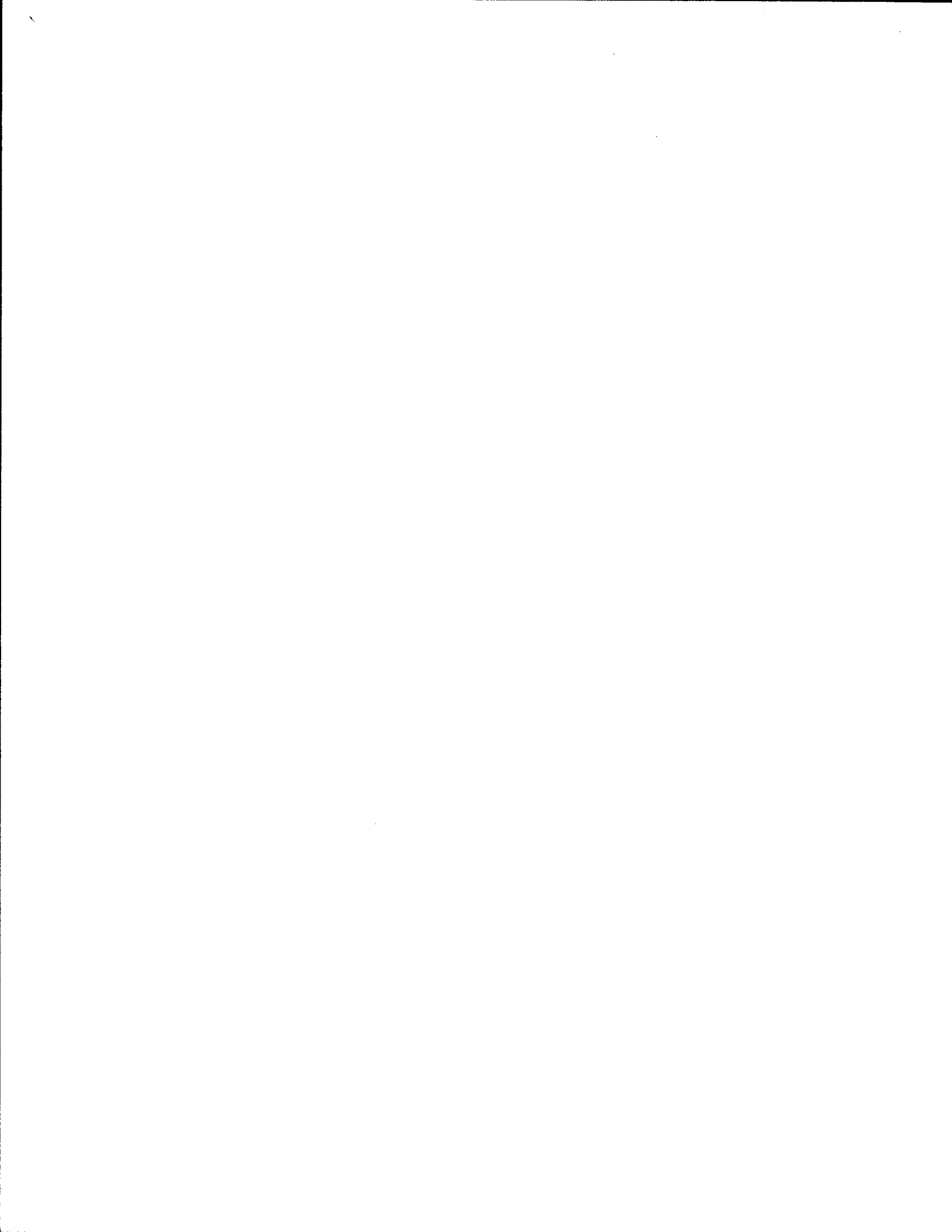
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November 1988



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				
in ²	square inches	645.2	millimetres squared	mm ²
ft ²	square feet	0.0929	metres squared	m ²
yd ²	square yards	0.836	metres squared	m ²
mi ²	square miles	2.59	kilometres squared	km ²
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
ft ³	cubic feet	0.0328	metres cubed	m ³
yd ³	cubic yards	0.0765	metres cubed	m ³

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

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				
mm ²	millimetres squared	0.0016	square inches	in ²
m ²	metres squared	10.764	square feet	ft ²
km ²	kilometres squared	0.39	square miles	mi ²
ha	hectares (10 000 m ²)	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
m ³	metres cubed	35.315	cubic feet	ft ³
m ³	metres cubed	1.308	cubic yards	yd ³

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

ABSTRACT

A computerized procedure was developed to make a comparison between the rehabilitation costs associated with the present 60-kip GVW limit and those costs associated with an increase to 80-kip gross weight (or any other specified limit). In order to properly take into consideration the effect of several climatic factors throughout the state, the following activities were conducted before using the computerized procedure: (a) division of the State of Texas into five climatically homogeneous regions; (b) determination of basic rehabilitation/maintenance performance and cost parameters for each region. In summary, the computerized methodology developed for the analysis of the FM system consists of: (a) a procedure that transforms vehicle loadings into 18-kip ESALs; (b) a load shifting procedure that allows the consideration of given traffic distributions under new GVW limits; (c) a cost estimation procedure that computes miles in need of rehabilitation by using appropriate pavement survival relationship and typical rehabilitation alternatives and costs. Using a highway cost index of 5.5%, an interest rate of 5.5% and an ESAL growth rate of 3.35%, the procedure developed in this study indicates that the average annual rehabilitation cost would increase by approximately \$230 million if all load zones are removed. Similar estimates can be obtained for any specified set of input data.

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DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration, or the State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation.

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1. INTRODUCTION

The purpose of this research effort is to study the effects of changing legal load limits (gross vehicle weight) on load-zoned FM highways. These effects are measured in terms of both maintenance and rehabilitation costs for each of the years of a specified planning period. A computerized model was developed to make a comparison between the costs associated with present legal load zone limits and those costs associated with an increase to 80-kip gross weight (or to any other given limit). The objectives of this research can be summarized as follows:

- (1) To estimate levels of heavy traffic (in 18-kip ESALs) on the FM system, assuming a change of legal load limits. Truck weight and traffic data provided by SDHPT were considered as input for the procedure developed in the study.
- (2) To measure the economic impact of the change in legal load limits in terms of maintenance and rehabilitation costs. In the determination of these costs, several climatic factors affecting FM road performance (PSI loss or distress) were considered.

The results of this study will assist SDHPT in making a more complete assessment of the economic effects of increasing the FM legal load limit to 80,000 pounds, or to any other specified level. In particular, the Department can advise the Texas Legislature on the basis of the results from this study and a more complete FM load zoning policy can be evaluated using its findings.

A method was needed to help make cost-effective decisions concerning a possible change in legal load limits on FM roads due in part to increasing truck traffic and specialized vehicle and equipment using these roads. The cost analysis of load-zoning was based on a procedure that essentially compares FM road service cycles under two different scenarios: (a) current traffic distribution, current road conditions, and present load limits; (b) load-shifted traffic distributions and modified road performance relationships that predict the behavior of FM roads under increased load limits.

The economic comparison between present and proposed truck load limits was performed by developing a computerized procedure that utilizes several features included in the RENU [5], RENU2 [3], and RENU3 [6] methodologies. As part of Study 129 [Interagency contract with TTI and SDHPT (D-7)], conversations between TTI and SDHPT personnel were conducted to discuss desirable changes in the RENU models.

The new procedure, referred to as the RENU3 model, currently provides enhancement in four key areas which serve to simplify and improve the efficiency of the process of estimating rehabilitation/maintenance costs. These include:

- (1) Division of the Texas State road network into five climatically homogeneous areas.
- (2) Determination of basic rehabilitation/maintenance cost parameters by climatic areas.
- (3) Determination of pavement performance and survivor relationships for climactic areas for the three types of pavements: hot mix, black-base, and overlaid.
- (4) Rehabilitation of pavements older than terminal serviceability (POTTS) in a specified number of years.

In order to use a modified version of the RENU3 computerized procedure in the analysis of the FM system, it was necessary to develop both performance and survival relationship for typical sections in each of the five homogeneous climatic areas of the state.

The new procedure for estimating the cost associated with the elimination of FM load zones will result in the following benefits for SDHPT:

- (a) SDHPT will be able to estimate rehabilitation and maintenance budgets for individual roads, Districts, regions or subregions of the FM system.
- (b) The model developed will assist the Department in predicting the effect of new load limits when faced with several "what-if" situations resulting from proposed load zone changes.
- (c) The most critical road segments of the FM system can be identified in each of the climatic areas.

2. REHABILITATION AND COST METHODOLOGY

The methodology developed for estimating FM road costs under present and new GVW limits is based on the RENU3 computerized procedure [6]. The following activities were accomplished in order to make this procedure suitable for the analysis of the FM system:

- (a) All subroutines concerning rigid pavements were deleted.
- (b) Only one type of pavement was included in the system of flexible pavements. This type was defined as the FM system.
- (c) The procedure for calculating the thickness of overlays of both rigid and flexible pavements was eliminated.
- (d) New performance and survival relations for PSI and several types of distress were developed for typical FM sections in each climatic region.
- (e) Cost data on maintenance and rehabilitation of FM roads were updated by interviewing on the telephone Construction Engineers of selected Districts.
- (f) A data base was created with the following information:
 - Road performance data
 - Mileage age distributions
 - Axle-load distributions
 - GVW distributions
 - Truck traffic distribution (from the classification file)

In summary, the computerized methodology developed for the analysis of the FM system consists of: (a) a procedure that transforms vehicle loadings into 18-kip ESALs; (b) a load shifting procedure that allows the consideration of given traffic distributions under new GVW limits; (c) a cost estimation procedure that computes miles in need of rehabilitation by using appropriate pavement survival relationships and typical rehabilitation alternatives and costs. A simplified flowchart of the computerized methodology is shown in Figure 1. A brief description of each of the above procedures is presented next.

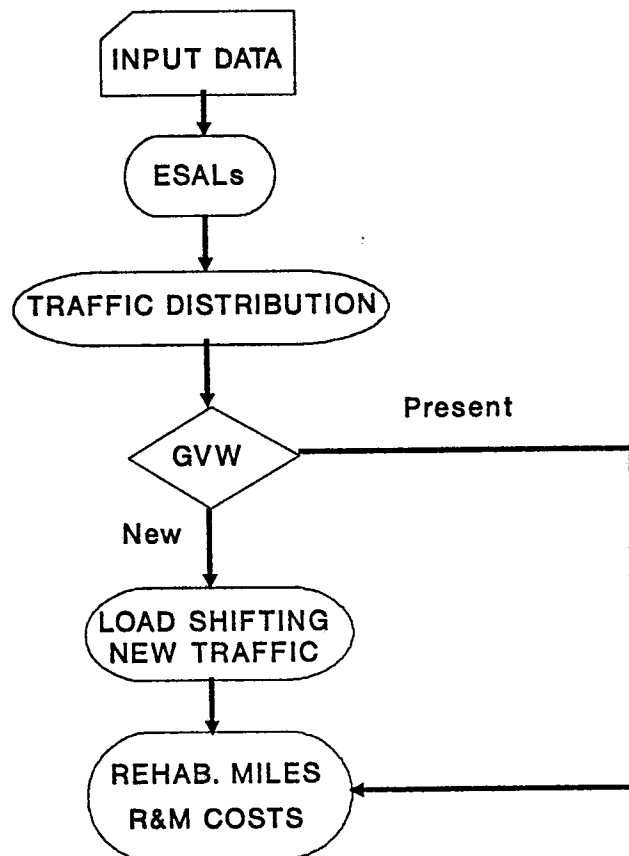


Fig. 1 Computerized Procedure

(a) Computation of ESALs

The objective of this procedure is to transform the total vehicle loadings on the pavement network into 18-kip Equivalent Single Axle Loads (ESALs). Computation of ESALs is affected primarily by the traffic intensity and by several other factors [2]. Among them are load condition (magnitude, axle configuration, tire spacing), pavement structure (structural properties, physical response), environmental condition (temperature, moisture), and failure type (PSI loss, distress mode). Value of these factors for a specific road segment are input data to the program and are used to compute the ESALs following a method proposed by AASHO (American Association of State Highway Officials) which is explained in detail in Reference 1. When ESALs under future load regulations are to be computed, load conditions under such regulations (new weight and axle load distributions) are estimated using a load shifting procedure; this procedure is explained next.

(b) Load Shifting Procedure

In order to evaluate the effect of legal load limit changes of future truck weight distributions, the cumulative percentage of gross vehicle weight (GVW) is shifted according to trends observed in recent years. The shifting procedure is a simple relationship according to which the existing GVW upper limit is multiplied by a factor that increases linearly from 1.0 to the ratio of practical maximum GVW at present (PMGVWP). As the GVW increases from the lower limit of the first weight interval to the value of PMGVWP, the factor is linearly increased and at the limit becomes constant and equal to $PMGVWP/PMGVWF$. The result is the endpoint of a new interval. Thus, the shifting is done by calculating a ratio, obtained from past experience, that will give the gross future vehicle weight distribution for a certain truck type. Afterwards, the relation between the future GVW and the axle weights is calculated manually for each truck type, and the future axle weight distribution is obtained. Since not all the trucks experience an increment in weight, only a certain percentage is shifted for each truck type. Only those vehicles operating in the upper GVW ranges would truly take advantage of the new allowable weight limits; therefore, they should experience a substantial shift to the right.

A recent study [2] showed that a shifting from the 50% for truck types 2D and 3A, and 33% for truck types 3-S2 and 2-S1-2 should be considered.

(c) Cost Estimation Procedure

In order to estimate the rehabilitation and maintenance costs, the computer program developed in this study performs the following steps:

- (1) calculation of the number of miles needing rehabilitation
- (2) computation of rehabilitation costs
- (3) computation of the cost of preventive maintenance on the total number of miles in the network.

The number of miles needing rehabilitation during each year of the planning horizon is calculated using the pavement survival relationships developed in Section 4. Such relationships are based on the probability that a given type of pavement survives (does not need rehabilitation) after a given accumulated traffic load has been applied on it. ESALs computed for both types of load regulations (present and proposed limits) are considered as inputs to the pavement survival models to generate the number of miles in need of rehabilitation under specified GVW limits. Adjustment to the pavement age distribution is made simultaneously with the analysis of rehabilitated miles in each age category along the specified planning horizon. Total rehabilitation costs are calculated on the basis of typical road rehabilitation alternatives under both load regulations and for each climatic region. Likewise the cost of preventive maintenance is calculated using typical cost figures for every region; the policy of preventive maintenance considered in this study is to apply a seal coat on each mile every six years.

Output of the program shows the number of miles to rehabilitate, the total rehabilitation cost, and the total preventive maintenance cost for every year during a given planning horizon. For projection of costs in the future, the program considers the use of interest rates and highway cost indexes.

3. IDENTIFICATION OF CLIMATIC REGIONS

Many climatic factors such as temperature, precipitation, freeze/thaw cycles and evaporation can influence the performance of FM roads. To make a pavement rehabilitation and maintenance model sensitive to climatic factors, the pavement network should be divided into homogeneous climatic regions; then the model should be applied to the pavements within each climatic region using different parameters for each region.

In this section a procedure followed to find a very realistic division of the state into climatic areas is presented. The main technique used in such a procedure is known as Cluster Analysis. To divide the state into regions, each county is used as a reference unit. It is desirable that all counties with similar climatic conditions will be assigned to the same cluster. In this project the 254 counties of the state will be divided into five homogeneous climatic regions.

3.1 Basic Concepts

Clustering is a process of partitioning objects into groups as suggested by characteristic data, rather than defined a priori, with the result that objects in a particular group are similar to each other but dissimilar to objects in any other group. Clusters may be hierarchial, disjoint, or overlapping. In hierarchial clustering a cluster may be totally contained in another; in disjoint clustering an object belongs to one and only one group; and in an overlapping clustering an object may belong to two or more groups.

For the purpose of this study, disjoint clusters are obviously more appropriate and clustering is performed using a SAS utility named FASTCLUS [8].

The FASTCLUS procedure is based on a group of techniques known as k-means system. This group of techniques uses the Euclidean distance between the centroid (representing a region) and a point (representing a county) as the basis for assigning counties to each climatic region. This distance is known as a similarity coefficient.

At each iteration in the assignment process, FASTCLUS represents each county by a point in a n -dimensional Euclidean space (each of the n climatic factors constitutes one dimension in the space), and each region by the centroid of its member points. A set of points called cluster seeds is selected as a first guess of the means or centroids of the

clusters. A county is assigned to the region with the smallest centroid-to-point distance or similarity coefficient to form temporary clusters. When all counties have been assigned, new centroids are computed for each region, the seeds are replaced by these centroids, and the assignment process is repeated. Clustering is complete when two consecutive values of the centroid for each region remain unchanged.

The initial seed selection is very important to minimize the number of iterations. FASTCLUS differs from other nearest centroid sorting methods in how the initial cluster seeds are selected. FASTCLUS always selects the first complete observation as the first seed. The next complete observation becomes the second seed; later observations are selected as new seeds, as long as the maximum number of seeds is not exceeded.

If an observation fails to qualify as a new seed, FASTCLUS considers using it to replace one of the old seeds. Two tests are made to see if the observation can qualify as a new seed:

1. An old seed is replaced if the distance between the two closest seeds is less than the distance from the observation to the nearest seed. The seed that is replaced is selected from the two seeds that are closest to each other, and is the one of these two that is also closest to the observation.
2. If test 1 fails, the observation replaces the nearest seed if the smallest distance from the observation to all seeds other than the nearest one is greater than the shortest distance from the nearest seed to all other seeds. If this test fails, FASTCLUS goes on to the next observation.

The algorithm followed by FASTCLUS can be summarized in the following four steps:

1. Observations called cluster seeds are selected.
2. Optionally, temporary clusters are formed by assigning each observation to the cluster with the nearest seed. Each time an observation is assigned, the cluster seed is updated as the current mean of the cluster.
3. Optionally, clusters are formed by assigning each observation to the nearest seed. After all observations are assigned, the cluster seeds are replaced by the cluster means. This step can be repeated until the changes in the cluster seeds become small or zero.
4. Final clusters are formed by assigning each observation to the nearest seed.

3.2 Development of the Input Data Matrix

3.2.1 Identification of Significant Factors

The purpose of this step is to analyze the existing data and to identify the most significant factors or attributes that can influence the differentiation among climatic divisions.

Thirteen climatic factors (attributes) were identified and measurements obtained from "CLIMDATA," a file in the climatological data base of the Texas Transportation Institute which contains monthly data from each county of Texas. The selected climatic factors include:

- Thornthwaite Index (TI)
- Average Winter Temperature (AVT1)
- Average Summer Temperature (AVT2)
- Total Freeze-Thaw Cycles in one year (FT)
- Total Precipitation or Rainfall from month 4 to month 8 (R)
- Minimum Monthly Moisture Change (MC1)
- Maximum Monthly Moisture Change (MC2)
- Actual Evapotranspiration in one year (AE)
- Days with Precipitation in one year (DP)
- Highest monthly Mean Maximum Temperature (MMT)
- Mean Potential Evapotranspiration (PE)
- Mean Max. Days with Continuous Precipitation (MDCP)
- Total Wet Freeze-Thaw cycles in one year (WFT).

Twenty-year monthly averages for each factor were used for the purpose of this study, calculated for each of the 254 counties of Texas. A short description of each climatic factor follows:

- Temperature. Unit: degrees Fahrenheit.
- Precipitation. Is the general term for all forms of falling moisture - rain, snow, hail, ice pellets, etc. It is measured by a rain gauge. Unit: inches.
- Evapotranspiration. Is the amount of moisture from a liquid to vapor. Unit: inches.

- Potential Evapotranspiration. Is the amount of moisture that would be evaporated from the soil and transpired by vegetation if it were available. Unit: inches.
- Freeze-Thaw Cycle. Is a single process of freezing and thawing. No units.
- Moisture Change. Is a rate defined as $100*(S - D)/PE$ where S is the water surplus, D is the water deficit, and PE is the potential evapotranspiration. Unit: percentage.
- Thornthwaite Index. Thornthwaite devised an empirical formula based on the concept of potential evapotranspiration. He said that actual measurements of PE were inadequate in number and duration for a worldwide classification of climates. This index is given by:

$$TI = \frac{100 * (\text{w. surplus}) - 60 * (\text{w. deficit})}{PE}$$

In order to evaluate the relative statistical significance of various climatic factors, the primary input data were analyzed using the following procedure. In the first run, only three attributes were considered; in the second, four attributes were considered; in the third run, five; and so on until the last run where the thirteen attributes are considered. An attribute is said to be significant when the between-cluster variance or index of discrimination for such attribute is higher than a critical value, say 0.70. Summary of the results generated by the clustering utility is shown in Table 1. An analysis of that table shows that the significant attributes are: Thornthwaite Index, Winter Average Temperature, Precipitation, Days with Precipitation and Freeze-Thaw Cycles.

Then, correlated variables were identified and discarded. From the significant attributes found previously, Precipitation and Days with Precipitation were found to be logically correlated; therefore, the first one was retained and the second one was dropped. Lastly, the mean standard deviation for each attribute was computed to support the results obtained. The mean standard deviations for each attribute are shown in Table 2.

