DEVELOPMENT AND IMPLEMENTATION OF AN ENHANCED

PROCEDURE FOR ESTIMATING PAVEMENT REHABILITATION

AND MAINTENANCE EXPENDITURES

A Thesis

by

JUAN CARLOS GARCIA-DIAZ

Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

August 1987

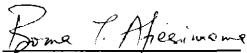Major Subject: Industrial Engineering

DEVELOPMENT AND IMPLEMENTATION OF AN ENHANCED PROCEDURE FOR ESTIMATING PAVEMENT REHABILITATION AND MAINTENANCE EXPENDITURES

A Thesis

by

JUAN CARLOS GARCIA-DIAZ
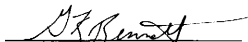
Approved as to style and content by:

Boma T. Afiesimama
(Chairman of Committee)

Robert P. Beals
(Member)

Daniel Colunga
(Member)

G. Kemble Bennett
(Head of Department)

August 1987

ABSTRACT

Development and Implementation of an Enhanced

Procedure for Estimating Pavement Rehabilitation

and Maintenance Expenditures. (August 1987)

Juan Carlos Garcia-Diaz, B.S., Industrial University of Santander

Chairman of Advisory Committee: Dr. Boma T. Afiesimama

The main focus of interest in this thesis is the improvement of the efficiency and accuracy of the process of estimating rehabilitation/maintenance costs and measuring the impact of changing legal axle load limits on those costs. The current methodology uses performance and survivor curves to estimate the number of lane miles of a pavement network that need rehabilitation along a planning horizon; simple cost models are used to calculate the cost of this rehabilitation and the maintenance of the remaining lane miles.

The improved procedure retains the key elements of the current methodology which include the basic procedure for calculating rehabilitation, and routine and preventive maintenance costs, the capability to evaluate the impact of changes in legal load limits on costs and pavement condition, application of survivor curves for flexible pavements and for different performance levels, and the rehabilitation/maintenance planning capability.

The enhancements included in the new methodology include the demarcation of the Texas pavement network into five climatically homogeneous regions, the application of survivor curves per climatic region for both flexible and rigid

pavements, system sensitivity to traffic composition and intensity; a fully automated data input procedure; the development of basic rehabilitation/maintenance cost parameters per climatic area, and a simpler more efficient procedure to calculate probabilities of failure based on survivor curves. With the enhanced system an overall and realistic analysis of the entire state road network is possible; this should prove valuable to the budget planning process for the state road network. Also, this system has the capability to analyze and report data of rehabilitation and maintenance at either state, region, district, or lower levels, and the capability to analyze the impact of changing legal axle load limits at those levels as well.

ACKNOWLEDGMENTS

I would like to express my sincerest and deepest gratitude to Dr. Boma Afies-imama, Chairman of the Advisory Committee, for his personal assistance, confidence, and direction of this research. I am especially grateful to Dr. Alberto Garcia-Diaz, my brother; without his support, his great kindness, his encouragement, and his contributions to the development of this project, the degree I am getting now would be impossible. I am also grateful to Dr. Robert P. Beals; his continued help and instruction are deeply appreciated. Thanks also go to Dr. Daniel Colunga for acting as an advisory committee member. Finally I want to thank the staff members of the Texas Transportation Institute who contributed in many ways to the development of this research, especially to Mr. Dock Burke, Dr. Arturo Villarreal, and Mr. Nazario Ramirez.

I dedicate this work to my parents, Joaquin and Lucrecia, to my brothers and sisters, and to Martha Isabel, in sincere appreciation of their love, support, faith, and encouragement during the many months of study and research in the pursuit of my Master's degree at Texas A&M University.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

CHAPTER I

INTRODUCTION

A number of models have been formulated to forecast rehabilitation and maintenance costs on rural and urban road networks. The general approach is to identify the number of lane-miles in the network that fall below a prescribed performance level, and then determine costs for various rehabilitation and maintenance strategies.