Table 1. Indices of Discrimination for Each Attribute in Each Clustering

Attributes	Number of Discriminant Variables											Ave
	3	4	5	6	7	8	9	10	11	12	13	
TI	.80	.80	.85	.83	.83	.83	.82	.83	.83	.82	.83	.82
FT	.86	.87	.85	.84	.84	.84	.84	.85	.84	.85	.84	.85
R	.78	.77	.84	.84	.84	.84	.80	.80	.81	.80	.80	.80
AVT1		.81	.74	.70	.70	.70	.71	.72	.72	.71	.71	.73
DP			.72	.73	.73	.73	.73	.72	.73	.73	.72	.72
AE				.69	.69	.69	.69	.69	.69	.68	.68	.69
MC2					.67	.67	.67	.67	.67	.67	.67	.67
MDCP						.68	.67	.67	.68	.68	.67	.67
PE							.64	.65	.65	.66	.65	.65
AVT2								.64	.64	.63	.64	.64
MC1									.47	.46	.46	.46
WFT										.64	.64	.64
MMT											.37	.37

Table 2. Average Standard Deviation by Cluster

Attributes	Number of Discriminant Variables						
	3	4	5	6	7	8	13
TI	10.04	8.26	8.84	9.65	9.65	9.65	9.64
AVT1		1.70	2.67	2.52	2.52	2.52	2.44
FT	9.30	9.11	9.77	9.76	9.76	9.76	9.59
R	4.87	4.89	4.49	4.52	4.52	4.52	4.55

3.2.2. Standardization of Input Data

Standardization serves to convert the original attributes to new unitless attributes. This eliminates any arbitrary effects on the similarity coefficients (next basic step), and causes attributes to contribute more equally to the similarities among counties. An attribute with a wider range of values across counties will tend to be weighted more heavily in the similarity coefficient than one with a narrow range of values without standardization.

To standardize a sample of attribute values, the difference between each single value of the attribute and its sample mean is divided by the standard deviation of the sample:

$$Z_{ij} = \frac{(X_{ij} - \bar{X}_i)}{S_i}$$

where:

X_{ij} : value of attribute i for county j

\bar{X}_i : mean value of attribute i

S_i : standard deviation of attribute i

Z_{ij} : standardized value of attribute i for county j .

3.3 Results From Clustering Procedure

The value of each of the four selected attributes for each county was standardized according to the procedure described in Section 3.2. With those data, a clustering procedure was performed using FASTCLUS. There are five clusters and each county has an associated cluster. A discussion of these results follows:

It is important to note that pavement sections are usually identified by districts rather than counties; therefore, a representation which maintains district integrity is preferable. The results from Cluster analysis of the 254 Texas counties indicate that several districts identify with more than one climatic area. For example, District 10 has three climatic areas with five of the eight counties in the same area as Districts 1, 12, 19 and 20 in East Texas. Wood and Smith Counties identify with the Panhandle districts, while Henderson

County shows the same climatic area as Central Texas districts. Thus, districts such as District 10 are said to possess outlier counties. The presence of outlier counties dictates three possible representations of the results, depending on how the outlier are treated: Case 1: No regard for district boundaries; outlier allowed to remain in climatic "home" region; Case 2: No regard for district boundaries; outlier incorporated into region of greatest physical proximity; Case 3: Respect district boundaries; each district assigned to climatic region identified with majority of member counties; outlier not allowed.

Case 3 was chosen because it is the most practical and is consistent with the past practice of dividing the state of Texas into five regions without violating district boundaries. Figure 2 shows the final division of the state according to the results from Case 3. Table 3 shows the average value of each significant attribute for each climatic region.

Table 3. Attribute Means for Each Region

Region	TI	AVT	FT	R
1	-10.55	64.66	35.49	31.24
2	-31.55	63.47	48.98	18.71
3	-19.61	58.27	84.57	19.56
4	-15.96	69.57	11.56	31.70
5	32.49	65.37	27.85	46.85

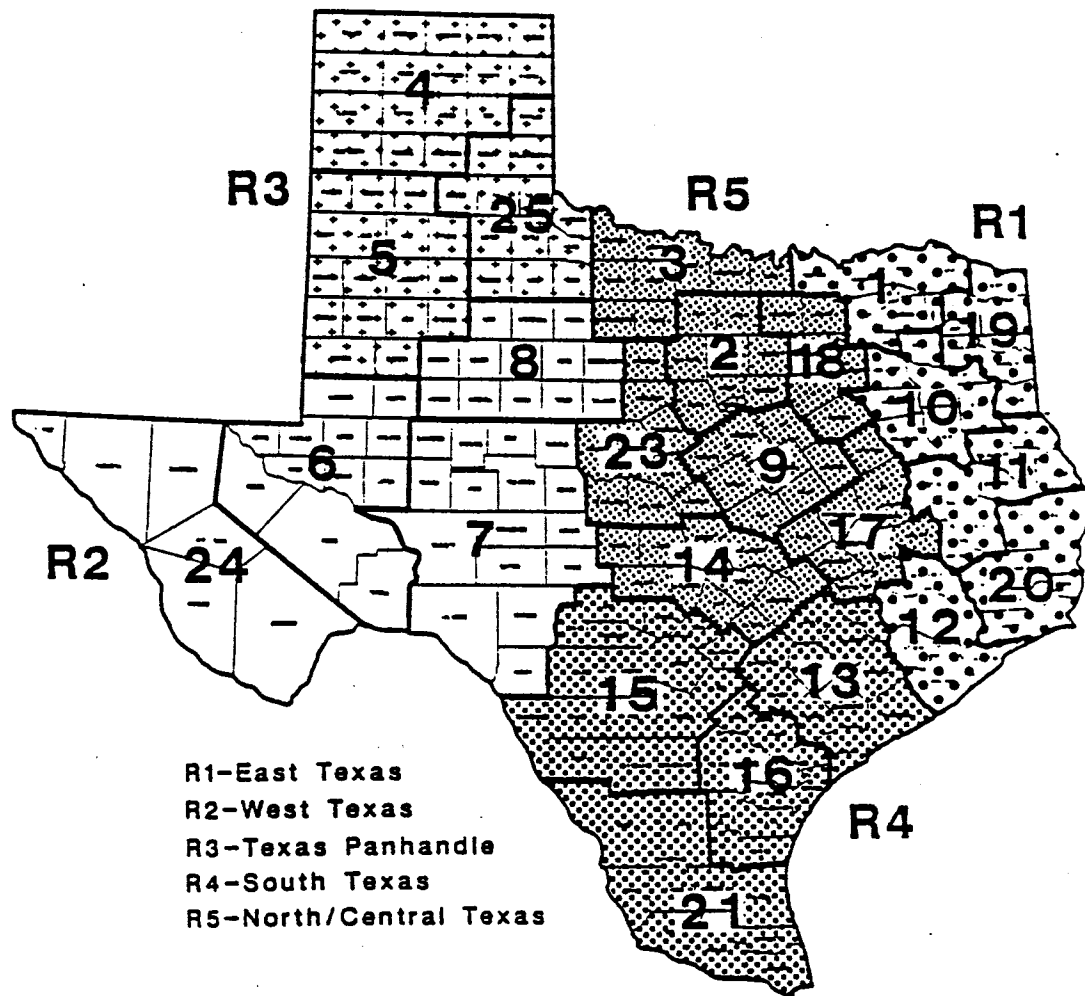


Fig. 2 Homogeneous Climatic Regions

4. DEVELOPMENT OF SURVIVAL RELATIONSHIPS

Based on actual FM road conditions data (from TTI master file), performance functions were developed for typical FM road sections in each of the five climatic regions of the state. These performance relationships were in turn used to estimate the service life (in 18-kip ESALs) of each road section considered. For any particular road, an estimate of the service life was obtained from each of several performance functions measuring PSI, rutting, alligator cracking, longitudinal cracking and transverse cracking. The service life estimate actually chosen for the road section was the one associated with the minimal number of 18-kip ESALs.

Once several service life estimates were available for FM roads of similar characteristics (such as climatic region, traffic level, type of distress or PSI causing the need for rehabilitation), the Weibull distribution [4] was used to predict the percent of lane-miles that need to be rehabilitated each year of a specified planning horizon (18 years in this case). The methodology for developing estimates of the parameters of the Weibull distribution can be divided into two steps:

- (a) FM Road Performance Modeling
- (b) FM Road Survivability Analysis

4.1 FM Road Performance Modeling

For a specified critical level of performance measured in terms of PSI or distress (rutting, alligator cracking, longitudinal cracking, transverse cracking), a sample of service lives w_1, w_2, \dots, w_n can be generated from the general relationship

$$g(w) = e^{-(\rho/w)^\beta} \quad (1)$$

where

- w: load applications on the pavement
- g: critical level of performance or pavement damage function
- ρ : scale parameter
- β : shape parameter

The above relationship has been used in several SDHPT studies [5] to investigate pavement performance. Solving Equation (1) for w , we obtain

$$w = \frac{\rho^\beta}{\ln(g_c)} \quad (2)$$

where g_c represents the specified critical level of performance.

If the performance data correspond to measurements of the present serviceability index (PSI), the critical performance index is calculated as

$$g(w) = \frac{P_0 - P_t}{P_o - P_f} \quad (3)$$

Otherwise, it is directly specified as a value between 0 and 1 indicating the maximum level of distress acceptable before rehabilitation is needed.

For Equation (3) to yield a valid value of g_c , it is necessary that $P_c \geq P_r$. Therefore, when considering test sections of a given type of pavement, Equation (2) can be used only in the case of sections having a P_t value less than or equal to the specified value P_c . All other sections violating this condition cannot be used to generate w values.

In the case of pavement distress analysis, the critical value g_c is directly specified as an input parameter. If A_c and S_c represent critical values associated with area and severity, the values of w can be obtained by solving the following equation:

$$e^{-(\rho/w)^\beta} = \begin{cases} 1 - A_c = g_c & \text{(area)} \\ 1 - S_c = g_c & \text{(severity)} \end{cases} \quad (4)$$

4.2 FM Road Survivability Analysis

A survivor curve is a functional relationship that predicts the percentage of mileage in a given pavement category that does not require immediate rehabilitation at a specified time. This specified time can be considered as the time at which the pavement has reached a given traffic load level, or the time since last rehabilitation. Evidently, to

decide if a pavement requires or does not require some kind of rehabilitation, it is first necessary to define a measure of pavement performance. This measure of performance has been defined in terms of PSI or distress as shown in the previous sections. the fundamental idea behind the development of a survivor curve is the concept that since the performance relationship is deterministic, it would be meaningful to determine a second relationship that estimates the percent of pavement mileage that actually survives when the performance function reaches a critical value.

Survival times are data that measure the time to failure. These times are subject to random variations, and like any random variables, form a distribution; the two-parameter Weibull distribution [8] is assumed as the survival distribution for predicting the survival or failure rate of pavements. The Weibull distribution is one of the well-known survival distributions; its applicability to various failure situations, such as electron tube failure and the fatigue life of deep-groove ball bearings, has been extensively investigated and recommended.

The Weibull distribution is characterized by two non-negative parameters λ and γ ; its probability density function, $f(w)$, and the cumulative distribution function, $F(w)$, are defined as follows:

$$f(w) = \gamma \lambda^\gamma w^{\gamma-1} e^{-(\lambda w)^\gamma} \quad (5)$$

$$(6)$$

$$F(w) = 1 - e^{-(\lambda w)^\gamma}$$

In the specific application of the Weibull distribution to the study of pavement survivability, w represents the traffic load (N-18 for PSI, Time for distress) at which the pavement reaches a critical performance level. The parameters λ and γ are referred to as a "scale parameter" and a "shape parameter," respectively.

The survival function, denoted by $s(w)$, is defined as the probability that an individual mile of pavement of a given type survives a traffic load larger than w . From the definition of the cumulative distribution function $F(w)$, it can be concluded that $s(w) = 1 - F(w)$. That is,

$$s(w) = e^{-(\lambda w)^\gamma} \quad (7)$$

As explained here, $s(w)$ is the survival rate of a given type of pavement structure under w

traffic loads.

The maximum likelihood estimation method [7] can be applied to obtain estimates of λ and γ on the basis of a random sample of survival times or traffic loads w_1, w_2, \dots, w_n . The corresponding estimates are the solution to the following non-linear system of Equations:

$$\frac{\sum_{i=1}^n w_i^{\hat{\gamma}} \ln(w_i)}{\sum_{i=1}^n w_i^{\hat{\gamma}}} - \frac{1}{\hat{\gamma}} - \frac{1}{n} \sum_{i=1}^n \ln(w_i) = 0 \quad (8)$$

$$\frac{1}{\hat{\lambda}^{\hat{\gamma}}} - \frac{1}{n} \sum_{i=1}^n w_i^{\hat{\gamma}} = 0 \quad (9)$$

Equation (8) can be approximately solved using the Newton-Raphson method [9] to find $\hat{\gamma}$, which in turn is used in Equation (9) to find $\hat{\lambda}$.

When a change in the legal GVW limit is considered, traffic distributions are shifted in order to reflect an increase in higher axle loads. Since it is not possible to use real data on FM road service life under a new legal load limit, it is necessary to estimate the lane-mileage needing rehabilitation by using a Weibull distribution with its parameters appropriately adjusted to reflect the impact of higher axle loads.

Suppose that the probability that an FM road needs rehabilitation at least 15 years after its last rehabilitation (i.e. removal of load zone limitation) is 0.95. If the shape parameter λ of the Weibull distribution is assumed to be unaffected by this rehabilitation, the new value of scale parameter would be given by:

$$\lambda = \frac{1}{w} \left[\ln \left(\frac{1}{0.95} \right) \right]^{\frac{1}{\gamma}} \quad (10)$$

where:

$$w = 15 E \quad (11)$$

and E is the average number of 18-kip ESALs per year. Combining Equations (10) and (11), we obtain

$$\lambda = \frac{1}{15E} \left[\ln \left(\frac{1}{0.95} \right) \right]^{\frac{1}{\gamma}} \quad (12)$$

Equation (12) will be used to estimate the scale parameter of the Weibull distribution corresponding to the service life of FM roads after removing the load zones.

4.3 Calculation of Performance and Survival Parameters

To find the performance and survival parameters for FM pavements in each climatic region, the methodology described in Sections 4.1 and 4.2 was followed. Field measurements from the data base for flexible pavements at the Texas Transportation Institute [4] were used. Specifically those data consisted of values of the present serviceability index (PSI), area and severity index for several types of distress and the corresponding traffic load levels measured at representative FM test sections across the entire state.

Performance parameters for typical test sections for each pavement type in each climatic region are shown in Appendix A (Table 12). Each performance curve developed for each test section was used to generate survivor curves using the method outlined in Section 4.2. Within each climatic region, for each type of pavement, the parameters λ and γ of the Weibull distribution were estimated for three different critical levels of performance. The estimated parameters are shown in Appendix A (Table 13).



5. APPLICATION OF METHODOLOGY AND SUMMARY OF RESULTS

The main objective of this section is to present a summary of results, in terms of both rehabilitated mileage and rehabilitation cost, for the entire State of Texas concerning the removal of FM load zones. A secondary objective is to compare these results to partial results from Study 2473.

5.1 Road Selection and Trip Generation Methodology

5.1.1 Division of the State into Climatic Homogeneous Areas

The statistical approach developed in Section 3 was used to divide the state of Texas into five climatically homogeneous areas. Using data on twelve climatic factors with 20-year monthly averages, a statistical clustering procedure determined the following climatic areas:

Region 1: Districts 1, 10, 11, 12, 19, 20

Region 2: Districts 6, 7, 8, 24

Region 3: Districts 4, 5, 25

Region 4: Districts 13, 15, 16, 21

Region 5: Districts 2, 3, 9, 14, 17, 18, 23

5.1.2 Road Selection and Trip Generation

Road segments of the FM system with heavy traffic (in load zones) were identified from the Road Inventory file. For every road segment, the mileage age distribution and the average daily traffic were determined using this file and the Road Life file and software produced in Study 0129.

5.2 Weight and Truck Data Collection

Weight data for every road segment included the following distributions:

- Single and tandem axle load distributions
- Empty and gross vehicle weight distributions

The methodology developed in this study is general and can be used with any set of relevant data. In particular, the load distribution generated from portable WIM data is

an important piece of information in the analysis conducted for the FM system. The data for the calculation of axle load and gross vehicle weight distributions were supplied by the tenth division of the Texas State Department of Highways and Public Transportation. These data basically consist of vehicle weight observations collected at WIM stations located in different sites across the state. Due to the limited WIM information for the FM system, all available records were used in this study. A list of the selected stations and their location, the collection date, and the number of observations or records collected is shown in Appendix C, Table 15. Raw weight data from the stations listed in Appendix C were processed to generate distributions of single and tandem axle load and gross vehicle weight for each region. As an illustration of the results obtained, the weight distributions generated for Region 5 are shown in Appendix C, Table 16.

Truck data included traffic percentages for every type of truck considered (2D, 3A, 2S2, 3S2) for every road segment. These data were determined from summarized data collected at manual count stations located at different sites on FM roads during several years (Classification file).

Data required in either case were provided by SDHPT. Software produced in Study 0129 was used to generate the weight and truck traffic distributions under present legal load limits; the distributions under new legal load limits were obtained using a load shifting procedure from Study 298.

5.3 Development of Road Performance and Survival Relationships

An analysis of performance data of FM roads was performed to identify typical failure modes for FM highways in each of the climatic regions of the state (See results in Table 4). The road segments identified in Part (B) of Task 1 were grouped according to climatic region, failure mode, type of pavement, and type of subgrade. Test sections of FM roads in each group were identified, and performance parameters for each section were estimated using PSI and distress data available in the TTI master file. Performance parameters of the sections in each group were used to estimate the parameters of survival curves for three different critical levels of performance. These survival curves were used to estimate the approximate mileage to be rehabilitated and maintained under both present and proposed legal load limits.

Table 4. Typical Failure Modes

Region	Pavement	Mode	Percent
1	Surface Treatment	PSI	74
		Rutting	18
		A. Crack.	4
		L. Crack.	4
2	Surface Treatment	PSI	57
		Rutting	43
3	Surface Treatment	PSI	56
		Rutting	18
		A. Crack.	8
		L. Crack.	18
4	Surface Treatment	PSI	46
		Rutting	54
5	Surface Treatment	PSI	59
		Rutting	27
		L. Crack.	14
All	Overlay	PSI	23
		Rutting	54
		T. Crack.	23

Table 5. Rehabilitation Costs

Region	Rehabilitation Cost [\$ / lane-mile]
1	138,750
2	76,500
3	55,000
4	81,250
5	106,250

5.4 Computer Runs and Final Results

5.4.1 Identification of Rehabilitation/Maintenance Costs

Typical rehabilitation actions and costs were determined by a survey of representative districts in each region. The following districts were selected: 4, 5, 6, 8, 9, 10, 14, 15, 20 and 21. Results of this survey showed that:

1. A typical rehabilitation policy (time between rehabilitations about 15 to 20 years) needed to remove load zones from the FM system consists of the following operations:
 - Adding base materials (7" - 8")
 - Adding surface treatment (one or two courses)
 - Adding a hot mix overlay (1.5") in some cases.

The average rehabilitation cost per mile for each region is given in Table 5.

Preventive maintenance costs were estimated assuming a seal coat every 6 years. Average cost of seal coats by region is given in Table 6.

Table 6. Preventive Maintenance Costs

Region	Seal Coat Cost [\$/lane-mile]
1	4,783
2	4,714
3	4,714
4	4,783
5	4,146

5.4.2 Basic Computer Run Parameters

- Years in analysis period: 18
- Annual ESAL growth rate: 3.35%
- Annual interest rate: 5.5%
- Annual highway cost index: 5.5%

- Future gross vehicle weight limit: 80 Kips
- Single axle weight limit: 20 Kips
- Tandem axle weight limit: 34 Kips
- Time between rehabilitations: 10 years (under present regulations) and 15 years (under proposed regulations).
- Time for rehabilitation of FM roads older than 25 years: 10 years.
- Time between seal coats: 6 years

5.4.3 Summary of Results

The results obtained for the entire State FM Road System are summarized in Tables 7 through 11. For two scenarios defined on the basis of interest rate, highway cost index, and ESAL growth rate, we show for both present and proposed load regulations: (a) the total mileage in need of rehabilitation and the cost associated with the removal of load zones for each year of the planning horizon (Tables 7 and 8); (b) the total mileage in need of rehabilitation, the total associated cost, and the cost per year during the planning horizon for every climatic region in the state (Tables 9 and 10).

Analysis of Table 1 shows that for a highway cost index of 5.5%, an interest rate of 5.5%, and an ESAL growth rate of 3.35%, the average annual cost of removing load zones would be \$108,745,000 and \$338,259,000 for present and proposed load regulations, respectively; therefore, under such a scenario increasing the legal gross vehicle weight limit to 80,000 pounds would represent an increase of \$229,514,000 per year in rehabilitation costs for the entire state. If the highway cost index, the interest rate, and the ESAL growth rate were assumed to be zero (see Table 8), the annual average cost of removing load zones is \$66,608,000 and \$206,234,000 for present and proposed regulations, respectively. In this case, the change of legal load limits represents an increase of \$139,626,000 in the total rehabilitation cost per year.

In addition to the mileage and cost associated with the elimination of FM load zones, Table 11 shows the cost of maintaining the FM system during each period of the 18-year planning period under both present and proposed regulations. The typical maintenance activity considered for this analysis was a seal coat each 6 years with a state average cost of \$4,783 per lane-mile.

Table 7. Annual Rehabilitation Cost for Present and Proposed Regulations. Case A: Annual Cost Index=5.5%, Annual Interest Rate=5.5%, Annual ESAL Growth Rate=3.35%

YEAR	PRESENT LOAD REGULATIONS		FUTURE LOAD REGULATIONS		DIFFERENCE
	Lane-Mil. to Rehab.	Cost	Lane-Mil. to Rehab.	Cost	Cost
1	8512	\$269,431,364	8588	\$905,203,904	\$635,772,540
2	2376	\$79,358,738	2344	\$268,656,715	\$189,297,977
3	2320	\$81,743,294	2295	\$280,236,877	\$198,493,583
4	2219	\$82,479,138	2205	\$282,400,759	\$199,921,621
5	2203	\$86,404,128	2188	\$296,437,965	\$210,033,837
6	2230	\$92,260,940	2211	\$314,719,907	\$222,458,967
7	2196	\$95,838,029	2175	\$327,690,138	\$231,852,109
8	2200	\$101,307,567	2176	\$346,511,579	\$245,204,012
9	2172	\$105,540,015	2144	\$359,619,290	\$254,079,275
10	2168	\$111,095,751	2135	\$377,020,616	\$265,924,865
11	5682	\$307,215,987	231	\$45,239,069	(\$261,976,918) *
12	1033	\$58,967,034	210	\$43,343,605	(\$15,623,429)
13	985	\$59,284,598	204	\$44,271,542	(\$15,013,056)
14	900	\$57,196,477	200	\$45,697,887	(\$11,498,590)
15	887	\$59,440,745	198	\$47,387,050	(\$12,053,695)
16	912	\$64,482,577	5627	\$1,368,320,592	\$1,303,838,015
17	879	\$65,589,214	968	\$246,879,653	\$181,290,439
18	881	\$69,362,003	931	\$251,566,533	\$182,204,530

* Numbers in parentheses are negative

Table 8. Annual Rehabilitation Cost for Present and Proposed Regulations. Case B: Annual Cost Index=0.0%, Annual Interest Rate=0.0%, Annual ESAL Growth Rate=0.0%

YEAR	PRESENT LOAD REGULATIONS		FUTURE LOAD REGULATIONS		DIFFERENCE
	Lane-Mil. to Rehab.	Cost	Lane-Mil. to Rehab.	Cost	Cost
1	8086	\$242,518,163	8155	\$823,272,273	\$580,754,110
2	2432	\$72,963,781	2401	\$245,525,492	\$172,561,711
3	2335	\$70,041,476	2314	\$239,071,447	\$169,029,971
4	2208	\$66,244,876	2192	\$225,792,814	\$159,547,938
5	2184	\$65,525,179	2167	\$223,776,529	\$158,251,350
6	2208	\$66,243,867	2188	\$224,921,837	\$158,677,970
7	2172	\$65,144,905	2148	\$221,675,760	\$156,530,855
8	2175	\$65,241,506	2148	\$222,004,607	\$156,763,101
9	2144	\$64,313,375	2114	\$218,048,334	\$153,734,959
10	2138	\$64,151,374	2104	\$216,510,136	\$152,358,762
11	5627	\$168,803,491	198	\$20,792,712	(\$148,010,779) *
12	1005	\$30,153,048	177	\$18,393,391	(\$11,759,657)
13	957	\$28,698,465	170	\$17,648,698	(\$11,049,767)
14	867	\$26,016,758	166	\$17,132,026	(\$8,884,732)
15	854	\$25,614,518	163	\$16,729,398	(\$8,885,120)
16	880	\$26,404,439	5563	\$573,720,288	\$547,315,849
17	847	\$25,404,015	935	\$95,246,914	\$69,842,899
18	849	\$25,475,148	898	\$91,957,146	\$66,481,998

* Numbers in parentheses are negative

Table 9. Rehabilitation Cost per Region, for Present and Proposed Regulations. Case A: Annual Cost Index=5.5%, Annual Interest Rate=5.5%, Annual ESAL Growth Rate=3.35%

Region	PRESENT LOAD REGULATIONS			FUTURE LOAD REGULATIONS		
	Lane-Mil. to Rehab.	Total Cost	Cost per Year	Lane-Mil. to Rehab.	Total Cost	Cost per Year
1	10161	\$304,848,896	\$27,107,138	9266	\$1,285,660,670	\$114,320,839
2	2440	\$73,216,032	\$6,510,363	2109	\$161,413,360	\$14,352,862
3	2517	\$75,535,184	\$6,716,582	2228	\$122,550,320	\$10,897,164
4	11399	\$341,988,096	\$30,409,553	10241	\$832,121,088	\$73,992,137
5	14245	\$427,368,960	\$38,001,612	13198	\$1,402,343,420	\$124,696,260

Table 10. Rehabilitation Cost per Region, for Present and Proposed Regulations. Case B: Annual Cost Index=0.0%, Annual Interest Rate=0.0%, Annual ESAL Growth Rate=0.0%

Region	PRESENT LOAD REGULATIONS			FUTURE LOAD REGULATIONS		
	Lane-Mil. to Rehab.	Total Cost	Cost per Year	Lane-Mil. to Rehab.	Total Cost	Cost per Year
1	9906	\$297,191,424	\$16,510,635	8997	\$1,248,430,850	\$69,357,269
2	2409	\$72,285,952	\$4,015,886	2079	\$159,073,968	\$8,837,443
3	2433	\$73,013,632	\$4,056,313	2156	\$118,596,128	\$6,588,674
4	11344	\$340,334,848	\$18,907,492	10165	\$825,938,688	\$45,885,483
5	13872	\$416,179,712	\$23,121,095	12801	\$1,360,168,960	\$75,564,942

Table 11. Cost of Preventive Maintenance
Under Both Present and Proposed
Regulations. Annual Cost Index=9.0%

Year	Number of Miles	Cost
1	2865	\$13,348,927
2	2865	\$14,550,330
3	2865	\$15,859,860
4	2865	\$17,287,248
5	2865	\$18,843,100
6	2865	\$20,538,979
7	2865	\$22,387,487
8	2865	\$24,402,361
9	2865	\$26,598,573
10	2865	\$28,992,445
11	2865	\$31,601,765
12	2865	\$34,445,924
13	2865	\$37,546,057
14	2865	\$40,925,202
15	2865	\$44,608,470
16	2865	\$48,623,232
17	2865	\$52,999,323
18	2865	\$57,769,262

REHABILITATION COST

Cost Index=0. %, Interest Rate=0. %, ESAL Growth Rate=0. %
DOLLARS (Millions)

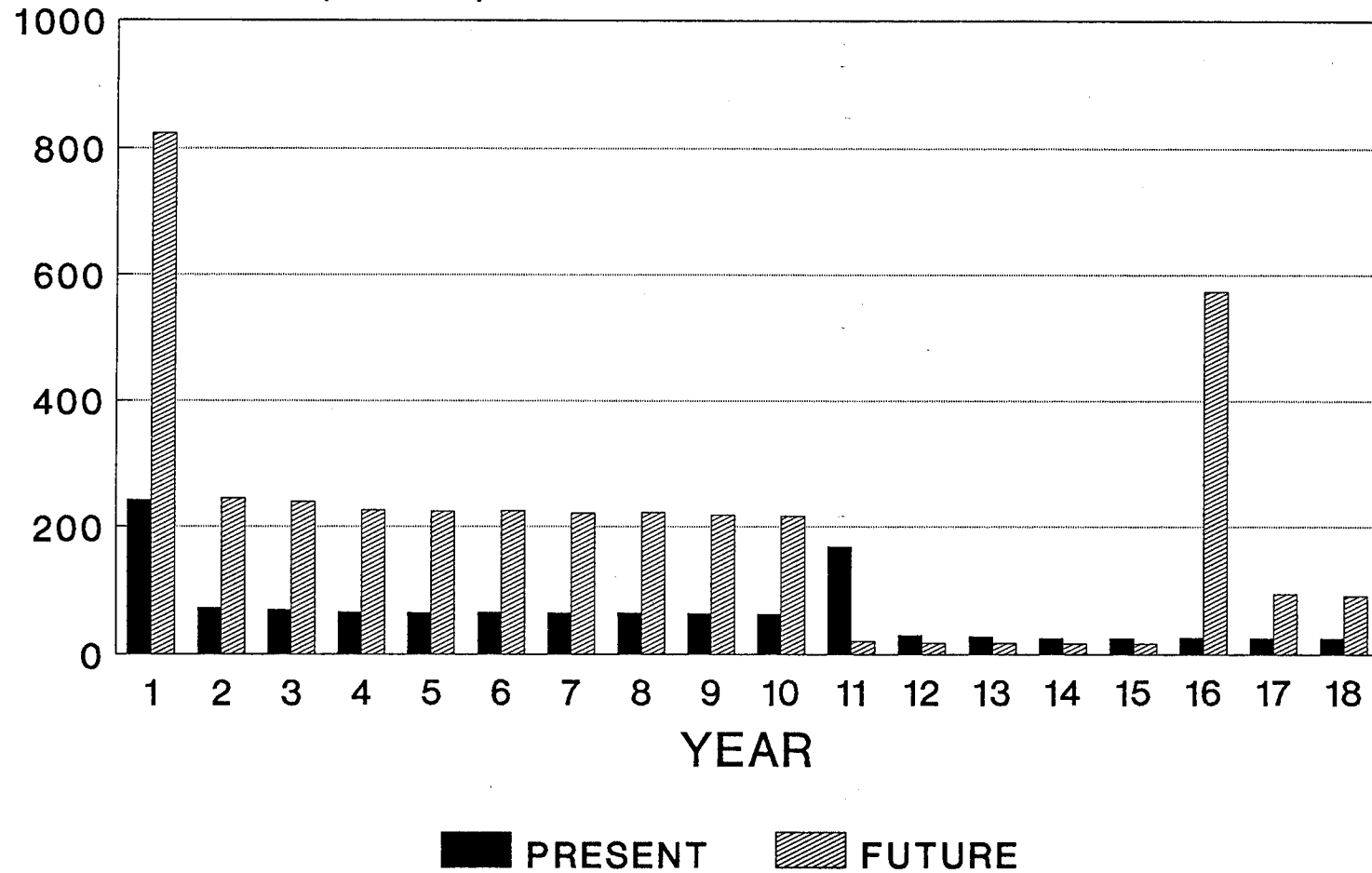


Fig. 3 Rehabilitation Cost Distribution (Case A)

REHABILITATION COST

Cost Index=5.5%, Interest Rate=5.5%, ESAL Growth Rate=3.35%
DOLLARS (Millions)

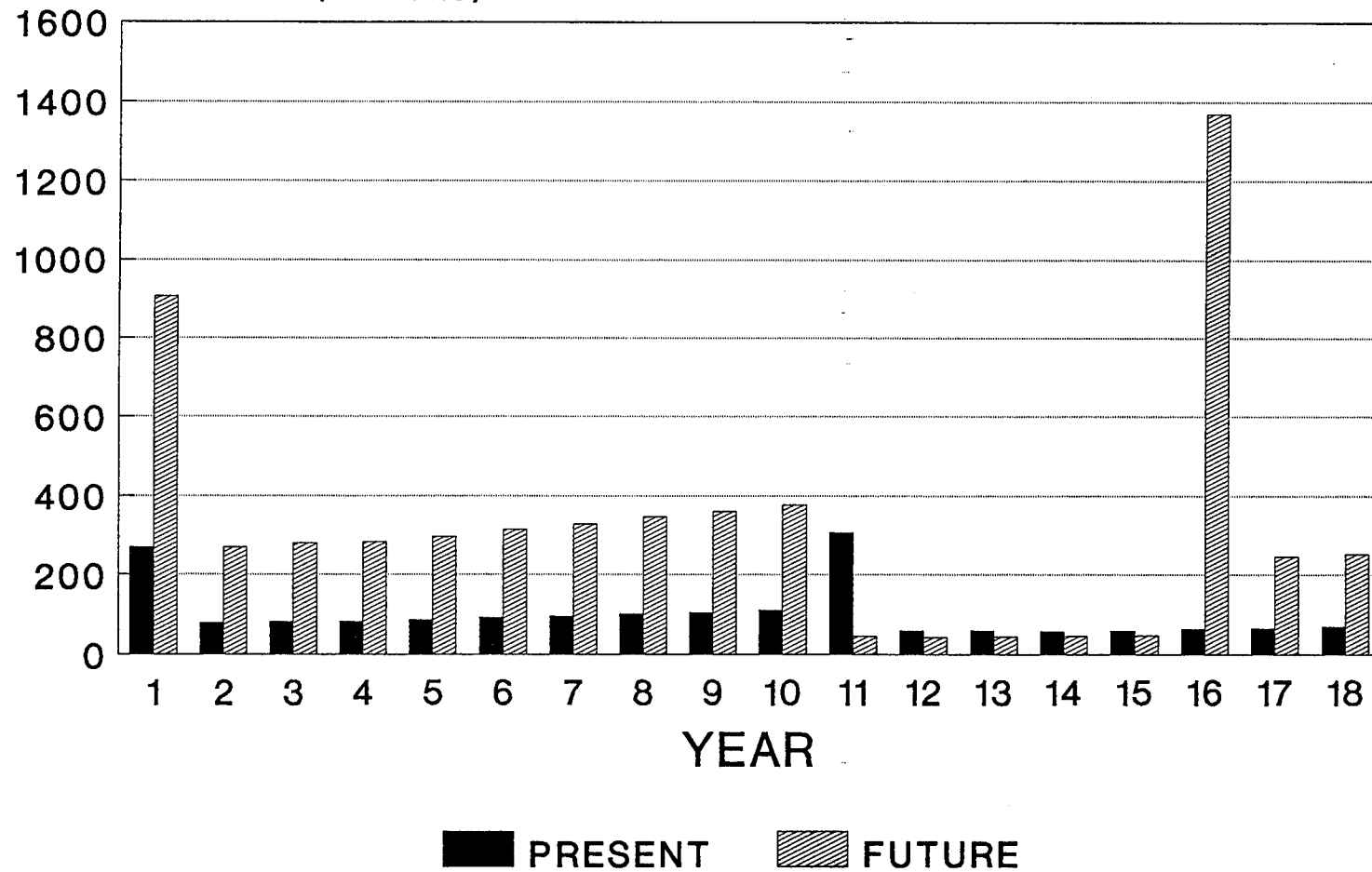


Fig. 4 Rehabilitation Cost Distribution (Case B)

Figures 3 and 4 show the rehabilitation cost distribution along the 18-year planning horizon for each of the two basic scenarios considered. As can be seen in these figures, the expenditures needed to remove FM load zones under both scenarios are relatively uniform in years 2 through 10, years 12 through 15, as well as in years 17 and 18.

5.5 Comparison Between Studies 1132 and 2473

It should be pointed out that the computer program developed in Study 2473, "Investigation of the Effects of Raising Legal Load Limits to 80,000 lbs. on Farm-to-Market Roads," is a project level program which will determine costs on a project-by-project basis, based upon field deflection measurements. By way of contrast, the computer program which is used in Study 1132, "A Model to Evaluate DHT Load Zoning Policy on the FM System," is a network level program which computes the deterioration of several typical pavement types which are thought to typify the pavements in the statewide or district wide FM system. Because it relies for its accuracy upon formulas that have been developed from historical data, it cannot predict responses, except in an overall way, of the FM system to traffic and weather changes. As a consequence, it is a good idea to have an alternative method of computing network level costs by sampling techniques and project level computations such as in Study 2473. In this way, each method of estimating network level costs may be used as a check on the other. The small effort in Study 2473 to satisfy Area II's immediate needs showed the value of this later approach, and as such served as a pilot investigation. In summary, this effort does not duplicate the work of 2473, but compliments it.

In order to compare partial results from Study 2473 to those obtained from Study 1132, three FM road sections were considered:

- FM 2497 (8.5 miles, sand subgrade, District 11)
- FM 1818B (4.0 miles, clay subgrade, District 11)
- FM 421 (12.0 miles, clay subgrade, District 20)

The methodology developed in Study 1132 was used to analyze several scenarios corresponding to six combinations of GVW and ADT values for each of the three FM

Table 12. Results for Selected FM Roads

		FM 2497 (sand)				FM 1818B (clay)				FM 421 (clay)			
		P = Present (60 kip)		ADT(1132): 255		ADT(1132): 271		ADT(1132): 539					
		F = Future (80 kip)		ADT(2473): 1405		ADT(2473): 400		ADT(2473): 1136					
GW Limit	ADT from Study	Rehab. Cost	Rehab. Lanemiles	\$/18yrs.	\$/yr.	Rehab. Lanemiles	\$/18yrs.	\$/yr.	Rehab. Lanemiles	\$/18yrs.	\$/yr.		
P	1132	\$30,000	11.71	351,203	19,511	5.28	158,538	8,807	16.48	494,421	27,467		
P	2473	\$30,000	12.12	363,638	20,202	5.40	161,978	8,998	17.26	517,812	28,767		
F	1132	\$138,750	11.45	1,588,179	88,232	5.00	693,087	38,504	15.48	2,147,909	119,328		
F	1132	\$85,000(*)	11.45	972,941	54,052	5.00	424,594	23,588	15.48	1,315,835	73,101		
F	2473	\$138,750	11.76	1,631,681	90,648	5.09	705,606	39,200	16.11	2,234,936	124,163		
F	2473	\$85,000(*)	11.76	999,592	55,532	5.09	432,264	24,014	16.11	1,369,149	76,063		

(*) From Reference 10

roads selected. Table 12 shows a summary of the results obtained. The rehabilitation costs shown in the third column of this table are given in \$/lanemile. These costs come from Table 5, with the exception of those directly taken from Reference 10, as indicated in Table 12.

As an illustration of the comparison made in this section, let us assume that ADT = 255 and GVW = 60 kip for FM 2497. The following results were obtained using the computerized procedure (Appendix B):

- (a) Lanemiles rehabilitated = 11.71
- (b) Total rehabilitation cost for an 18-year period = \$351,203
- (c) Average rehabilitation cost per year = \$19,511

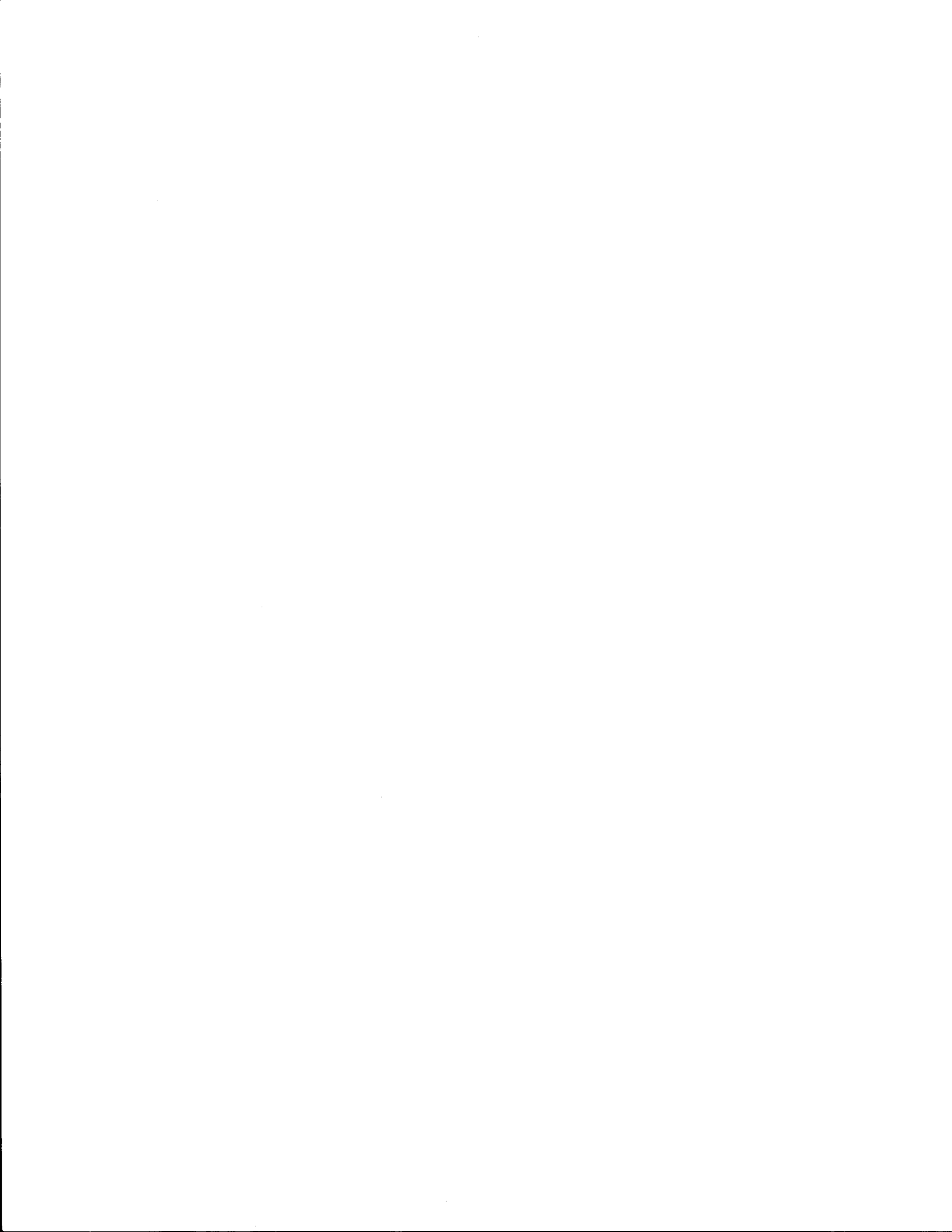
Considering again ADT = 255 but GVW = 80 kip, the corresponding results for the same FM road (FM 2497) are:

- (a) Lanemiles rehabilitated = 11.45
- (b) Total rehabilitation cost for an 18-year period = \$1,588,179
- (c) Average rehabilitation cost per year = \$88,232