As part of its continuing effort to increase the overall efficiency of the planning process related to pavement rehabilitation and maintenance operations, the Texas State Department of Highways and Public Transportation (SDHPT) sponsored the development of the original computerized RENU procedure [6] between June 1980 and August 1981. Subsequently, a modified RENU2 procedure [4] was developed for SDHPT between September 1981 and February 1982 in order to use the program as a planning tool in preparing portions of an operational planning study. RENU2 performs three major functions: determination of miles in need of rehabilitation, with associated cost; calculation of cost of preventive and routine maintenance for existing pavement network; and, determination of cost impact of changing legal axle load limits. The basic methodology of RENU2 is shown in Fig. 1.

The program requires input data that characterize the entire network for which the estimate is being made, including lane-miles distributions with age, truck traffic level and axle load distributions, typical layer thickness designs, overlay thicknesses, present serviceability index, and unit costs of pavement maintenance and rehabilitation activities. The main steps in the methodology are the following:

Style and format used here conform with those of the *IIE Transactions*.

```
            ┌─────────────────────────┐
            │    Generate Input Data  │
            └────────────┬────────────┘
                         │
            ┌────────────┴──────────────────┐
            │          Calculate:           │
            │ 1.  Total Allowable 18-kip ESAL│
            │ 2.  Number 18-kip ESAL per year│
            └────────────┬──────────────────┘
                         │
            ┌────────────┴──────────────────┐
            │   Traffic Loading Forecast    │
            └────────────┬──────────────────┘
                         │
            ◇────────────┴──────────────◇────────┐
            │   Proposed Legal Limits?  │        │
            ◇───────────┬───────────────◇        │
                  Yes   │          no            │
                        │                        │
            ┌───────────┴───────────────┐        │
            │ Load Distribution Shifting│        │
            └───────────┬───────────────┘        │
                        │                        │
            ┌───────────┴────────────────┐       │
            │ Traffic Loading Under New Limits │  │
            └───────────┬────────────────┘       │
                        │                        │
            ┌───────────┴──────────────────────┐ │
            │  Determine Life Cycle for each    │ │
            │ representative section, including:│ │
            │   1.  Performance History         ├─┘
            │   2.  Time of Overlay             │
            │   3.  Overlay Requirements        │
            │   4.  Remaining Life              │
            └───────────┬──────────────────────┘
                        │
            ┌───────────┴──────────────────────┐
            │ Calculate Routine Maintenance Costs│
            │   for each representative section │
            └───────────┬──────────────────────┘
                        │
            ┌───────────┴──────────────┐
            │ Calculate Overlay Costs for│
            │ each representative section│
            └───────────┬──────────────┘
                        │
            ┌───────────┴──────────────────────┐
            │  Calculate Total Costs for all    │
            │ lane miles of each representative │
            │ section by year of analysis period│
            │   for both loading situations     │
            └───────────┬──────────────────────┘
                        │
            ┌───────────┴──────────────┐
            │ Generate Output for System│
            └───────────────────────────┘
```

Fig. 1 Basic Methodology of RENU2

1. Calculation of Performance Parameters.

Performance can be defined either as a function of the serviceability index which is a general measure of roughness, or as a function of distress which is usually represented by the area or the severity of the distress [5]. A performance analysis based on the serviceability criterion is possible by defining a damage function that reflects the loss in serviceability after a given traffic load. A similar analysis is possible when using the distress criterion; in this case, the maximum allowable loss in performance before rehabilitation can be represented either as the maximum allowable area covered by a specified type of distress, or as the maximum allowable severity level of the same type of distress. The degree or range to which a type of distress is extended can be expressed as the percent of the total pavement surface area in need of repair. For the RENU2 program performance parameters are calculated from historical data of serviceability indices and loads in test section along the entire state.