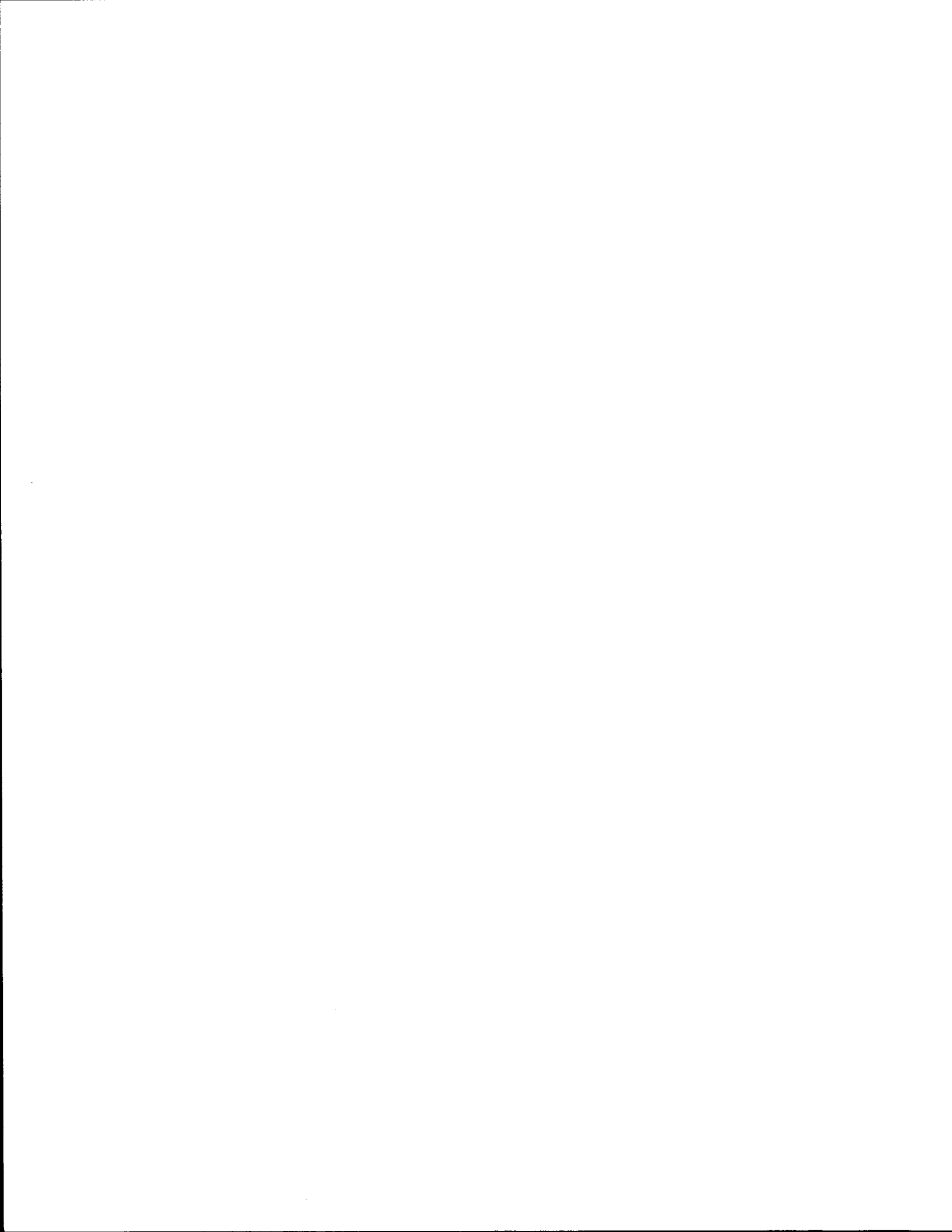
As can be seen, the increase in rehabilitation costs associated with a change in GVW from 60 kip to 80 kip is estimated as \$68,721 per year. A similar analysis for FM 1818B suggests an annual increment cost equal to \$29,697. Additionally, for FM 421 the annual increment cost would be \$91,861.

Partial findings from Study 2473 [10] indicate that the annual incremental rehabilitation costs for FM 2497, FM 1818B and FM 421 are \$16,099, \$29,796 and \$43,587, respectively. These figures were obtained using a rehabilitation cost of \$85,000 per lanemile, as used in Study 2473. It can be pointed out that the differences between the results obtained from Studies 1132 and 2483 can in part be explained by differences in rehabilitation costs per lanemile, as well as in ADT values.

In order to eliminate the effect of different rehabilitation costs per lanemile and different ADT values, a common rehabilitation cost of \$85,000 per lanemile and ADT = 1405 were considered. In this case, Study 1132 estimates that the increase in annual rehabilitation costs would be \$35,330 for FM 2497. Similarly using ADT = 400 for FM 1818B and ADT = 1136 for FM 421, the corresponding results are \$15,016 and \$47,296,

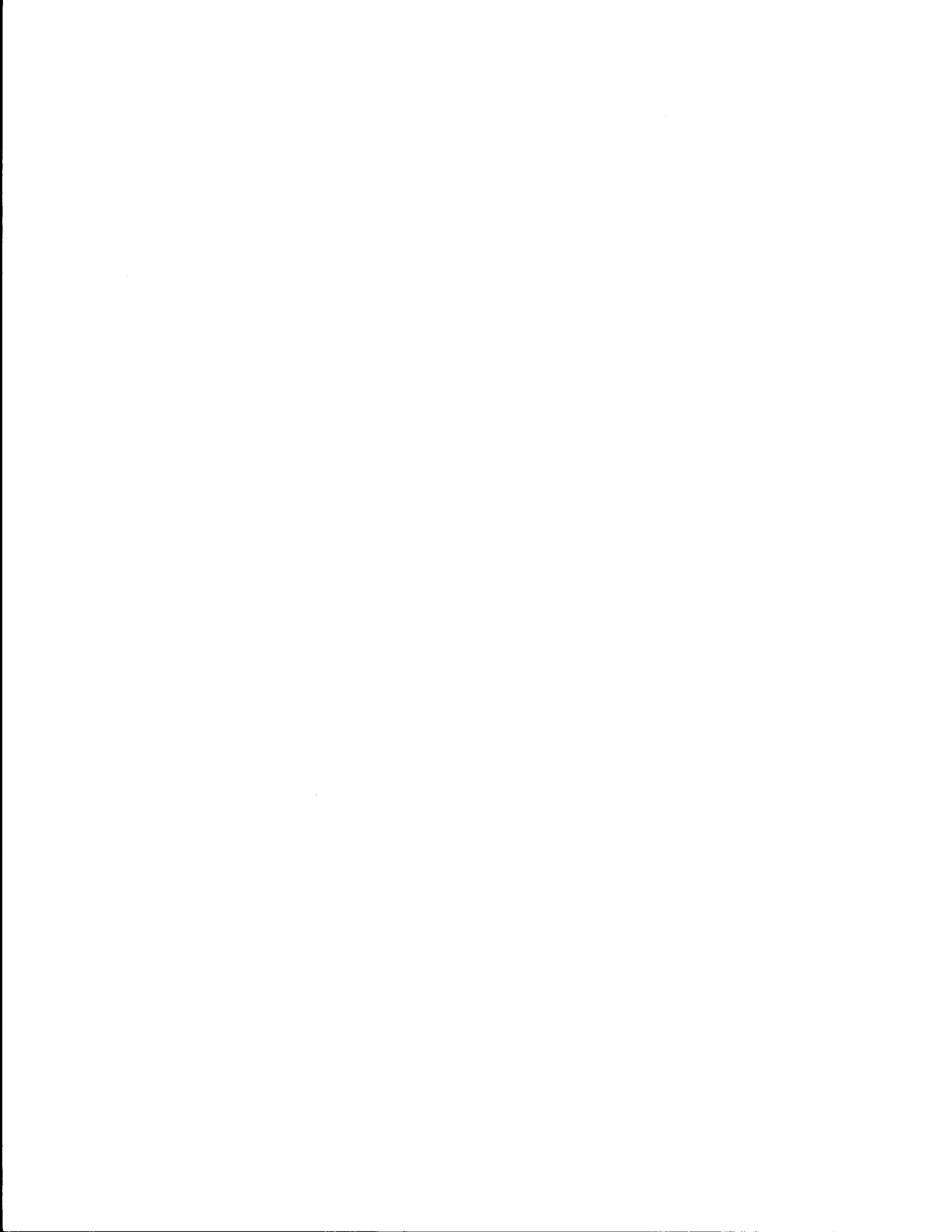


respectively. It is noted that these results are consistent with those suggested by Study 2473: \$16,099 for FM 2497, \$20,796 for FM 1818B, and \$43,587 for FM 421.



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8. SAS Institute, SAS User's Guide: Statistics, SAS Institute, Cary, NC (1982).
9. Stark, P.A., Introduction to Numerical Methods, MacMillan Publishing Co. Inc., New York, NY (1970).
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APPENDIX A
PERFORMANCE AND SURVIVAL PARAMETERS

Table 13. Representative Performance Parameters for FM Pavements

A. Performance Parameters for Surface Treatment Pavements

Type of Failure/ Subgrade	Region 1		Region 2		Region 3		Region 4		Region 5	
	Rho	Beta	Rho	Beta	Rho	Beta	Rho	Beta	Rho	Beta
PSI Clay	.0455	.7235	.0166	.3579	.0027	.5380	.0013	.6746	.0048	.4754
PSI Sand	.1421	.6557	.0032	.5348	N.A.		.0062	.4392	N.A.	
Rutting Clay	.0712	.2257	.0158	.3035	N.A.		.0691	6.448	.0325	.2556
Alligator Cracking Clay	.0502	1.246	N.A.		.2269	7.651	N.A.		N.A.	
Longitud. Cracking Clay	.0596	5.744	N.A.		.1285	2.848	N.A.		.0596	5.744
Rutting Clay	.0287	.2786	.2825	.1934	.0674	4.559	.0158	.3035	N.A.	

B. Performance Parameters for Overlay Pavements

Type of Failure/ Subgrade	Region 1		Region 2		Region 3		Region 4		Region 5	
	Rho	Beta	Rho	Beta	Rho	Beta	Rho	Beta	Rho	Beta
PSI Clay	.0021	.5664	.0021	.5664	.0021	.5664	.0021	.5664	.0021	.5664
Rutting Clay	.7407	.1734	.7407	.1734	.7407	.1734	.7407	.1734	.7407	.1734
Transv. Cracking Clay	.0397	3.640	.0397	3.640	.0397	3.640	.0397	3.640	.0397	3.640

Table 14. Survival Parameters for FM Pavements

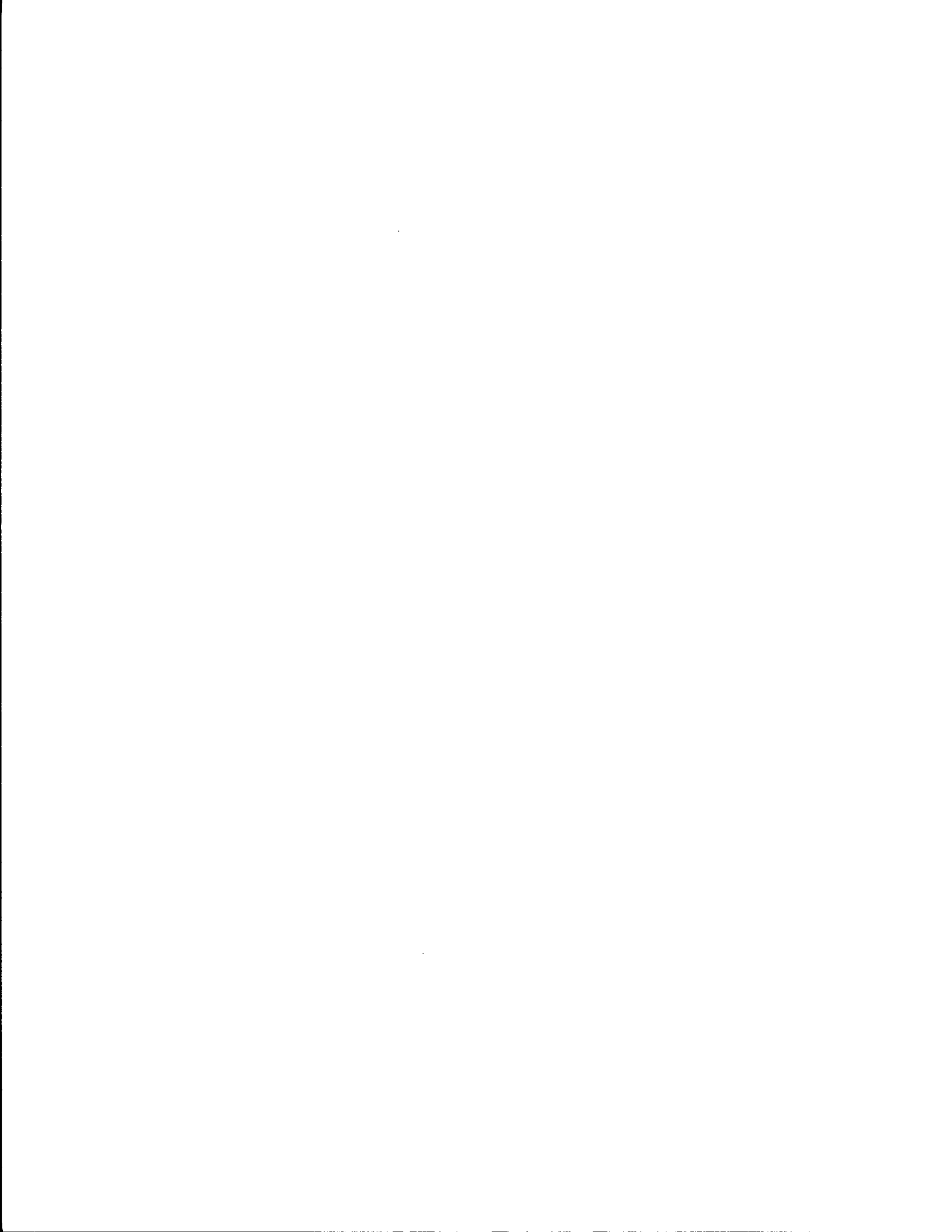
A. Survival Parameters for Surface Treatment Pavements

Type of Failure/ Subgrade	Critical Lev.	Region 1		Region 2		Region 3		Region 4		Region 5	
		Gam.	Lam.	Gam.	Lam.	Gam.	Lam.	Gam.	Lam.	Gam.	Lam.
PSI Clay	1	0.320	0.431	0.620	0.234	0.999	0.001	0.999	0.001	0.222	0.444
	2	0.449	1.845	0.590	2.457	0.943	7.548	1.393	19.63	0.312	1.491
	3	0.575	5.760	0.602	10.08	0.456	23.61	0.779	46.50	0.563	0.563
PSI Sand	1	1.639	0.827	0.999	0.001			0.999	0.001		
	2	1.101	3.219	0.231	0.333	N.A.		1.119	1.361	N.A.	
	3	1.063	12.59	0.199	1.977			1.285	47.32		
Rutting Clay	0.50	0.149	0.019	0.258	0.171			1.896	5.639	0.160	0.068
	0.35	0.303	0.460	1.111	12.71	N.A.		0.946	13.18	0.479	1.800
	0.17	0.565	3.840	2.755	17.42			0.689	21.82	0.726	9.393
Alligator Cracking Clay	0.17	2.973	6.423			0.882	3.230				
	0.35	1.002	13.34	N.A.		0.948	13.29	N.A.		N.A.	
	0.50	0.872	16.02			0.742	17.15				
Longitud. Cracking Clay	0.17	0.999	0.001			3.518	6.734			0.964	5.020
	0.35	0.190	0.018	N.A.		3.622	8.583	N.A.		2.060	11.66
	0.50	0.449	1.116			3.549	9.181			2.280	13.37
Rutting Sand	0.17	0.197	.0001	0.315	0.236	0.999	0.001	0.301	0.083		
	0.35	0.291	.0024	0.941	7.922	1.366	7.623	2.672	12.62	N.A.	
	0.50	0.324	2.502	1.278	28.89	1.647	22.20	1.140	18.93		

B. Survival Parameters for Overlay Pavements

Type of Failure/ Subgrade	Critical Lev.	Region 1		Region 2		Region 3		Region 4		Region 5	
		Gam.	Lam.	Gam.	Lam.	Gam.	Lam.	Gam.	Lam.	Gam.	Lam.
PSI Clay	1	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
	2	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
	3	9.396	3.726	9.396	3.726	9.396	3.726	9.396	3.726	9.396	3.726
Rutting Clay	0.17	0.421	5.015	0.421	5.015	0.421	5.015	0.421	5.015	0.421	5.015
	0.25	3.214	0.657	3.214	0.657	3.214	0.657	3.214	0.657	3.214	0.657
	0.50	0.191	0.031	0.191	0.031	0.191	0.031	0.191	0.031	0.191	0.031
Transv. Cracking Clay	0.17	1.894	6.628	1.894	6.628	1.894	6.628	1.894	6.628	1.894	6.628
	0.25	1.952	6.289	1.952	6.289	1.952	6.289	1.952	6.289	1.952	6.289
	0.50	2.145	5.371	2.145	5.371	2.145	5.371	2.145	5.371	2.145	5.371

APPENDIX B
MODIFIED RENU3 FORTRAN CODE



```

*****
*
*      COMPUTER PROGRAM FOR FM REHABILITATION/MAINTENANCE COST STUDY
*
*****

```

```

REAL XLAMB, TLAMB
CHARACTER*3 MC
COMMON /SHIFT/ ISHIFT
COMMON /FMTYPE/ KSUBG, IFAIL
COMMON /MECH/XKT, NRU, NLH, ND, NDEL, IACR, NREG, IYR, JYR, CONSTR(50)
COMMON /COSTS/ COSM(20,2), COSV(20,2), COSMS(20,2), COSVS(20,2),
1 CSMPW(2), CSVPW(2), CSMUA(2), CSVUA(2), COSC(20,2)
COMMON /EALPAY/ EALPT(10,2), APPT(10,2)
COMMON /EXPVT/NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC
COMMON /FUNDS/ APOF(50,2), RTINT, RTINF
COMMON /IO/ LI, LO, LD
COMMON /LMP/ XLM(50), YLM(50), POTLM(50,2), OUTP(50,2),
1 TOTALM, PPF, TPF, PFNO, NASL, NSLR, TOVLM(50,2), XLM2(50)
COMMON /OUT/ PSIE(30,2), EALREM(30,2), COSTM(20,30,2), CSTOV(30,2)
1 PSIB(30)
COMMON /OVLAY/XHCIO, XHCM, WLANE, WPSH, WGS, PPVDSH, NRHC, CAC, CGR
1 CSOAT, NPMC, AGF
COMMON /PSI/ PF, PICON, PTERM, PIOV, PTOV
COMMON /STRCOE/ STRCD(8), CC(4), NC, STRC(5), RFS(4), RFB(4)
COMMON /STRMC/ MC(11)
COMMON /TEMPC/ CONTP(25), DISTCT
COMMON /STRUC/ SN, SS, R, D, AGG, XJ, XK, E
COMMON /TIME/ OVLIF, NYAP, NYR, YR(100)
COMMON /TITLE/ TITLE(20,3), SECTTL(20)
COMMON /HOR/A(10), B(10), C(10), DT(10), DF(10), S(10), T(10), TR(5), PI(5)
*, PT(5), AC(5), AA, SCT(5), XMNW18(10), XKTO
COMMON /EXTRA/ PTOVTK, TPE, PFO, XMNOTK, XMXOTK, NIS
COMMON /BURKE/ XLAMB, GAMMA, TFBAP, TLAMB
COMMON /COST/ COSTRH(50), COSTRM(50), COSTPM(50), FMILES(50)
-, FMILEP(50)
COMMON /ACOST/ ACCRM(50), ACCRH(50), ACCPM(50), ACCFM(50)
-, ACCFP(50)
DIMENSION TITLES(5)
CALL INIT(1)
CALL INPRNT
DO 50 K=1, 50
    ACCRM(K)=0.
    ACCRH(K)=0.
    ACCPM(K)=0.
    ACCFM(K)=0.
    ACCFP(K)=0.
50 CONTINUE
100 CALL INPUT (IGO, ADT)
GO TO (110, 200, 300, 300), IGO
110 CALL INIT(2)
CALL EALGET
CALL COSCAL (ADT)
CALL ACOST
GO TO 100

```

```

200 CONTINUE
GO TO 100
300 CONTINUE
CALL PCOST
STOP
END

```

BLOCK DATA

```

CHARACTER*3 MC
COMMON /TEMPC/ CONTP(25),DISTCT
COMMON /MECH/XKT,NRU,NLH,ND,NDEL,IACR,NREG,IYR,JYR,CONSTR(50)
COMMON/HOR/A(10),B(10),C(10),DT(10),DF(10),S(10),T(10),TR(5),PI(5)
*,PT(5),AC(5),AA,SCT(5),XMNW18(10),XKTO
COMMON /EXTRA/ PTOVTK,TPE,PFO,XMNOTK,XXOTK,NIS
COMMON /CNSTS/ NAPOV, PAPOV, SIZE, AVRG
COMMON /EXPVT/ NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC
COMMON /FUNDS/ APOF(50,2), RTINT, RTINF
COMMON /IO/ LI, LO, LD
COMMON /LMP/ XLM(50), YLM(50), POTLM(50,2), OUTP(50,2),
1 TOTALM, PPF, TPF, PFNO, NASL, NSLR,TOVLM(50,2),XLM2(50)
COMMON /OVLAY/XHCIO,XHCIM,WLANE,WPSH,WGSH,PPVDSH,NRHC,CAC,CGR
1 , CSCOAT,NPMC,AGF
COMMON /PSI/ PF,PICON, PTERM, PIOV, PTOV
COMMON /STEER/ EQFACT(15,5), PTST(4)
COMMON /STRUC/ SN,SS,R,D,AGG,XJ,XK,E
COMMON /STRCOE/ STRCD(8),CC(4),NC,STRC(5),RFS(4),RFB(4)
COMMON /STRMC/ MC(11)
COMMON /TIME/ OVLIF, NYAP, NYR, YR(100)
DATA NAPOV, PAPOV, SIZE, AVRG /21, 5.0, 3.0, 100./
DATA XHCIO/0.0/,XHCIM/0.0/
DATA PICON, PTERM, PIOV, PTOV / 4*-1. /
DATA IF, IR, IC /1, 2, 3 /
DATA LI, LO, LD /10, 6, 1/
DATA SS, R, AGG, XK, E /3., 1., 195.43, 150., 4.0E6/
DATA NYAP, OVLIF, NYR / 20, 20., 40 /
DATA RTINT, RTINF /0., 0. /
C TABLE OF STEERING AXLE EQUIVALENCIES BY AXLE LOAD AND TERMINAL PSI
DATA XMNW18/10*0.0/
DATA SCT/.5,.5,.5,.5,.5/
DATA A/13.,13.,10.,8.,10.,10.,10.,10.,10.,0./
DATA AC/.5,.5,.5,.5,.5/
DATA B/12.,12.,10.,7.,10.,10.,10.,10.,40.,0./
DATA C/9.,-30.,125.,20.,16.,55.,0.,0.,0.,0./
DATA DT/.5,0.,0.,0.,0.,0.,0.,0.,0.,0./
DATA DF/1.5,1.,2.225,0.,0.,0.,0.,0.,0.,0./
DATA T/15.,0.,0.,0.,0.,0.,0.,0.,0.,0./
DATA TR/36000.,36000.,36000.,36000.,36000./
DATA S/5.,50.,30.,40.,0.,0.,0.,0.,0.,0./
DATA PI/4.7,4.73,4.41,4.81,4.6/
DATA PT/2.5,2.5,2.5,2.5,2.5/
DATA PPF,TPF,PFNO /0., 0., 0. /
DATA PTST /1.5, 2.0, 2.5, 3.0/
DATA EQFACT /2., 4., 6., 8., 10., 12., 14., 16., 18., 20., 22.,

```

```

1          24., 26., 28., 30.,
2          .0005, .008, .04, .13, .28, .52, .92, 1.42, 2.12,
3          2.95, 4.02, 5.29, 6.73, 8.31, 10.19,
4          .0009, .01, .05, .14, .31, .54, .86, 1.31, 1.94,
5          2.52, 3.35, 4.4, 5.49, 6.67, 8.05,
6          .002, .02, .06, .18, .36, .62, .93, 1.33, 1.9, 2.44,
7          3.15, 3.95, 4.82, 5.83, 6.8,
8          .004, .03, .09, .23, .41, .66, .94, 1.28, 1.74,
9          2.16, 2.7, 3.28, 3.89, 4.59, 5.23/
DATA STRCD / .44, .34, .23, .14, .30, .18, .11, .14 /
DATA RFS / .9, .7, .5, .5/
DATA RFB / 1., .9, .7, .5/
DATA CC / 1.0, 0.85, 0.75, 0.75 /
DATA NC / 11/
DATA MC / 'ACP', 'ATB', 'CTB', 'AGB', 'SAB', 'LTB', 'AGS', 'LTS',
1         'JCP', 'CRC', 'ACO'/
DATA CONTP / 21., 22., 22., 9., 16., 23., 26., 26., 28., 24., 28., 33., 33.,
1         31., 31., 36., 30., 26., 25., 32., 38., 31., 25., 24., 19./
END

```

```

*****
*
*   SUBROUTINE INPUT: READS ALL INPUT DATA, INITIALIZES SOME
*   VARIABLES, AND PROVIDES PRINTOUTS OF DATA
*
*****

```

```

SUBROUTINE INPUT (IGO,ADT)
CHARACTER*3 MC,MCODE(5)
CHARACTER*4 ISTOP, KEY, IACO
CHARACTER*4 KWORD
COMMON /TEMPC/ CONTP(25),DISTCT
COMMON /FMTP/ KSUBG,IFAIL
COMMON /EXTRA/ PTOVTK,TPE,PFO,XMNOTK,XXOTK,NIS
COMMON /MNTPAR/ S,DISS,DCON,DIN
COMMON /MECH/XKT,NRU,NLH,ND,NDEL,IACR,NREG,IYR,JYR,CONSTR(50)
COMMON /EALPAY/ EALPT(10,2), APPT(10,2)
COMMON /EXPVT/ NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC
COMMON /FUNDS/ APOF(50,2), RTINT, RTINF
COMMON /INTVLS/ STARTS(6)
COMMON /IO/ LI, LO, LD
COMMON /LDS/ PGVWL, PSAL, PTAL, PTRAL, FGVWL, FSAL, FTAL, FTRAL,
1         PSTAW(10), FSTAW(10)
COMMON /LMP/ XLM(50),YLM(50),POTLM(50,2),OUTP(50,2),TOTALM, PPF,
1         TPF, PFNO, NASL, NSLR,TOVLM(50,2),XLM2(50)
COMMON /NEWSYS/ NEWSYS
COMMON /NMBR/ SA(30,11), TA(30,11), TR(50,11), VE(30,11),
1         VG(500,11), NLDI(6), EPI(10), ST(30,11)
COMMON /OUTSWH/ IOUT
COMMON /OVLAY/XHCIO,XHCIM,WLANE,WPSH,WGSH,PPVDSH,NRHC,CAC,CGR
1         , CSCOAT,NPMC,AGF
COMMON /PSI/ PF,PICON, PTERM, PIOV, PTOV
COMMON /STRCOE/ STRCD(8),CC(4),NC,STRC(5),RFS(4),RFB(4)
COMMON /STRMC/ MC(11)
COMMON /STRUC/ SN,SS,R,D,AGG,XJ,XK,E

```

```

COMMON /TIME/ OVLIF, NYAP, NYR, YR(100)
COMMON /TITLE/ TITLE(20,3), SECTTL(20)
COMMON /TRTYP/ TTYP(2,10), PTTYP(10), PERCT(4),
1 NAXLES(10,4), NT(4), NTTY, NATT, NTT, NEWTRK
COMMON /SWTCHS/ PCTINT, PCTINF, TPFPC, PFNOPC, AGR, SPCJT,
1 XMLI,
2 INTT, IDST, NLD, TFCDNS
COMMON /SHIFT/ ISHIFT
DIMENSION KWORD(5), IVAL(2), VAL(5), KEY(16), STRCIN(5)
DIMENSION UNTCST(5)
DATA ISTOP /'STOP'/
DATA KEY /'STOP', 'EXEC', 'FLEX', 'PERF', 'AGE ', 'OVER',
1 'TRUC', 'SYST', 'RUN ',
2 'LOAD', 'SING', 'TAND', 'TRID', 'GVW ', 'EMPT', 'STEE'/
DATA IACO /'ACO '/
DATA NKEY /17/
IDST = 0
NEWTRK = 0
NEWSYS = 0

C
C READ AND ECHO PRINT A KEYWORD CARD
C
2 READ (LI,3) KWORD, IVAL, VAL
3 FORMAT(5A4,2I5,5F10.0)
WRITE (LO,4) KWORD, IVAL, VAL
4 FORMAT(1X,5A4,2I5,5(F10.2,2X))

C
C TEST FOR NORMAL PROGRAM TERMINATION
C
IF (KWORD(1) .EQ. ISTOP) GO TO 9992

C
C SEARCH THE KEY TABLE FOR THE KEYWORD READ IN
C
DO 10 I=1,NKEY
IKEY = I
IF (KWORD(1) .EQ. KEY(I)) GO TO 15
10 CONTINUE
GO TO 9996
15 GO TO (9998, 9997, 100, 300, 400, 500, 900,
1 1000, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900)
2 , IKEY

C
C *** FLEXIBLE SECTION ***
C
100 IP = IF
WLANE = VAL(1)
PF=VAL(4)
PFO=VAL(5)

C
C READ A TITLE CARD FOR THIS SECTION
C
101 READ (LI,102) SECTTL
102 FORMAT (20A4)
WRITE (LO,103) SECTTL
103 FORMAT (1X,20A4)

```

```

C
C   READ AND ECHO PRINT THE MATERIALS CARD
READ(LI,19) NDIST,NPT,KSUBG,NRU,NLH,NDEL, XMNOTK, XMXOTK,
1   IACR,NREG,IYR,JYR,IFAIL,ADT
DISTCT=FLOAT(NDIST)
IF (ADT.GE.150000.) ADT=150000.
TFCDNS= ADT*365.
19  FORMAT(6I5,2F5.0,5I5,F10.0)
WRITE(LO,21) NDIST,NPT,KSUBG,NRU,NLH,NDEL, XMNOTK, XMXOTK,
1   IACR,NREG,IYR,JYR,IFAIL,ADT
21  FORMAT(1X,6I5,2F5.2,5I5,F10.2)
READ (LI,110) (MCODE(I), THICK(I), STRCIN(I), I=1,4)
MCODE(1)=MC(1)
MCODE(2)=MC(4)
MCODE(3)=MC(8)

```

```

C
C   THICK REPRESENTS THE LAYER THICKNESSES OF REPRESENTATIVE
C   SECTIONS
C
C

```

```

IF(THICK(1).NE.0) GO TO 1010
IF(NPT.NE.2.OR.NRU.NE.1) GO TO 50
THICK(1)=.75
THICK(2)=6.0
GO TO 1010
50  IF(NPT.NE.2.OR.NRU.NE.2) GO TO 51
THICK(1)=0.75
THICK(2)=8.0
GO TO 1010
51  IF(NPT.NE.1.OR.NRU.NE.1.OR.NLH.NE.1) GO TO 52
THICK(1)=2.0
THICK(2)=8.0
GO TO 1010
52  IF(NPT.NE.1.OR.NRU.NE.1.OR.NLH.NE.2) GO TO 53
THICK(1)=4.0
THICK(2)=12.0
GO TO 1010
53  IF(NPT.NE.1.OR.NRU.NE.2.OR.NLH.NE.1) GO TO 54
THICK(1)=2.0
THICK(2)=8.
THICK(3)=6.0
GO TO 1010
54  IF(NPT.NE.1.OR.NRU.NE.2.OR.NLH.NE.2) GO TO 55
THICK(1)=4.0
THICK(2)=10.0
THICK(3)=6.0
GO TO 1010
55  MCODE(2)=MC(2)
MCODE(3)=MC(4)
MCODE(4)=MC(8)
IF(NPT.NE.3.OR.NRU.NE.1.OR.NLH.NE.1) GO TO 56
THICK(1)=2.0
THICK(2)= 2.0
THICK(3)=8.0

```

```

56   GO TO 1010
    IF(NPT.NE.3.OR.NRU.NE.1.OR.NLH.NE.2) GO TO 57
    THICK(1)=3.0
    THICK(2)= 4.0
    THICK(3)=12.0
    GO TO 1010
57   IF(NPT.NE.3.OR.NRU.NE.2.OR.NLH.NE.1) GO TO 58
    THICK(1)=2.0
    THICK(2)= 2.0
    THICK(3)=8.0
    THICK(4)=6.0
58   IF(NPT.NE.3.OR.NRU.NE.2.OR.NLH.NE.2) GO TO 1010
    THICK(1)=3.0
    THICK(2)= 4.0
    THICK(3)=10.0
    THICK(4)=6.0
1010 CONTINUE
110  FORMAT(5(A3,2X,2F5.0,1X))
    WRITE (LO,120) (MCODE(I), THICK(I), STRCIN(I), I=1,4)
120  FORMAT(1X,5(A3,2X,F5.2,1X,F5.3,1X))
C
C   DETERMINE THE NUMBER OF LAYERS IN THE PAVEMENT STRUCTURE
C
    IPFLG = 0
    DO 140 I=1,4
    IF (THICK(I) .LE. 0.0) GO TO 160
    NLAY = I
    STRC(I) = STRCIN(I)
    DO 135 J=1,NC
    IF (MCODE(I) .NE. MC(J)) GO TO 135
    IF ((IP .EQ. IF) .AND. ((J .EQ. 9) .OR. (J .EQ. 10))) GO TO 9994
    MTYPE(I) = J
    GO TO 140
135  CONTINUE
    GO TO 9993
140  CONTINUE
160  IF (IPFLG .EQ. 0) GO TO 165
    IF (MTYPE(2) .NE. 9 .AND. MTYPE(2) .NE. 10) GO TO 9989
    NIS=1
    IP = IC
165  STRC(5) = STRC(1)
    MCODE(5) = IACO
    GO TO 2
C
C   *** PERFORMANCE SECTION ***
C
300  PTERM = VAL(2)
    PIOV = VAL(3)
    PTOV = PTERM
    OVLIF = NYAP
    IF (VAL(4) .GT. 0.) OVLIF = VAL(4)
    GO TO 2
C
C   *** AGE DISTRIBUTION SECTION ***
C

```



```

400 NASL = IVAL(1)
C
C READ AND ECHO PRINT THE DISTRIBUTION OF LANE MILES BY AGE
C
  READ (LI,410) (YLM(I),I=1,NASL)
410 FORMAT(16F5.0,/,14F5.0)
  DO 415 I=1,NASL-5
415 YLM(I)=YLM(I+5)
  YLM(1)=4.
  NASL=25
  WRITE (LO,420) (YLM(I),I=1,NASL)
420 FORMAT(1X,15F8.1/1X,15F8.1)
404 IF(NASL.LE.25) GO TO 421
C DO 422 I=26,NASL
C 422 YLM(25)=YLM(25)+YLM(I)
  NASL=25
421 CONTINUE
  GO TO 2

C
C *** OVERLAY SECTION ***
C
500 PPVDSH = VAL(1)
  WPSH = VAL(2)
  WGSB = VAL(3)
  GO TO 2

C
C *** TRUCK TYPES SECTION ***
C
900 NTTY = IVAL(1)
  NATT = IVAL(2)
  PERCT(1)=VAL(1)
  PERCT(2)=VAL(2)
  PERCT(3)=VAL(3)
  PERCT(4)=VAL(4)
  NEWTRK = NEWTRK + 1
  IF ((NTTY+NATT) .GT. 10) GO TO 9995
  NTT = NTTY
  K = 0
  INTT = NTT + NATT

C
C READ AND ECHO PRINT THE TRUCK LABELS
C
  READ (LI,910) ((TTYP(M,J),M=1,2),J=1,10)
910 FORMAT(8(2A4,2X),/,2(2A4,2X))
  WRITE (LO,920) ((TTYP(M,J),M=1,2),J=1,10)
920 FORMAT(1X,8(2A4,2X),/,1X,2(2A4,2X))

C
C READ AND ECHO PRINT THE AXLE CONFIGURATIONS
C
  READ (LI,921) ((NAXLES(M,J),J=1,4),M=1,10)
921 FORMAT(8(4I2,2X),/,2(4I2,2X))
  WRITE (LO,922) ((NAXLES(M,J),J=1,4),M=1,10)
922 FORMAT(1X,8(4I2,2X),/,1X,2(4I2,2X))
  DO 929 J=1,4
  NT(J) = 0

```

```

          DO 928 M=1,NTT
          NT(J) = NT(J) + NAXLES(M,J)
928 CONTINUE
929 CONTINUE
C
C   READ AND ECHO PRINT THE TRUCK PERCENTAGES
C
935 READ (LI,930) I, (PTTYP(J),J=1,10)
930 FORMAT(I3,1X,10F6.0)
      WRITE (LO,940) I, (PTTYP(J),J=1,10)
940 FORMAT(1X,I3,1X,10F6.2)
      GO TO 2
C
C   *** TITLE CARD SECTION ***
C
C   READ AND ECHO PRINT THE THREE TITLE CARDS
C
1000 DO 1030 J=1,3
      READ (LI,102) (TITLE(I,J),I=1,20)
      WRITE (LO,103) (TITLE(I,J),I=1,20)
1030 CONTINUE
      NEWSYS = 1
      GO TO 2
C
C   *** RUN PARAMETERS ***
C
1200 IF (IVAL(1) .NE. 0) NYAP = MIN0(IVAL(1),18)
      ISHIFT=IVAL(2)
      AGR = VAL(1)
      RTINT = VAL(2)
      RTINT=RTINT/100.
      IF(VAL(3) .NE.0.0)XHCIO=VAL(3)
      IF(VAL(4) .NE.0.0)XHCIM=VAL(4)
      GO TO 2
C
C   *** LOAD LIMITS SECTION ***
C
C   READ THE PRESENT AND FUTURE LOAD LIMITS
C
1300 IEWS = IVAL(1)
      IDST = 1
      NEWTRK = NEWTRK + 2
      READ (LI,1310) PGVWL, PSAL, PTAL
1310 FORMAT(4F10.0)
      WRITE (LO,1315) PGVWL, PSAL, PTAL
1315 FORMAT(1X,4F10.2)
      READ (LI,1310) FGVWL, FSAL, FTAL
      WRITE (LO,1315) FGVWL, FSAL, FTAL
      DO 1320 I = 1,10
      PSTAW(I)=0.
      FSTAW(I)=0.
1320 CONTINUE
      PTRAL=0.
      FTRAL=0.
      GO TO 2

```

```

C
C   *** SINGLE AXLE SECTION ***
C
1400 NLDI(1) = IVAL(1)
      NLD = IVAL(1)
      NTT = INTT
      STARTS(1) = VAL(1)
      NEWTRK = NEWTRK + 2
C
C   READ THE LOAD INTERVALS AND, FOR EACH TRUCK TYPE, THE NUMBER OF
C   SINGLE AXLES FOR EACH INTERVAL
C
      DO 1420 L=1,NLD
      READ (LI,1410) ELDINT, (SA(L,J),J=1,NTT)
1410  FORMAT(F10.0,10F7.0)
      WRITE (LO,1415) ELDINT, (SA(L,J),J=1,NTT)
1415  FORMAT(1X,F10.0,10F7.0)
      SA(L,11) = ELDINT
1420  CONTINUE
      DO 1424 J=1,NTT
      INDIC=0
      DO 1425 L=1,NLD
      IF (SA(L,J).NE.0.) INDIC=1
1425  CONTINUE
      IF (INDIC.EQ.0) SA(1,J)=1.
1424  CONTINUE
      GO TO 2
C
C   *** TANDEM AXLE SECTION ***
C
1500 NLDI(2) = IVAL(1)
      NLD = IVAL(1)
      NTT = INTT
      STARTS(2) = VAL(1)
      NEWTRK = NEWTRK + 2
C
C   READ THE LOAD INTERVALS AND NUMBER OF DOUBLES PER TRUCK TYPE PER
C
      DO 1510 L=1,NLD
      READ (LI,1410) ELDINT, (TA(L,J),J=1,NTT)
      WRITE (LO,1415) ELDINT, (TA(L,J),J=1,NTT)
      TA(L,11) = ELDINT
1510  CONTINUE
      DO 1426 J=1,NTT
      INDIC=0
      DO 1427 L=1,NLD
      IF (TA(L,J).NE.0.) INDIC=1
1427  CONTINUE
      IF (INDIC.EQ.0) TA(1,J)=1.
1426  CONTINUE
      GO TO 2
C
C   *** TRIPLE AXLE SECTION ***
C
1600 NLDI(3) = IVAL(1)

```

```

NLD = IVAL(1)
NTT = INTT
STARTS(3) = VAL(1)
NEWTRK = NEWTRK + 2
C
C   READ THE LOAD INTERVALS AND NUMBER OF TRIPLES PER TRUCK TYPE PER
C
DO 1610 L=1,NLD
READ (LI,1410) ELDINT, (TR(L,J),J=1,NTT)
WRITE (LO,1415) ELDINT, (TR(L,J),J=1,NTT)
TR(L,11) = ELDINT
1610 CONTINUE
GO TO 2
C
C   *** GROSS VEHICLE WEIGHT SECTION ***
C
1700 NLDI(4) = IVAL(1)
NLD = IVAL(1)
NTT = INTT
STARTS(4) = VAL(1)
NEWTRK = NEWTRK + 2
C
C   READ THE LOAD INTERVALS AND THE NUMBER OF EACH TRUCK TYPE WHOSE G
C   WITHIN EACH INTERVAL
C
DO 1710 L=1,NLD
READ (LI,1410) ELDINT, (VG(L,J),J=1,NTT)
WRITE (LO,1415) ELDINT, (VG(L,J),J=1,NTT)
VG(L,11) = ELDINT
1710 CONTINUE
GO TO 2
C
C   *** EMPTY VEHICLE WEIGHT SECTION ***
C
1800 NLDI(5) = IVAL(1)
NLD = IVAL(1)
NTT = INTT
STARTS(5) = VAL(1)
NEWTRK = NEWTRK + 2
C
C   READ THE LOAD INTERVALS AND THE NUMBER OF EACH TRUCK TYPE WHOSE E
C   WITHIN EACH INTERVAL
C
DO 1810 L=1,NLD
READ (LI,1410) ELDINT, (VE(L,J),J=1,NTT)
WRITE (LO,1415) ELDINT, (VE(L,J),J=1,NTT)
VE(L,11) = ELDINT
1810 CONTINUE
GO TO 2
C
C   *** STEERING AXLES SECTION ***
C
1900 NLDI(6) = IVAL(1)
NLD = IVAL(1)
NTT = INTT