2. Determination of cause of deterioration.

As aging occurs or loads accumulate, signs of distress become evident and the serviceability index may decrease. Distresses appear on some pavements before they reach their terminal serviceability index; those pavements are said to fail because of distress. When the terminal serviceability is reached first, the pavement is said to fail because of serviceability. In each case, the corresponding performance analysis is applied in order to find the mileage with critical values of performance.

3. Calculation of Survival Parameters.

The time elapsed until a new pavement section needs a major rehabilitation is known as the service life of the pavement. The statistical distribution of the service life is referred to as a survivor distribution. The mileage with critical performance values is assumed to be distributed according to a survivor distribution whose parameters are

estimated using observed pavement data. Based on this density function, a survivor curve is generated to predict the extent of pavement rehabilitation requirements in each of the periods of a planning horizon [5].

4. Calculation of miles needing rehabilitation.

Traffic loads are calculated using the axle load distributions and the traffic levels. With the traffic load data the performance and survival analysis described above is performed. The result of such analysis will be the number of miles to rehabilitate in each period of the planning horizon. When impact of changing legal load limits is to be measured, the program uses a load shifting procedure that modifies the current axle load distributions to reflect such a change; and then finds new traffic load values.

5. Calculation of overlay thickness for pavements needing rehabilitation.

If a pavement fails because of distress, a specified thickness of overlay is applied. This thickness is a user input and can vary from one type of pavement to another. If a pavement fails because of serviceability, overlay thickness is calculated utilizing elastic layer theory employing the Russian Equations [14]. The resulting overlay thickness is that which satisfies a maximum dynaflect deflection criterion when subjected to a specific load determined by the traffic load to be applied during the design period.

6. Cost calculation.

Three types of cost are calculated: rehabilitation, and routine and preventive maintenance. The rehabilitation cost is a function of the number of lane miles to rehabilitate, the thickness of the overlay, the cost of the materials used (input by user), and the width of lane (input by user). Routine maintenance consists of bituminous skin patching, crack sealing, and bituminous base and surface repair; and is a function of the number of miles to maintain and the age of those miles. Its cost is calculated

by using the EAROMAR procedure [6]. Preventive maintenance cost is calculated as a function of the cost of placing seal coats on the pavement.

RENU2 has some serious shortcomings. First, it is only applicable to typical scenarios due to the huge amount of input data needed to make a real run for the entire state. Second, it is insensitive to different types of vehicles and the number of trips for each type of vehicle. Third, it is not sensitive to different climatic conditions which, as known, influence pavement performance. Fourth, rigid pavements cannot be considered efficiently because RENU2 lacks survivor curves for rigid pavements. Fifth, probability of failure calculation is too complex and difficult to understand. Lastly, the model includes a huge set of subroutines many of which perform overlapping operations; thus making the program very difficult to maintain and understand. Therefore, a new effort is proposed to improve the accuracy, reliability and user-friendliness of the RENU2 methodology by developing solutions to the above problems.

The objective of this project is to improve the efficiency and accuracy of the process of estimating rehabilitation/maintenance costs and measuring the impact of changing legal truck axle load limits on those costs. Specific tasks to be performed will include:

1. Development of a procedure to divide a road network into climatically homogeneous areas.

2. Evaluation of performance and survivor characteristics by climatic area, and development of a simpler procedure to find probabilities of failure based on such characteristics.

3. Development of a procedure to make the system sensitive to different types of vehicle and number of trips for each type of vehicle.

4. Full automation of the data input procedure for a large traffic/road data base.

Chapters III thru VI are devoted to analyzing the achievement of each one of the above objectives. In Chapter VII the application of the new methodology is presented; the data collection procedure, the results and possible extensions are also described. Finally, in Chapter VIII conclusions of the study, limitations of the new methodology and recommendations for future research are presented.

CHAPTER II

LITERATURE REVIEW

In the last twenty years, since the AASHTO Road Test began, the concept of pavement performance has been broadly developed. Several studies have been conducted to analyze performance of pavement sections and some computerized procedures have been developed in order to forecast performance of a pavement network over a planning horizon. The importance of forecasting pavement performance comes from the necessity of estimating the road rehabilitation and maintenance requirements. A brief description of such efforts in that field is given in this Chapter.

Roughly, performance can be classified into three types [5]:

1. **Functional Performance.** This is the measure that was adopted by the AASHTO Road Test: the present serviceability index which measures the quality of riding conditions from the point of view of the traveling public. Performance function can be represented by performance curves which indicate the damage on a pavement in function of the traffic load applied on such pavement.

2. **Structural Performance.** This is a measure of deterioration of structural performance which is determined by the appearance of various types of distress.

3. **Survival.** The survival of a pavement is determined by the amount of time that it lasts before major maintenance or rehabilitation must be performed. Pavement survival function can be represented by "survivor curves" which indicate the probability that a given pavement is still in service a number of years after its construction.

The first attempt to estimate road rehabilitation requirements by using per-

formance and survival functions was the REHAB program [6,10]. REHAB did not generate performance parameters but it had to read them from input data; then, it evaluated the rehabilitation requirements. The performance parameters entered to REHAB were calculated from the original AASHTO pavement functional performance equation which is the following:

$$g(w) = (\frac{w}{\rho})^\beta \qquad (2.1)$$

where g is the value of the damage function; w is the quantity of loads; ρ and β are parameters that determine the shape and curvature of the curve respectively.

After REHAB a new procedure called NULOAD [2,6] was developed. Such procedure did generate performance curves in addition to survivor curves. The performance function implemented in NULOAD was the same as in REHAB, namely, the AASHTO equations. For the survival function, a normal survivor curve with the standard deviation defined by the user was selected. The mean of the curve was defined as the year at which the pavement reaches its terminal PSI (P_t). Specifically, the survivor curve represented the miles of pavement that reach P_t at each of the years in the planning horizon centered about the average age of P_t. These mileages were calculated, using the survivor curve, by first computing the probability that some mileage will reach P_t during a given year; and then this probability is multiplied by the total mileage of that age.

Two shortcomings of NULOAD were identified [6]. First, the AASHTO Road Test equations did not represent general pavement performances, specifically for Texas pavements; and secondly NULOAD was assuming curves instead of generating them on the basis of observed data.

A third computerized procedure was developed to correct the shortcomings presented by REHAB and NULOAD; this procedure was called RENU [6]. The methodology of RENU was similar to NULOAD but with Texas data-based per-

formance and survivor curves. For the application of performance curves RENU considered two alternatives: (1) the old AASHTO Road Test equations and (2) a special function based on Texas performance data. Such function is formulated as:

$$g(w) = e^{-k/w^n} \qquad (2.2)$$

where k and n are parameters and w is the traffic load applied. Survivor curves for RENU were empirically generated based on historical data. Such curves can be generally written as:

$$V = 1 - e^{-1/w^r} \qquad (2.3)$$

where V is the percent of surviving mileage; q and r are parameters; and w is the number of 18-kip loads since construction or last rehabilitation. Also, in RENU, a computerized procedure to evaluate the effects on costs and pavement condition of changing legal axle load limits was implemented. Such procedure is known as a "load shifting procedure" [2].

A new effort to improve the RENU procedure was made in 1983. The new procedure was called RENU2 [4] and is the procedure being currently used by the Texas State Department of Highways and Public Transportation in the analysis of rehabilitation and maintenance costs of the Texas road network. This procedure included the following improvements on its predecessor:

1. A S-shaped performance curve which proved to be superior to the AASHTO performance equation for Texas roads [5].

2. Development of new survivor curves based on a statistical survivor distribution. Such survivor distribution is the Weibull distribution [8] which has been broadly used in survivability and reliability analysis. Its applicability to various failure situations, such as electron tube failures, the fatigue life of deep-groove ball bearings, etc, has been extensively investigated and recommended.