```

```

STARTS(6) = VAL(1)
IDST = 6
NEWTRK = NEWTRK + 2
C
C READ THE LOAD INTERVALS AND, FOR EACH TRUCK TYPE, THE NUMBER OF
C STEERING AXLES FOR EACH INTERVAL
C
DO 1910 L=1,NLD
READ (LI,1410) ELDINT, (ST(L,J),J=1,NTT)
WRITE (LO,1415) ELDINT, (ST(L,J),J=1,NTT)
ST(L,11) = ELDINT
1910 CONTINUE
GO TO 2
C
C *** KEYWORD ERROR PROCESSING SECTION ***
C
9989 WRITE (LO,9089) IPFLG
9089 FORMAT(/1X,'*** ERROR IN LAYER ',I1,' ***'//
1 ' ACP NOT PERMITTED FOR RIGID PAVEMENT '/
2 ' UNLESS ABOVE JCP OR CRC LAYER'//
3 ' RUN TERMINATED')
GO TO 9999
9992 IGO = 3
GO TO 99999
9993 WRITE (LO,9093)
9093 FORMAT(/1X,'*** UNRECOGNIZABLE MATERIALS CODE ***'//
1 ' RUN TERMINATED')
GO TO 9999
9994 WRITE (LO,9094)
9094 FORMAT(/1X,'*** ILLEGAL MATERIAL CODE FOR THIS TYPE OF PAVEMENT',
1 ' ***'//' RUN TERMINATED')
GO TO 9999
9995 WRITE (LO,9095)
9095 FORMAT(/1X,'*** TOO MANY TRUCK TYPES ***'//
1 ' RUN TERMINATED')
GO TO 9999
9996 WRITE (LO,9096)
9096 FORMAT(/1X,'*** SPECIFIED KEYWORD NOT FOUND IN TABLE ***',
1 //' RUN TERMINATED')
GO TO 9999
9997 IGO = 1
GO TO 99999
9998 WRITE (LO,9098)
9098 FORMAT(/1X,'*** STOP DIRECTIVE FOUND OUT OF SEQUENCE ***',
1 //' RUN TERMINATED')
9999 IGO = 4
99999 DO 3500 I=1,30
XLM(I) = YLM(I)
3500 CONTINUE
S = SPCJT
XML = 0.
IF (XMLI .NE. 0.) XML = XMLI
LP = MINO(4, MAXO(1,INT(7.1 - 2.*PTERM)))
RETURN
END

```

```

*****
*
*   SUBROUTINE INPRNT: READS SURVIVAL CURVE PARAMETERS   *
*
*****

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```

SUBROUTINE INPRNT
COMMON /FUNDS/ APOF(50,2), RTINT, RTINF
COMMON /OVLAY/XHCIO,XHCIM,WLANE,WPSH,WGSH,PPVDSH,NRHC,CAC,CGR
1   , CSCOAT,NPMC,AGF
COMMON /SWTCHS/ PCTINT, PCTINF, TPFPC, PFNOPC, AGR, SPCJT,
1   XMLI,
2   INTT, IDST, NLD, TFCDNS
COMMON /CMAT/ UNTCST(5,4),BZ(5,3),BB(5,2),RBZ(2,2)
COMMON /SURVP/ FPLAM(2,3,5),FPGAM(2,3,5),FDGAM(4,3,5),
-FDLAM(4,3,5),FOPLAM(4,3,1),FOPGAM(4,3,1),FODLAM(5,3,1),
-FODGAM(5,3,1)
10  FORMAT(1X,F3.0,/)
FOPLAM(4,1,1)=1.0
FOPLAM(4,2,1)=0.0
FOPLAM(4,3,1)=3.726
FOPGAM(4,1,1)=0.0
FOPGAM(4,2,1)=1.0
FOPGAM(4,3,1)=9.396
FODLAM(1,1,1)=0.03049
FODLAM(1,2,1)=0.65715
FODLAM(1,3,1)=5.01518
FODGAM(1,1,1)=0.191
FODGAM(1,2,1)=0.32141
FODGAM(1,3,1)=0.42128
FODGAM(5,1,1)=2.1448
FODGAM(5,2,1)=1.9520
FODGAM(5,3,1)=1.8945
FODLAM(5,1,1)=5.370
FODLAM(5,2,1)=6.289
FODLAM(5,3,1)=6.6278
READ(9,10) X
DO 70 I=1,2
DO 70 J=1,3
READ(9,60) (FPGAM(I,J,K),FPLAM(I,J,K),K=1,5)
WRITE (6,*) 'IFAIL=',I,' IACR=',J
WRITE (6,60) (FPGAM(I,J,K),FPLAM(I,J,K),K=1,5)
60  FORMAT(7X,10F6.0)
70  CONTINUE
READ(9,80) X
80  FORMAT(1X,F3.0,///)
DO 90 I=1,4
DO 90 J=1,3
READ(9,60) (FDGAM(I,J,K),FDLAM(I,J,K),K=1,5)
90  CONTINUE
99999 RETURN
END

```

```

*****
*
* SUBROUTINE INIT:INITIALIZES CERTAIN ARRAYS TO ZERO AND CALC- *
* ULATES STRUCTURAL NUMBERS FOR FLEXIBLE SECTIONS *
*
*****

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SUBROUTINE INIT (IGO)
COMMON /EXPVT/ NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC
COMMON /STRUC/ SN,SS,R,D,AGG,XJ,XK,E
COMMON /STRCOE/ STRCD(8),CC(4),NC,STRC(5),RFS(4),RFB(4)
COMMON /TIME/ OVLIF, NYAP, NYR, YR(100)
DATA ICON, F /2, 1. /
C   ICON IS THE INDEX ON CONDITION FACTOR USED TO RELATE AN OLD PCC
C   PAVEMENT WITH AN AC OVERLAY TO AN EQUIVALENT SLAB THICKNESS.
C   F IS A FACTOR ALSO USED IN THE ABOVE RELATION.
GO TO (100, 200, 900), IGO
C   HERE FOR PROGRAM INITIALIZATION, FIRST EXECUTION.
100 DO 110 J=1,NYR
    YR(J) = FLOAT(J)
110 CONTINUE
    GO TO 900

C
C   HERE FOR SET UP CHORES AFTER READING INPUT DATA.
200 CONTINUE
C   WE HAVE ALL THE INPUT FOR A REPRESENTATIVE SECTION. DETERMINE -S
C   OR -D- FOR COMPOSITE PAVTS, AS WELL AS SET UP STRUCTURAL COEF.
    SN = 0.
    DO 215 L=1,NLAY
        M = MTYPE(L)
        REPLACE VALUE IN DATA STATEMENT WITH VALUE READ IN.
        IF (STRC(L) .NE. 0.) STRCD(M) = STRC(L)
        IF NO VALUE READ IN, SET VALUE FROM THE DATA STATEMENT.
        IF (STRC(L) .EQ. 0.) STRC(L) = STRCD(M)
215 SN = SN + STRC(L)*THICK(L)
C   SET -A- VALUE FOR OVERLAY = -A- FOR AC IF NOT READ IN SEPARATELY.
C   IF (STRC(5) .EQ. 0.) STRC(5) = STRCD(1)
900 CONTINUE
    RETURN
    END

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*****
*
* SUBROUTINE DISTR: CALCULATES FAILURE PROBABILITIES FOR FLEX- *
* IBLE PAVEMENTS USING SURVIVAL CURVES *
*
*****

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SUBROUTINE DISTR ( P, NHIST, NSLICE, IPAR)
COMMON /SWTCHS/ PCTINT, PCTINF, TPFPC, PFNOPC, AGR, SPCJT,
1      XMLI,
2      INTT, IDST, NLD, TFCDNS
COMMON /MECH/XKT,NRU,NLH,ND,NDEL,IACR,NREG,IYR,JYR,CONSTR(50)
COMMON /BURKE/ XLAMB, GAMMA, TFBAP, TLAMB
COMMON /EXPVT/ NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC

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COMMON /JUNK/ACU(60)
DIMENSION P(60)
TF=(TFBAP*15.)/1000000.
IF (IPAR.EQ.0) TLAMB=XLAMB
100 IF (IPAR.EQ.1) TLAMB=(1./TF)*(ALOG(1./0.95))**(1./GAMMA)
C->GET INITIAL TRAFFIC
AGF=AGR/100.
WO=TFBAP*(1+AGF)**(-NSLICE)
C->GET P(I) FOR I=1 TO NHIST
ACUM=0
ACPLYR=0
DO 10 I=1,NHIST
C----->TRANSFORM YEARS INTO ACCUMULATED LOADS AT AGE I
ACUM=ACUM + WO*(1+AGF)**I
C----->GET CUMMULATIVE FRACTION OF PAVEMENTS THAT FAILED
C "ACUMIL" STANDS FOR ACCUMULATED EAL IN MILLIONS
ACUMIL = ACUM/1000000
ACU(I)=ACUMIL
POWER = -(TLAMB*ACUMIL)**GAMMA
IF (POWER .GT. -5.4E-79) POWER = -5.4E-79
ACPNOW=1-EXP(POWER)
C----->GET FRACTION OF PAVEMENTS THAT FAILED DURING YEAR I
P(I)=ACPNOW-ACPLYR
C----->UPDATE POINTER AND DO IT AGAIN
ACPLYR=ACPNOW
10 CONTINUE
999 RETURN
END

```

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*****
*
* SUBROUTINE EALGET: CALCULATES EALS AT BEGINNING OF THE ANALY-*
* SIS PERIOD FOR BOTH PRESENT AND PROPOSED REGULATIONS *
*
*****

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```

SUBROUTINE EALGET
COMMON /EALPAY/ EALPT(10,2), APPT(10,2)
COMMON /EXPVT/ NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC
COMMON /PSI/ PF,PICON, PTERM, PIOV, PTOV
COMMON /STRUC/ SN,SS,R,D,AGG,XJ,XK,E
COMMON /TIME/ OVLIF, NYAP, NYR, YR(100)
COMMON /SWTCHS/ PCTINT, PCTINF, TPFPC, PFNOPC, AGR, SPCJT,
1 XMLI,
2 INTT, IDST, NLD, TFCDNS
COMMON /TRTYP/ TTYP(2,10), PTTYP(10),PERCT(4),
1 NAXLES(10,4),NT(4),NTTY, NATT, NTT, NEWTRK
COMMON /BURKE/ XLAMB, GAMMA, TFBAP, TLAMB
COMMON /SHIFT/ ISHIFT
DIMENSION S1(10), S2(10), T1(10), T2(10), TFB(2)
IPVT = IP
IF (IP .EQ. IC) IPVT = IR
C CALL -TRAFFIC- ONLY IF NEW LIMITS OR WEIGHT DISTRIBUTIONS
C READ FOR THIS PROBLEM
IF (NEWTRK .GT. 1) CALL TRAFFIC

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CALL EAL18 (SN, D, PTERM, IPVT)
C EAL18 RETURNS 18K EAL PER AVERAGE TRUCK, EALPT, AND PAYLOAD PER
C AVERAGE TRUCK, APPT, FOR EACH TRUCK TYPE.
C FOR EACH YEAR OBTAIN THE (NORMALIZED) TOTAL PAYLOAD AND TOTAL 18K
C EAL
CALL MULT (PTTYP(1), APPT(1,1), NTTY, S1)
CALL MULT (PTTYP(1), EALPT(1,1), NTTY, T1)
CALL MULT (PTTYP(1), EALPT(1,2), NTT, T2)
CALL SUM (T2, NTT, TUM2)
CALL SUM (S1, NTTY, SUM1)
CALL SUM (T1, NTTY, TUM1)
TFB(1)=TUM1*TFCDNS/100.
TFB(2)=TUM2*TFCDNS/100.
WRITE(6,*) 'TFBAP(1)=', TFB(1), 'TFBAP(2)=', TFB(2)
TFBAP=TFB(1)
IF (ISHIFT.EQ.1) TFBAP=TFB(2)
RETURN
END

```

```

*****
*
* SUBROUTINE TRAFIC: COMPUTES THE FOLLOWING *
* 1. THE ADJUSTED AVERAGE EMPTY WEIGHT OF VEHICLES *
* WEIGHED EMPTY *
* 2. ADJUSTED GROSS WEIGHT AND TOTAL PAYLOAD CARRIED *
* FOR PRESENT AND PROPOSED REGULATIONS *
* 3. DISTRIBUTION OF AXLE WEIGHTS--PRESENT AND PRO- *
* POSED REGULATIONS *
* 4. AXLE WEIGHT DISTRIBUTIONS BY VEHICLE CLASSIFICA- *
* TION--PROPOSED REGULATIONS *
*
*****

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SUBROUTINE TRAFIC
COMMON /TRFFIC/ ELVWI(500), APVWE(500), APVWG(500), SAAPV(500),
1 TAAPV(500), TRAPV(500), STAPV(500), NGVW
COMMON /EXPVT/NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC
COMMON /TRTYP/ TTYP(2,10), PTTYP(10), PERCT(4),
1 NAXLES(10,4), NT(4), NTTY, NATT, NTT, NEWTRK
COMMON /NMBR/ SA(30,11), TA(30,11), TR(50,11), VE(30,11),
1 VG(500,11), NLDI(6), EMPTY(10), ST(30,11)
COMMON /LDS/ PGVWL, PSAL, PTAL, PTRAL, FGVWL, FSAL, FTAL, FTRAL,
1 PSTAW(10), FSTAW(10)
COMMON /CNSTS/ NAPOV, PAPOV, SIZE, AVRG
COMMON /TRINDX/ ITT
COMMON /IO/ LI, LO, LD
COMMON /OUTPTS/ TD4(10,6,2)
COMMON EVWI(500), EVWMP(500), ELVWMP(500), GLVWNI(500), VWE(500),
2 PVWE(500), TWFAV(500), TPFVAV(500), TVWE(500),
3 APPV(500), PPV(500), FACT(500), SAI(500), TAI(500), TRI(500),
4 SAA(500), TAA(500), TRA(500), SLA(500), TLA(500),
5 TRLA(500), APSA(500), APTA(500), APTR(500), APOV(500),
6 GWA(500), GWAF(500), SLAR(500), TLAR(500), TRLAR(500),
7 SANOV(500), TANOV(500), TRNOV(500), PSA(500), PTA(500),
8 PTR(500), SLAT(500), TLAT(500), TRLAT(500), STA(500),

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9   PST(500), STLA(500), STLAR(500), STLAT(500), APST(500),
A   STI(500), STNOV(500), NLDISV(6)
IF (NEWTRK .EQ. 1) GO TO 9999
DO 6 K=1,2
DO 4 J=1,6
DO 2 I=1,10
TD4(I,J,K) = 0.0
2  CONTINUE
4  CONTINUE
6  CONTINUE
DO 7 I=1,6
NLDISV(I) = NLDI(I)
7  CONTINUE
DO 160 IT=1,NTT
PERC =PERCT(IT)
ITT = IT
VTN = 0.
NSA = 0
NTA = 0
NTR = 0
NNA = 0
NNT = 0
NNR = 0
APV = 0.
PAPV = 0.
DO 8 I=1,500
PSA(I) = 0.
PTA(I) = 0.
PTR(I) = 0.
PST(I) = 0.
SAI(I) = 0.
TAI(I) = 0.
TRI(I) = 0.
STI(I) = 0.
SANOV(I) = 0.
TANOV(I) = 0.
TRNOV(I) = 0.
STNOV(I) = 0.
ELVWI(I) = 0.
APVWE(I) = 0.
APVWG(I) = 0.
SAAPV(I) = 0.
TAAPV(I) = 0.
TRAPV(I) = 0.
STAPV(I) = 0.
FACT(I) = 0.
GLVWNI(I) = 0.
APSA(I) = 0.
APTA(I) = 0.
APTR(I) = 0.
APST(I) = 0.
8  CONTINUE
DO 9 I=1,6
NLDI(I) = NLDISV(I)
9  CONTINUE

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```

C
C   *** ADJUSTED AVERAGE EMPTY WEIGHT SECTION ***
C
C   CALL INTVL (VE, EVWI, NLDI(5), NI, 5, 30, VWE, IT)
C
C   CALCULATE THE NUMBER OF EMPTY VEHICLES WEIGHED IN EACH 2-KIP GROSS
C   EMPTY WEIGHT INTERVAL
C
C   CALL PCTAGE (VWE, NI, PVWE)
C   CALL ACMLTE (PVWE, NI, APVWE)
C   CALL MIDPNT (EVWI, NI, EVWMP)
C   CALL MULT (PVWE, EVWMP, NI, TWFAV)
C   CALL AVRGE (TWFAV, NI, AVRG, AEW)
C
C   COMPUTE THE PRACTICAL MAXIMUM GROSS VEHICLE WEIGHT FOR PRESENT AND
C   PROPOSED LIMITS AND MAKE SURE THAT THE VEHICLE GROSS INTERVALS
C   INPUT HAS A MAXIMUM END-OF-INTERVAL VALUE GREATER THAN OR EQUAL TO
C   THE CALCULATED PMGW.
C
C   K = 1
C   TD4(IT,6,K) = AEW
C   TD4(IT,1,K) = PSTAW(IT)
C   TD4(IT,2,K) = PSAL
C   TD4(IT,3,K) = PTAL
C   TD4(IT,4,K) = PTRAL
C   PSTAW(IT)=0.
C   TD4(IT,5,K) = PSTAW(IT) + PSAL*FLOAT(NAXLES(IT,1)) + PTAL *
1      FLOAT(NAXLES(IT,2)) + PTRAL*FLOAT(NAXLES(IT,3))
C   NLD = NLDI(4)
11  IF (TD4(IT,5,1) .LE. VG(NLD,11)) GO TO 15
C   NLD = NLD + 1
C   VG(NLD,11) = VG(NLD-1,11) + SIZE
C   DO 12 ID=1,NTT
C   VG(NLD,ID) = 0.
12  CONTINUE
C   GO TO 11
15  NLDI(4) = NLD
C   K = K+1
C   TD4(IT,6,K) = AEW + (EMPTY(IT) * 0.01 * AEW)
C   TD4(IT,1,K) = FSTAW(IT)
C   TD4(IT,2,K) = FSAL
C   TD4(IT,3,K) = FTAL
C   TD4(IT,4,K) = FTRAL
C
C   *** ADJUSTED GROSS WEIGHT AND TOTAL PAYLOAD CARRIED - PRESENT REGS
C
C   FSTAW(IT)=0.
C   TD4(IT,5,K) = FSTAW(IT) + FSAL*FLOAT(NAXLES(IT,1)) + FTAL *
1      FLOAT(NAXLES(IT,2)) + FTRAL*FLOAT(NAXLES(IT,3))
C   NLDS = NLDI(4)
C   CALL COUNT (VG(1,IT), NLDS)
C   CALL INTVL (VG, ELVWI, NLDS, NJ, 4, 500, TVWE, IT)
C   ELOAD = ELVWI(NJ)
C   CALL PCTAGE (TVWE, NJ, PVWE)
C   CALL ACMLTE (PVWE, NJ, APVWE)

```



```

I = NJ
40 NJ = NJ+1
ELVWI(NJ) = ELVWI(I) + SIZE
I = I+1
IF (ELVWI(I) .LT. ELI) GO TO 40
CALL ITRP (GLVWNI, APVWE, ELVWI, 1, NJ, NK, APVWG, 0)
PVWE(1) = APVWG(1)
CALL DIFF (APVWG, NJ, PVWE)
50 CALL MIDPNT (ELVWI, NJ, ELVWMP)
DO 60 I=1,NJ
PPV(I) = ELVWMP(I) - TD4(IT,6,2)
60 CONTINUE
CALL MULT (PVWE, PPV, NJ, TPFV)
CALL AVRGE (TPFV, NJ, AVRG, PAPV)

```

C
C
C
C

```

*** NUMBER OF VEHICLES REQUIRED TO CARRY TOTAL PAYLOAD (CARGO) -
PROPOSED LIMITS ***

```

```

IF (PAPV.EQ.0.) PAPV=1.
VTN = APV / PAPV * 100.

```

C
C
C

```

*** DISTRIBUTION OF AXLE WEIGHTS - PRESENT LIMITS ***

```

```

IF (NAXLES(IT,1) .EQ. 0) GO TO 64

```

C
C
C

```

SINGLE AXLES

```

```

NLDS = NLDI(1)
CALL COUNT (SA(1,IT), NLDS)
CALL INTVL (SA, SAI, NLDS, NSA, 1, 30, SAA, IT)
CALL PCTAGE (SAA, NSA, PSA)
CALL ACMLTE (PSA, NSA, APSA)
NNA = NSA

```

```

64 IF (NAXLES(IT,2) .EQ. 0) GO TO 66

```

C
C
C

```

TANDEM AXLES

```

```

NLDS = NLDI(2)
CALL COUNT (TA(1,IT), NLDS)
CALL INTVL (TA, TAI, NLDS, NTA, 2, 30, TAA, IT)
CALL PCTAGE (TAA, NTA, PTA)
CALL ACMLTE (PTA, NTA, APTA)
NNT = NTA

```

```

66 IF (NAXLES(IT,3) .EQ. 0) GO TO 68

```

C
C
C

```

TRIPLE AXLES

```

```

NLDS = NLDI(3)
CALL COUNT (TR(1,IT), NLDS)
CALL INTVL (TR, TRI, NLDS, NTR, 3, 50, TRA, IT)
CALL PCTAGE (TRA, NTR, PTR)
CALL ACMLTE (PTR, NTR, APTR)
NNR = NTR

```

```

68 IF ((NAXLES(IT,4) .EQ. 0) .OR. (IP .NE. IF)) GO TO 69

```

C

C STEERING AXLES

C

```

NLDS = NLDI(6)
CALL COUNT (ST(1,IT), NLDS)
CALL INTVL (ST, STI, NLDS, NST, 6, 30, STA, IT)
CALL PCTAGE (STA, NST, PST)
CALL ACMLTE (PST, NST, APST)
NNS = NST
69 IF (IT .GT. NTTY) GO TO 146
   NGVW = NJ

```

C

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*** DISTRIBUTION OF SINGLE/TANDEM/TRIDEM AXLE WEIGHTS - PROPOSED L

SET UP THE TABLE OF SELECTED CUMULATIVE PERCENTAGES DEFINING THE
GROSS WEIGHT AND AXLE WEIGHT CURVES

```

P = 0.0
DO 70 I=1,NAPOV
  APOV(I) = P
  P = P + PAPOV
70 CONTINUE

```

FOR THE GROSS WEIGHT PRESENT AND PROPOSED, AND FOR THE AXLE
WEIGHTS, FIND, BY INTERPOLATION, THE WEIGHTS CORRESPONDING TO THE
PERCENTAGES IN ARRAY *APOV*. COMPUTE THE RATIOS OF THE AXLE
WEIGHTS TO THE GROSS WEIGHTS IN *GWA* AND FINALLY, COMPUTE THE
AXLE WEIGHT DISTRIBUTIONS FOR THE PROPOSED REGS. USING *GWAF*.

```

GWA(1) = ELVWI(1) - SIZE
IF (GWA(1) .LT. 0.0) GWA(1) = 0.0
CALL ITRP (APVWE, ELVWI, APOV, 2, NAPOV, NK, GWA, 0)
GWAF(1) = ELVWI(1) - SIZE
IF (GWAF(1) .LT. 0.0) GWAF(1) = 0.0
CALL ITRP (APVWG, ELVWI, APOV, 2, NAPOV, NJ, GWAF, 0)
IF (NAXLES(IT,1) .EQ. 0) GO TO 72
SLA(1) = SAI(1) - SIZE
IF (SLA(1) .LT. 0.0) SLA(1) = 0.0
CALL ITRP (APSA, SAI, APOV, 2, NAPOV, NSA, SLA, 0)
DO 80 I=1,NAPOV
  IF (GWA(I) .EQ. 0.0) GO TO 79
  SLAR(I) = SLA(I) / GWA(I)
  GO TO 80
79 SLAR(I) = 0.
80 CONTINUE
  CALL MULT (SLAR, GWAF, NAPOV, SLAT)
72 IF (NAXLES(IT,2) .EQ. 0) GO TO 75
  TLA(1) = TAI(1) - SIZE
  IF (TLA(1) .LT. 0.0) TLA(1) = 0.0
  CALL ITRP (APTA, TAI, APOV, 2, NAPOV, NTA, TLA, 0)
  DO 82 I=1,NAPOV
    IF (GWA(I) .EQ. 0.0) GO TO 81
    TLAR(I) = TLA(I) / GWA(I)
    GO TO 82
81 TLAR(I) = 0.
82 CONTINUE

```



```

125 IF (NAXLES(IT,3) .EQ. 0) GO TO 145
C
C TRIPLE AXLES
C
IF (TRLAT(NAPOV) .LE. TRI(NTR)) GO TO 140
ELI = TRLAT(NAPOV)
130 I = NTR + 1
TRI(I) = TRI(NTR) + SIZE
NTR = I
IF (TRI(I) .LT. ELI) GO TO 130
140 CALL ITRP (TRLAT, APOV, TRI, 1, NTR, NAPOV, TRAPV, 0)
CALL DIFF (TRAPV, NTR, TRNOV)
145 IF ((NAXLES(IT,4) .EQ. 0) .OR. (IP .NE. IF)) GO TO 170
C
C STEERING AXLES
C
IF (STLAT(NAPOV) .LE. STI(NST)) GO TO 168
ELI = STLAT(NAPOV)
162 I = NST + 1
STI(I) = STI(NST) + SIZE
NST = I
IF (STI(I) .LT. ELI) GO TO 162
168 CALL ITRP (STLAT, APOV, STI, 1, NST, NAPOV, STAPV, 0)
CALL DIFF (STAPV, NST, STNOV)
170 CONTINUE
GO TO 150
146 DO 147 I=1,NSA
SAAPV(I) = APSA(I)
SANOV(I) = PSA(I)
PSA(I) = 0.
147 CONTINUE
NNA = NSA
DO 148 I=1,NTA
TAAPV(I) = APTA(I)
TANOV(I) = PTA(I)
PTA(I) = 0.
148 CONTINUE
NNT = NTA
DO 149 I=1,NTR
TRAPV(I) = APTR(I)
TRNOV(I) = PTR(I)
PTR(I) = 0.
149 CONTINUE
NNR = NTR
DO 151 I=1,NST
STAPV(I) = APST(I)
STNOV(I) = PST(I)
PST(I) = 0.
151 CONTINUE
NNS = NST
DO 152 I=1,NJ
APVWG(I) = APVWE(I)
152 CONTINUE
NGVW = MAX0(NSA,NTA,NTR,NST,NJ)
C

```



```

C      WRITE TO DISK FOR RECALL IN EQUIVALENT LOAD APPLICATIONS ROUTINE
C
150 WRITE (LD) NSA, NTA, NTR, NST, NNA, NNT, NNR, NNS,
1      (PSA(I), I=1, NNA), (PTA(I), I=1, NNT), (PTR(I), I=1, NNR),
2      (PST(I), I=1, NNS), (SANOV(I), I=1, NSA),
3      (TANOV(I), I=1, NTA), (TRNOV(I), I=1, NTR),
4      (STNOV(I), I=1, NST), (SAI(I), I=1, NSA), (TAI(I), I=1, NTA),
5      (TRI(I), I=1, NTR), (STI(I), I=1, NST), VTN, APV, PAPV
160 CONTINUE
9999 RETURN
      END

```

```

*****
*
*      SUBROUTINE EAL18: CALCULATES THE EQUIVALENT 18 KIP *
*      AXLE LOAD APPLICATIONS FOR EACH VEHICLE USING IN- *
*      FORMATION FROM SUBROUTINE TRAFIC *
*
*****

```

```

      SUBROUTINE EAL18 (STRNUM, SLBTHK, TPSI, IPVTV)
      DIMENSION PSA(500), PTA(500), PTR(500), SANOV(500), TANOV(500),
1      TRNOV(500), EFSA(500), EFTA(500), EFTR(500), SAN18(500),
2      TAN18(500), TRN18(500), SPN18(500), DPN18(500), TPN18(500),
3      SAI(500), TAI(500), TRI(500), SAM(500), TAM(500), TRM(500),
4      PST(500), STNOV(500), EFST(500), STN18(500), STPN18(500),
5      STI(500), STM(500)
      COMMON /EALPAY/ EALPT(10,2), APPT(10,2)
      COMMON /EXPVT/ NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC
      COMMON /CNSTS/ NAPOV, PAPOV, SIZE, AVRG
      COMMON /TRTYP/ TTYP(2,10), PTTYP(10), PERCT(4),
1      NAXLES(10,4), NT(4), NTTY, NATT, NTT, NEWTRK
      COMMON /IO/ LI, LO, LD
      COMMON /PSI/ PF, PICON, PTERM, PIOV, PTOV
      DATA PSI1, PK1, PSI2, PK2 /4.2, 2.7, 4.5, 3.0/
      REWIND 1
      NTT = NTTY + NATT
      DO 1000 IT=1, NTT

```

```

C
C      READ FROM DISK THE INFORMATION STORED BY SUBROUTINE TRAFIC
C
      READ (LD) NSA, NTA, NTR, NST, NNA, NNT, NNR, NNS,
1      (PSA(I), I=1, NNA), (PTA(I), I=1, NNT), (PTR(I), I=1, NNR),
2      (PST(I), I=1, NNS), (SANOV(I), I=1, NSA),
3      (TANOV(I), I=1, NTA), (TRNOV(I), I=1, NTR),
4      (STNOV(I), I=1, NST), (SAI(I), I=1, NSA), (TAI(I), I=1, NTA),
5      (TRI(I), I=1, NTR), (STI(I), I=1, NST), VTN, APV, PAPV
      APPT(IT,1) = APV
      APPT(IT,2) = PAPV
C
C      COMPUTE THE 18-KIP EAL FOR EACH AXLE TYPE
C
      TSN18 = 0.
      TXN18 = 0.
      IF (NAXLES(IT,1) .EQ. 0) GO TO 50

```

C
C
C

SINGLE AXLES

```
CALL MIDPNT (SAI, NSA, SAM)
GT = ALOG10((PSI1 - TPSI) / PK1)
CALL FLEXEQ (SAM, NSA, 1.0, STRNUM, GT, EFSA)
CALL MULT (EFSA, PSA, NNA, SAN18)
CALL MULT (EFSA, SANOV, NSA, SPN18)
CALL SUM (SAN18, NNA, TSN18)
CALL SUM (SPN18, NSA, TXN18)
50 CONTINUE
TDN18 = 0.
TYN18 = 0.
IF (NAXLES(IT,2) .EQ. 0) GO TO 100
```

C
C
C

TANDEM AXLES

```
CALL MIDPNT (TAI, NTA, TAM)
GT = ALOG10((PSI1 - TPSI) / PK1)
CALL FLEXEQ (TAM, NTA, 2.0, STRNUM, GT, EFTA)
CALL MULT (EFTA, PTA, NNT, TAN18)
CALL MULT (EFTA, TANOV, NTA, DPN18)
CALL SUM (TAN18, NNT, TDN18)
CALL SUM (DPN18, NTA, TYN18)
100 CONTINUE
TTN18 = 0.
TZN18 = 0.
IF (NAXLES(IT,3) .EQ. 0) GO TO 150
```

C
C
C

TRIPLE AXLES

```
CALL MIDPNT (TRI, NTR, TRM)
GT = ALOG10((PSI1 - TPSI) / PK1)
CALL FLEXEQ (TRM, NTR, 3.0, STRNUM, GT, EFTR)
CALL MULT (EFTR, PTR, NNR, TRN18)
CALL MULT (EFTR, TRNOV, NTR, TPN18)
CALL SUM (TRN18, NNR, TTN18)
CALL SUM (TPN18, NTR, TZN18)
150 CONTINUE
TSTN18 = 0.
TWN18 = 0.
IF ((NAXLES(IT,4) .EQ. 0) .OR. (IP .NE. IF)) GO TO 200
```

C
C
C

STEERING AXLES

```
CALL MIDPNT (STI, NST, STM)
IA = -1.5 + 2. * TPSI
IF(IP. EQ. IF) IA = -1*PF + 2* TPSI
IA = MAX0(1, MIN0(4, IA))
CALL STEREQ (IA, EFST, NST, STM)
CALL MULT (EFST, PST, NNS, STN18)
CALL MULT (EFST, STNOV, NST, STPN18)
CALL SUM (STN18, NNS, TSTN18)
CALL SUM (STPN18, NST, TWN18)
200 EALPT(IT,1) = (TSN18*FLOAT(NAXLES(IT,1)) + TDN18 *
```

```

1          FLOAT(NAXLES(IT,2)) + TTN18*FLOAT(NAXLES(IT,3)) +
2          TSTN18*FLOAT(NAXLES(IT,4)) * 0.01
EALPT(IT,2) = (TXN18*FLOAT(NAXLES(IT,1)) + TYN18 *
1          FLOAT(NAXLES(IT,2)) + TZN18*FLOAT(NAXLES(IT,3)) +
2          TWN18*FLOAT(NAXLES(IT,4)) * 0.01
1000 CONTINUE
      REWIND 1
      RETURN
      END

```

```

*****
*
*   SUBROUTINE FLEXEQ: CALCULATES EQUIVALENCY FACTORS   *
*   FOR FLEXIBLE PAVEMENTS                             *
*
*****

```

```

      SUBROUTINE FLEXEQ (XL, NL, ST, SN, GT, EQ)
      DIMENSION XL(1), EQ(1)
      SNP = (SN + 1.0) ** 5.19
      GTB18 = GT / (0.40 + 1094.0 / SNP)
      B1 = SNP * ST ** 3.23
      CON = 6.125 + 4.33 * ALOG10(ST) - GTB18
      DO 20 L=1,NL
      B2 = 4.79 * ALOG10(XL(L) + ST)
      BX = 0.40 + 0.081 * (XL(L) + ST) ** 3.23 / B1
      E = CON - B2 + GT / BX
20 EQ(L) = 10.0 ** (-E)
      RETURN
      END

```

```

*****
*
*   SUBROUTINE STEREQ: COMPUTES STEERING AXLE EQUIVA-   *
*   LENCY FACTORS                                       *
*
*****

```

```

      SUBROUTINE STEREQ (IEQ, SEQ, NEQ, EQM)
      DIMENSION SEQ(1), EQM(1)
      COMMON /STEER/ EQFACT(15,5), PTST(4)
C   EQFACT(J,1) CONTAINS THE LOAD VALUES (J).
C   EQFACT(J,K) CONTAINS THE EQUIVALENCY FOR LOAD J, TERM PSI PTST(K-
C
      DO 30 I=1,NEQ
      IF (EQM(I) .LT. EQFACT(1,1)) GO TO 25
      DO 10 J=2,15
      IF (EQFACT(J,1) .GE. EQM(I)) GO TO 20
10 CONTINUE
      SEQ(I) = EQFACT(15,IEQ)
20 K = J-1
      SEQ(I) = EQFACT(K,IEQ) + (EQM(I) - EQFACT(K,1)) *
1          ((EQFACT(J,IEQ)-EQFACT(K,IEQ)) / (EQFACT(J,1)-EQFACT(K,1)
2          ))
      GO TO 30

```

```

25 SEQ(I) = EQFACT(1,IEQ) * EQM(I) / EQFACT(1,1)
30 CONTINUE
RETURN
END

```

```

*****
*
*   SUBROUTINE INTVL: CONVERTS THE END-OF-INTERVAL KIP *
*   TABLES TO EVENLY DISTRIBUTED INTERVALS           *
*
*****

```

```

SUBROUTINE INTVL (A1, A2, N, N1, IS, NN, A3, NM)
COMMON /INTVLS/ STARTS(6)
COMMON /CNSTS/ NAPOV, PAPOV, SIZE, AVRG
DIMENSION A1(NN,11), A2(500), A3(500), ACC(500)
XMLOAD = A1(N,11)
A2(1) = SIZE

```

```

C
C   SET *S* TO THE LARGEST EVEN NUMBER GREATER THAN OR EQUAL TO THE
C   FIRST END-OF-INTERVAL KIP VALUE
C

```

```

S = 0.
K = 0
5 IF (S .GE. STARTS(IS)) GO TO 7
S = S + SIZE
K = K+1
GO TO 5

```

```

C
C   SET UP THE EVENLY DISTRIBUTED END-OF-INTERVAL KIP TABLE AND ZERO
C   ALL INTERVALS AT BEGINNING OF TABLE IN WHICH NO TRUCKS/AXLES WERE
C   WEIGHED
C

```

```

7 I = 1
J = 1
10 IF (A2(I) .GE. XMLOAD) GO TO 20
I = I+1
A2(I) = A2(J) + SIZE
J = J+1
GO TO 10
20 N1 = I
DO 30 I=1,K
A3(I) = 0.
30 CONTINUE
I = K+1
CALL ACMLTE (A1(1,NM), N, ACC)
CALL ITRP (A1(1,11), ACC, A2, I, N1, N, A3, 1)
RETURN
END

```

```

*****
*
*   SUBROUTINE ITRP: PERFORMS LINEAR INTERPOLATION *
*
*****

```

```

SUBROUTINE ITRP (V1, V2, V3, LIS, NV, NL, V4, IV)
DIMENSION V1(500), V2(500), V3(500), V4(500)
IF (LIS .EQ. 1) V4(1) = 0.0
J = 1
DO 50 I=LIS,NV
DO 10 K=J,NL
C
C FIND THE SMALLEST X1 GREATER THAN OR EQUAL TO X
C
IF (V1(K) .GE. V3(I)) GO TO 20
10 CONTINUE
K = NL+1
V2SV = V2(K)
V1SV = V1(K)
V2(K) = V2(NL)
V1(K) = V3(I)
L = NL
GO TO 25
C
C SET X1 AND F1 VALUES APPROPRIATELY, THEN INTERPOLATE
C
20 J = K
L = K-1
IF (L .EQ. 0) GO TO 30
25 F1 = V2(L)
X1 = V1(L)
GO TO 40
30 X1 = 0.0
F1 = V4(1)
40 V4(I) = F1 + (V3(I)-X1) * ((V2(K)-F1) / (V1(K)-X1))
IF (K .LE. NL) GO TO 50
V2(K) = V2SV
V1(K) = V1SV
50 CONTINUE
C
C IF VALUES ARE CUMULATIVE, SUBTRACT TO GET CORRECT VALUES PER
C INTERVAL
C
IF (IV .EQ. 0) GO TO 999
J = NV
DO 60 I=2,NV
V4(J) = V4(J) - V4(J-1)
C WRITE(6,*) 'J=',J,' V4(J)=' ,V4(J)
J = J-1
60 CONTINUE
999 RETURN
END

```

```

*****
*
* SUBROUTINE PCTAGE: CONVERTS A SET OF NUMBERS TO *
* CORRESPONDING PERCENTAGES OF THEIR SUM *
*
*****

```

```

SUBROUTINE PCTAGE (P1, NP, P2)
DIMENSION P1(500), P2(500)
TOT = 0.0
DO 10 I=1, NP
TOT = TOT + P1(I)
10 CONTINUE
IF (TOT.EQ.0) TOT=1
DO 20 I=1, NP
P2(I) = P1(I) / TOT * 100.0
20 CONTINUE
RETURN
END

```

```

*****
*
*   SUBROUTINE COUNT: DETERMINES WHICH OF THE "ICA"
*   VALUES IN ARRAY CA IS THE LAST NON-ZERO VALUE
*
*****

```

```

SUBROUTINE COUNT (CA, ICA)
DIMENSION CA(500)
DO 10 I=1, ICA
IF (CA(I) .GT. 0.0) J = I
10 CONTINUE
ICA = J
RETURN
END

```

```

*****
*
*   SUBROUTINE ACMLTE: CONVERTS A LIST OF NUMBERS TO A
*   CUMULATIVE FUNCTION
*
*****

```

```

SUBROUTINE ACMLTE (AIN, NA, AOUT)
DIMENSION AIN(500), AOUT(500)
AOUT(1) = AIN(1)
NB = NA-1
DO 10 I=1, NB
J = I+1
AOUT(J) = AOUT(I) + AIN(J)
10 CONTINUE
RETURN
END

```

```

*****
*
*   SUBROUTINE MIDPNT: DETERMINES THE MIDPOINT OF EACH
*   INTERVAL BETWEEN MEMBERS OF A LIST OF NUMBERS
*
*****

```

```

SUBROUTINE MIDPNT (X1, NM, X2)
COMMON /CNSTS/ NAPOV, PAPOV, SIZE, AVRG
DIMENSION X1(500), X2(500)
I = 0
J = 1
ELI = X1(NM)
X2(1) = X1(1) - (SIZE/2.)
10 I = I+1
J = J+1
X2(J) = X2(I) + SIZE
IF (X1(J) .LT. ELI) GO TO 10
RETURN
END

```

```

*****
*
*   SUBROUTINE MULT: MULTIPLIES TWO VECTORS SUCH THAT *
*   YC(I) = YA(I)*YB(I) *
*
*****

```

```

SUBROUTINE MULT (YA, YB, NU, YC)
DIMENSION YA(500), YB(500), YC(500)
DO 10 I=1,NU
YC(I) = YA(I) * YB(I)
10 CONTINUE
RETURN
END

```

```

*****
*
*   SUBROUTINE AVRGE: COMPUTES THE AVERAGE OF THE VAL- *
*   UES IN ARRAY AV OVER AN *
*
*****

```

```

SUBROUTINE AVRGE (AV, NV, AN, AVG)
DIMENSION AV(500)
AVG = 0.0
DO 10 I=1,NV
AVG = AV(I) + AVG
10 CONTINUE
AVG = AVG / AN
RETURN
END

```

```

*****
*
*   SUBROUTINE DIFF: TAKES SUCCESSIVE DIFFERENCES OF *
*   THE VALUES IN ARRAY D1 *
*
*****

```

```

SUBROUTINE DIFF (D1, ND, D2)
DIMENSION D1(1), D2(1)

```

```

D2(1) = D1(1)
DO 10 I=2,ND
J = I-1
D2(I) = D1(I) - D1(J)
10 CONTINUE
RETURN
END

```

```

*****
*
* SUBROUTINE SUM: COMPUTES THE SUM OF VALUES IN ARRAY *
* S1 *
*
*****

```

```

SUBROUTINE SUM (S1, NS, S2)
DIMENSION S1(500)
S2 = 0.0
DO 10 I=1,NS
S2 = S2 + S1(I)
10 CONTINUE
RETURN
END

```

```

*****
*
* SUBROUTINE SURVIV: SETS SURVIVAL CURVE PARAMETERS, *
* XLAMB AND GAMM, FOR FLEXIBLE PAVEMENTS *
*
*****

```

```

SUBROUTINE SURVIV
COMMON /EXPVT/ NPT, THICK (4), MTYPE(4), NLAY, IP, IF, IR, IC
COMMON /MECH/XKT, NRU, NLH, ND, NDEL, IACR, NREG, IYR, JYR, CONSTR(50)
COMMON /FMTYPE/ KSUBG, IFAIL
COMMON /BURKE/ XLAMB, GAMMA, TFBAP, TLAMB
COMMON /PSI/ PF, PICON, PTERM, PIOV, PTOV
COMMON /SURVP/ FPLAM(2,3,5), FPGAM(2,3,5), FDGAM(4,3,5),
-FDLAM(4,3,5), FOPLAM(4,3,1), FOPGAM(4,3,1), FODLAM(5,3,1),
-FODGAM(5,3,1)
IF(NPT.EQ.2) GO TO 700
IF(PF.GE.PTERM) GO TO 200
IF (KSUBG.EQ.1) KS=2
IF (KSUBG.EQ.2) KS=1
XLAMB=FPLAM(KS, IACR, NREG)
GAMMA=FPGAM(KS, IACR, NREG)
RETURN
200 CONTINUE
IF(KSUBG.EQ.1) GO TO 300
XLAMB=FDLAM(IFAIL, IACR, NREG)
GAMMA=FDGAM(IFAIL, IACR, NREG)
RETURN
300 CONTINUE
IFAIL=IFAIL+3
XLAMB=FDLAM(IFAIL, IACR, NREG)

```



```

      GAMMA=FDGAM(IFAIL,IACR,NREG)
      RETURN
700  IF(IFAIL.NE.4) GO TO 900
      XLAMB=FOPLAM(IFAIL,IACR,1)
      GAMMA=FOPGAM(IFAIL,IACR,1)
      RETURN
900  XLAMB=FODLAM(IFAIL,IACR,1)
      GAMMA=FODGAM(IFAIL,IACR,1)
      RETURN
      END

```

```

*****
*
*   SUBROUTINE COSCAL: CALCULATES REHABILITATION AND
*   MAINTENANCE COSTS FOR EACH PERIOD OF THE PLANNING
*   HORIZON USING COST DATA AND FAILURE PROBABILITIES
*
*****

```

```

SUBROUTINE COSCAL (ADT)
LOGICAL ADJUST
COMMON /BURKE/ XLAMB, GAMMA, TFBAP, TLAMB
COMMON /FMTYPE/ KSUBG,IFAIL
COMMON /TEMPC/ CONTP(25),DISTCT
COMMON /PSI/ PF, PICON, PTERM, PIOV, PTOV
COMMON /TITLE/ TITLE(20,3), SECTTL(20)
COMMON /MECH/XKT,NRU,NLH,ND,NDEL,IACR,NREG,IYR,JYR,CONSTR(50)
COMMON /LMP/ XLM(50),YLM(50),POTLM(50,2),OUTP(50,2),
1  TOTALM, PPF, TPF, PFNO, NASL, NSLR,TOVLM(50,2),XLM2(50)
COMMON /OVLAY/XHCIO,XHCIM,WLANE,WPSH,WGSH,PPVDSH,NRHC,CAC,CGR
1  , CSCOAT,NPMC,AGF
COMMON /FUNDS/ APOF(50,2), RTINT, RTINF
COMMON /CMAT/ UNTCST(5,4),BZ(5,3),BB(5,2),RBZ(2,2)
COMMON /TIME/ OVLIF, NYAP,NYR,YR(100)
COMMON /MNTPAR/ S,DISS,DCON,DIN
COMMON /EXPVT/ NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC
COMMON /COST/ COSTRH(50), COSTRM(50), COSTPM(50),FMILES(50)
-,FMILEP(50)
COMMON /EXTRA/ PTOVTK,TPE,PFO,XMNOTK,XXOTK,NIS
COMMON /IO/ LI, LO, LD
COMMON /SHIFT/ ISHIFT
COMMON /JUNK/ACU(60)
REAL MAINTC(50)
DIMENSION PFAIL(70),ZMILES(70),REHPLM(50),PEHPLM(50),
*  RIGCPY(50),ZMILE1(70),PFAIL1(70)

```

```

C
C----> WRITE HEADER
C

```

```

      DATA ZMILES /70*0./
      DATA ZMILE1 /70*0./
      WRITE (LO,1234)
      WRITE(LO,610) DISTCT
610  FORMAT (1H1,////,40X,'DISTRICT:',2X,F5.0)
      IF (ISHIFT.EQ.1) WRITE (LO,611)
      IF (ISHIFT.EQ.0) WRITE (LO,612)

```

```

611 FORMAT (41X,'FUTURE LIMITS')
612 FORMAT (40X,'PRESENT LIMITS')
CALL SURVIV
C----> SET MAINTENANCE COST FUNCTION FOR FLEXIBLE
      SEALC=0.0
      IF (IFAIL.EQ.2) SEALC=2640.00
      IF (IFAIL.EQ.3) SEALC=1320.00
      SCOAT=4783.00
      DO 8 I=1,50
      MAINTC(I)=SCOAT+SEALC
      8 CONTINUE
C
C----> DEFINE "WORKING" AGE DISTRIBUTION ZMILES (=YLM AT YEAR ZERO)
C      YLM IS ORIGINAL, READ-IN AGE DISTRIBUTION
C
      CALL POTSET(POTMIL)
      DO 6 I=1,70
      ZMILES(I)=0.
      ZMILE1(I)=0.
      6 CONTINUE
      DO 7 IAGE=1,NASL
      ZMILES(IAGE)=YLM(IAGE)
      7 CONTINUE
C
C----> PERFORM PAVEMENT BEHAVIOR "SIMULATION" THROUGHOUT A.P.
C
      DO 199 IYEAR=1,NYAP
C
C-----> ESTIMATE FAILING MILES, SURVIVING MILES,
C      AND ROUTINE MAINTENANCE COSTS FOR CURRENT YEAR IYEAR
C      FAILML AND CMAIN ARE ACCUMULATORS. PFAILC IS
C      THE CUMMULATIVE PROBABILITY OF FAILURE AFTER
C      IAGE-1 YEARS.
C
      FAILML=0
      CMAIN=0
      PFAILC=0
      ADJUST=.FALSE.
C
      LIM10=IYEAR+NASL-1
      DO 10 IAGE=1,LIM10
C
C-----> IF PAVEMENT FAILS BY DISTRESS, IT IS REHABILITATED
C      EVERY NDEL YEARS; OTHERWISE, WHEN IT FAILS,
C      ACCORDING TO FAILURE PROBABILITY PFAIL
C
      IF (PF.GE.PTERM.AND.IAGE.GE.10 ) ADJUST=.TRUE.
      IF (ADJUST) GO TO 12
      ELSE
      CALL DISTR (PFAIL,IAGE,IAGE,0 )
      IF (PFAILC+PFAIL(IAGE).LT.1.) GO TO 14
      ELSE
      ADJUST=.TRUE.
      ENDIF
      THEN

```

```

12          IF (PFAILC.EQ. 1) PFAILC=0.
C
C          (THIS TRICK IS NECESSARY TO AVOID DIVISION BY ZERO)
C
          PFAIL(IAGE)=1.-PFAILC
          IF (IYEAR.NE.1) GO TO 14
C          ELSE
          FAILML=FAILML+ZMILES (IAGE)
          ZMILES (IAGE)=0
C          ENDIF
C          ENDIF
C          14  ORIGML=ZMILES (IAGE) / (1-PFAILC)
          FAILYR=ORIGML*PFAIL (IAGE)
          FAILML=FAILML+FAILYR
          ZMILES (IAGE)=ZMILES (IAGE) -FAILYR
          CMAIN=CMAIN+MAINTC (IAGE) *ZMILES (IAGE)
          PFAILC=PFAILC+PFAIL (IAGE)
C          10  CONTINUE
C
C-----> CALCULATE ADJUSTED COSTS FOR CURRENT YEAR IYEAR INCLUDING
C          COSTS FOR REHABILITATING PAVEMENTS IN POTTS
C
          IF (IYEAR.GT.IYR) POTMIL=0.
          POTRHC=POTMIL*85000.
          COSTRH (IYEAR)=(FAILML*85000.+POTRHC) *(1+XHCIO) **IYEAR
          COSTRM (IYEAR)=CMAIN*(1+XHCIM) **IYEAR
          FMILES (IYEAR)=FAILML
          FMILEP (IYEAR)=POTMIL
C
C-----> UPDATE AGE DISTRIBUTION FOR NEXT YEAR IYEAR+1
C
          LIM20=IYEAR+NASL
          DO 20 I=2, LIM20
          IAGE=LIM20+2-I
          ZMILES (IAGE)=ZMILES (IAGE-1)
C          20  CONTINUE
          ZMILES (1)=0.
C
          PFALC1=0.
          FAILML=0.
          ADJUST=.FALSE.
          DO 15 IAGE=1, LIM10
          IF (PF.GE.PTERM.AND.IAGE.GE.NDEL) ADJUST=.TRUE.
          IF (ADJUST) GO TO 13
          CALL DISTR (PFAIL1, IAGE, IAGE, 1)
          IF (PFALC1+PFAIL1 (IAGE) .LT.1) GO TO 18
          ADJUST=.TRUE.
C          13  IF (PFALC1.EQ.1) PFALC1=0.
          PFAIL1 (IAGE)=1.-PFALC1
          IF (IYEAR.NE.1) GO TO 18
          FAILML=FAILML+ZMILE1 (IAGE)
          ZMILE1 (IAGE)=0.
C          18  ORIGML=ZMILE1 (IAGE) / (1-PFALC1)
          FAILYR=ORIGML*PFAIL1 (IAGE)
          FAILML=FAILML+ORIGML*PFAIL1 (IAGE)

```

```

      ZMILE1(IAGE)=ZMILE1(IAGE)-ORIGML*PFAIL1(IAGE)
      PFALC1=PFALC1+PFAIL1(IAGE)
15  CONTINUE
      COSTRH(IYEAR)=COSTRH(IYEAR)+(FAILML*85000.)*(1+XHCIO)**IYEAR
      FMILES(IYEAR)=FMILES(IYEAR)+FAILML
      DO 25 I=2,LIM20
          IAGE=LIM20+2-I
          ZMILE1(IAGE)=ZMILE1(IAGE-1)
25  CONTINUE

      ZMILE1(1)=FMILES(IYEAR)+POTMIL
199 CONTINUE
      DO 100 I=1,50
          COSTPM(I)=0.
100 CONTINUE
      TINTML=0.
      DO 110 K=1,NASL
          TINTML=TINTML+YLM(K)
110 CONTINUE
      IF (IP.NE.IF.OR.JYR.EQ.0) GO TO 132
      TCNSTR=0.
      DO 120 I=1,NYAP
          TCNSTR=TCNSTR+CONSTR(I)
120 CONTINUE
C
C   PREVENTIVE MAINTENANCE COST
C
      CSCOAT=4783.00
      DO 130 I=1,NYAP
          COSTPM(I)=CSCOAT*TINTML/FLOAT(JYR)
          COSTPM(I)=COSTPM(I)*(1.+XHCIM)**I
130 CONTINUE
132 WRITE (LO,613) (SECTTL(J),J=1,20),TOTALM
613 FORMAT (/ ,20X,20A4,/,20X,'TOTAL MILES: ',F11.2,///)
      IF (TINTML.NE.0) GO TO 665
      DO 664 I=1,NYAP
          COSTRM(I)=0.
664 CONTINUE
665 WRITE (LO,600)
600 FORMAT (12X,'YEAR ',12X,'ROUT MAINT',13X,'REHAB MILES',
1      14X,' REHAB ',13X,
1      'PREV MAINT',/,29X,' COST ($) ',13X,'NPOT POT',13X,
2      ' COST ($) ',14X,' COST ($) ',/)
      DO 666 I=1,NYAP
          IF (NIS.EQ.2) COSTRM(I)=COSTRM(I)*0.382
          IF (NIS.EQ.3) COSTRM(I)=COSTRM(I)*0.316
          COSTRM(I)=ANINT(COSTRM(I))
          COSTRH(I)=ANINT(COSTRH(I))
          COSTPM(I)=ANINT(COSTPM(I))
666 CONTINUE
      WRITE(LO,601) (I,COSTRM(I),FMILES(I),FMILEP(I),COSTRH(I),
-COSTPM(I),I=1,NYAP)
601 FORMAT ((10X,I5,10X,F14.2,09X,F7.2,2X,F7.2,2(09X,F14.2)))
      PRMS=0.
      PRHS=0.

```

```

PPMS=0.
TFMS=0.
TPMS=0.
FCTR=1/(1+RTINT)
DO 150 J=1,NYAP
    PRMS=PRMS+COSTRM(J)*FCTR**J
    PRHS=PRHS+COSTRH(J)*FCTR**J
    PPMS=PPMS+COSTPM(J)*FCTR**J
    TFMS=TFMS+FMILES(J)
    TPMS=TPMS+FMILEP(J)
150 CONTINUE
    PRMS=ANINT(PRMS)
    PRHS=ANINT(PRHS)
    PPMS=ANINT(PPMS)
    WRITE (LO,603) TFMS,TPMS,PRMS,PRHS,PPMS,TFMS+TPMS
603 FORMAT(//,2X,'TOTAL',18X,23X,F7.2,2X,F7.2,
-         /,2X,'PRESENT COSTS',10X,F14.2,9X,16('-'),
-         2(9X,F14.2),/,2X,'TOTAL LANE MILES',34X,F9.2,///)
    WRITE (LO,1234)
1234 FORMAT (1X,'-----',
1         '-----',
2         '-----')
99 RETURN
END

```

```

*****
*
*   SUBROUTINE POTSET: INITIALIZE TOTALM AND POTTS,
*   TOTAL MILEAGE AND POTTS MILEAGE COUNTERS,RESPEC-
*   TIVELY
*
*****

```

```

SUBROUTINE POTSET(POTMIL)
COMMON /PSI/ PF,PICON,PTERM,PIOV,PTOV
COMMON /MECH/XKT,NRU,NLH,ND,NDEL,IACR,NREG,IYR,JYR,CONSTR(50)
COMMON /LMP/ XLM(50),YLM(50),POTLM(50,2),OUTP(50,2),
1 TOTALM,PPF,TPF,PFNO,NASL,NSLR,TOVLM(50,2),XLM2(50)
TOTALM=0
POTTS=0
C
C----> SELECT POTTS CUTOFF AGE, DEPENDING ON WHETHER THE PAVEMENT
C FAILS BY PSI (25 YEARS) OR DISTRESS (NDEL YEARS)
C
AGEPOT=25
IF (PF.GE.PTERM) AGEPOT=25
C
C   ENDIF
C
C----> COUNT INITIAL TOTAL MILEAGE AND MILEAGE IN POTTS
C
DO 10 IAGE=1,NASL
TOTALM=TOTALM+YLM(IAGE)
IF (IAGE.GE.AGEPOT) POTTS=POTTS+YLM(IAGE)
IF(IAGE.GE.AGEPOT) YLM(IAGE)=0.
C
C   ENDIF

```

10 CONTINUE

C

C---> COMPUTE PERCENTAGE OF PAVEMENTS IN POTTS, PPF
C AND POTTS MILEAGE TO FIX IN CURRENT YEAR, POTMIL

C

PPF=POTTS/TOTALM
POTMIL=POTTS/FLOAT(IYR)

C

RETURN
END

*
* SUBROUTINE ACOST: CALCULATES THE TOTAL COST OF ROU-*
* TIME AND PREVENTIVE MAINTENANCE, AND REHABILITATION *
* COST FOR THE PLANNING HORIZON *
*

SUBROUTINE ACOST
COMMON /TIME/ OVLIF, NYAP, NYR, YR(100)
COMMON /COST/ COSTRH(50), COSTRM(50), COSTPM(50), FMILES(50)
-, FMILEP(50)
COMMON /ACCOST/ ACCRM(50), ACCRH(50), ACCPM(50), ACCFM(50)
-, ACCFP(50)
DO 100 I=1, NYAP
ACCRM(I)=ACCRM(I)+COSTRM(I)
ACCRH(I)=ACCRH(I)+COSTRH(I)
ACCPM(I)=ACCPM(I)+COSTPM(I)
ACCFM(I)=ACCFM(I)+FMILES(I)
ACCFP(I)=ACCFP(I)+FMILEP(I)

100 CONTINUE
RETURN
END

*
* SUBROUTINE PCOST: CALCULATES PRESENT VALUE OF COST *
* STREAM OVER PLANNING HORIZON FOR SPECIFIED INTEREST *
* RATE *
*

SUBROUTINE PCOST
COMMON /TIME/ OVLIF, NYAP, NYR, YR(100)
COMMON /ACCOST/ ACCRM(50), ACCRH(50), ACCPM(50), ACCFM(50)
-, ACCFP(50)
COMMON /SHIFT/ ISHIFT
COMMON /FUNDS/ APOF(50,2), RTINT, RTINF
COMMON /IO/ LI, LO, LD
COMMON /EXPVT/ NPT, THICK(4), MTYPE(4), NLAY, IP, IF, IR, IC
COMMON /MECH/XKT, NRU, NLH, ND, NDEL, IACR, NREG, IYR, JYR, CONSTR(50)
COMMON /TEMPC/ CONTP(25), DISTCT
DIMENSION INCOV(6)
PRM=0.

```

PRH=0.
PPM=0.
TFM=0.
TPM=0.
FCTR=1/(1+RTINT)
DO 100 J=1,NYAP
    PRM=PRM+ACCRM(J)*FCTR**J
    PRH=PRH+ACCRH(J)*FCTR**J
    PPM=PPM+ACCPM(J)*FCTR**J
    TFM=TFM+ACCFM(J)
    TPM=TPM+ACCFP(J)
100 CONTINUE
    WRITE (LO,600)
600 FORMAT (1X,'-----',
1      '-----',
2      '-----',,,,,,42X,'COST SUMMARY')
    IF (ISHIFT.EQ.0) WRITE(LO,615)
    IF (ISHIFT.EQ.1) WRITE(LO,616)
615 FORMAT(40X,'PRESENT LIMITS')
616 FORMAT(40X,'PROPOSED LIMITS')
    IF (IP.EQ.IF) WRITE(LO,610) NREG
610 FORMAT (40X,'REGION :',2X,I5,/)
    WRITE (LO,601)
601 FORMAT (12X,'YEAR ',12X,'ROUT MAINT',13X,'REHAB MILES',
1      14X,' REHAB ',13X,
1      'PREV MAINT',/,29X,' COST ($) ',13X,'NPOT POT',13X,
2      ' COST ($) ',14X,' COST ($) ',/)
    DO 666 I=1,NYAP
        ACCRM(I)=ANINT(ACCRM(I))
        ACCRH(I)=ANINT(ACCRH(I))
        ACCPM(I)=ANINT(ACCPM(I))
666 CONTINUE
    WRITE(LO,602) (I,ACCRM(I),ACCFM(I),ACCFP(I),ACCRH(I),
-ACCPM(I),I=1,NYAP)
602 FORMAT ((10X,I5,10X,F14.2,09X,F13.2,2X,F7.2,2(09X,F14.2))
    PRM=ANINT(PRM)
    PRH=ANINT(PRH)
    PPM=ANINT(PPM)
    WRITE (LO,603) TFM,TPM,PRM,PRH,PPM,TFM+TPM
603 FORMAT(//,2X,'TOTAL',18X,23X,F7.2,1X,F8.2,
-      /,2X,'PRESENT COSTS',10X,F14.2,9X,16('-'),
-      2(9X,F14.2),/,2X,'TOTAL LANE MILES',34X,F9.2,///)
    WRITE(LO,619)
619 FORMAT (1X,'-----',
1      '-----',
2      '-----')
    RETURN
    END

```



APPENDIX C
VEHICLE WEIGHT DISTRIBUTIONS



Table 15. WIM Stations Selected for Calculation of Axle Load
and Gross Vehicle Weight Distributions

Site	Road	County	District	Region	Date	No. Records
967	FM 967	Hays	14	5	7/06/87	63
339	FM 339	Limestone	9	5	7/15/87	98
811	FM 811	Leon	17	5	7/21/87	50
711	FM 811	Leon	17	5	7/22/87	28
611	FM 811	Leon	17	5	7/23/87	42
P13	FM 624	Jim Wells	16	4	4/07/87	6
560	FM 1560	Bexar	15	4	7/07/87	52
022	FM 1022	Uvalde	15	4	7/08/87	115
P8	FM 1267	Ochiltree	4	3	4/09/87	25
W42	FM 1731	Bailey	5	3	3/19/87	90
W42	FM 1731	Bailey	5	3	3/20/87	8
620	FM 293	Carson	4	3	6/23/87	50
P4	FM 1776	Ward	6	2	4/07/87	45
P12	FM 1459	Brazoria	12	1	4/09/87	29
85	FM 2793	Walker	17	1	7/29/87	138
P9	FM 1499	Lamar	1	1	4/09/87	23

Table 16. Axle Load and Gross Vehicle Weight Distributions for Region 5.

Load Type	Intervals [kips]	2D	3A	2-S2	3-S2
SINGLE AXLES	0 - 3	0	1	6	1
	3 - 7	23	1	30	10
	7 - 8	4	6	4	21
	8 - 12	13	17	13	111
	12 - 16	5	9	4	12
	16 - 18	2	0	0	3
	18 - 19	2	0	0	0
	19 - 22	1	0	1	0
	22 - 24	0	0	2	0
	24 -	0	0	4	0
TANDEM AXLES	0 - 6	0	1	7	8
	6 - 12	0	4	8	39
	12 - 18	0	7	5	75
	18 - 24	0	4	4	20
	24 - 30	0	8	2	20
	30 - 32	0	0	3	7
	32 - 34	0	1	1	8
	34 - 36	0	2	0	11
	36 - 38	0	1	0	11
	38 - 42	0	2	2	28
	42 - 44	0	11	0	22
	44 - 46	0	1	1	21
46 -	0	2	1	3	
GROSS VEHICLE WEIGHT	0 - 10	3	0	1	0
	10 - 14	5	0	5	0
	14 - 20	8	4	7	3
	20 - 24	5	6	1	4
	24 - 28	3	3	1	1
	28 - 32	1	2	2	6
	32 - 36	0	1	4	13
	36 - 40	0	6	0	22
	40 - 45	0	2	2	14

Table 16. Axle Load and Gross Weight
Distribution for Region 5. (Continued)

Load Type	Intervals [kips]	2D	3A	2-S2	3-S2
GROSS VEHICLE WEIGHT (Continued)	45 - 50	0	3	1	7
	50 - 55	0	2	0	6
	55 - 60	0	3	0	1
	60 - 65	0	0	3	3
	65 - 70	0	1	2	4
	70 - 75	0	1	1	3
	75 - 80	0	0	0	9
	80 - 85	0	0	1	3
	85 - 90	0	0	2	7
	90 - 95	0	0	0	14
	95 - 100	0	0	0	15
	100 - 105	0	0	0	10
	105 -	0	0	0	10