Cluster analysis is a process of classifying objects into groups as suggested by characteristic data, rather than defined a priori, such that objects in a particular group are similar to each other but dissimilar to objects in any other group. Applications of cluster analysis to science, engineering, management and the social sciences abound in the literature [11]. A few that seem to bear some similarity to the present application are cited here for the purpose of illustration. Derr and Nagle [3] stratified 107 New Jersey townships, characterized by their agricultural, commercial, and demographic features, using cluster analysis. Having identified "similar" townships, random samples were generated from each group (cluster) to estimate statewide economic parameters. A 1973 study [1] of ratios considered as potential markets of multinational companies used cluster analysis to identify countries with similar market potentials. The results showed that markets which might have intuitively seemed quite different from each other proved to have more similarities, while others which might be considered very much alike proved to fall in different clusters and hence called for different marketing strategies. Other applications of cluster analysis to planning include an environmental impact study of recreational park sites and job evaluation for worker substitutability [11].

Techniques in cluster analysis can be classified in terms of their results as hierarchical, overlapping, and disjoint [12]. In hierarchical cluster analysis a cluster may be totally contained in another cluster; overlapping techniques assign an object to one or more clusters; and disjoint techniques assign each object to one and only one cluster. For the purpose of the present project, disjoint clustering is clearly the most appropriate approach.

CHAPTER III

CLIMATIC DECOMPOSITION

Many climatic factors such as temperature, precipitation, freeze/thaw cycles, evaporation, etc can influence on the performance of pavement roads. For instance, in regions where temperature is high pavements are more likely to dryness and cracking whereas where temperature is low they are not. Therefore, for different climatic conditions performance of pavements is expected to be different too. A climatic decomposition is necessary because the climate of any locality or region is composed of a great variety of elements and it may not be possible for two places to have identical climates. The objective of a climatic decomposition is to group the innumerable individual climates in such a way that all those having certain characteristics in common belong to one class.

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. The current RENU2 model uses a climatic breakdown that is based on arbitrary demarcation. To make the RENU2 model sensible to climatic factors the state is divided into five climatically homogeneous areas. Subsequently survival parameters for each climatic area will be found. As said before such parameters are calculated from historical data of PSI and load in test sections along the entire state; now the test sections within each climatic area will be used to calculate the survival parameters for that climatic area; this way the system will be sensitive to climatic effects.

In this section the procedure followed to find the most "real" division of the state into climatic areas is presented. The main technique used in such procedure

is a cluster analysis . Several Cluster analyses are performed involving different climatic factors or attributes; then, an exhaustive analysis of the different results is performed in order to choose the "best" division.

To divide the state into regions counties are used as reference units; that is, each region is represented by a given number of counties. It is desirable that the counties under the same climatic conditions be adjacent. The total number of counties in the state of Texas is 254 (see Appendix A: Distribution of Texas Counties). The Texas State Department of Highways and Public Transportation has traditionally divided the state into five regions for purpose of study of pavement behavior; in this project, this policy is kept, so the objective is to divide the state of Texas 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, such that objects in a particular group are similar to each other but dissimilar to objects in any other group. Clusters may be hierarchical, disjoint, or overlapping. In hierarchical 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 thesis disjoint clusters are obviously more appropriate and clustering is performed using a SAS utility named FASTCLUS [12].

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

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 on 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 for each county of Texas. The selected climatic factors include:

- Thorntwaite 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 is presented in Appendix A.

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 one four attributes were considered; in the third run, five; and so on until the last run where the thirteen attributes are considered. A sample of the results for a regular Cluster run is shown in Appendix B. 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: Thorntwaite

Table 1   Indices of Discrimination for Each attribute
in Each Clustering

| Attributes | Number of Discriminant Variables | | | | | | | | | | | |
	3	4	5	6	7	8	9	10	11	12	13	Ave
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	.81	.81	.81	.81	.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

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, mean standard deviation for each attribute was computed. This step is performed to support the results obtained. Mean standard deviation per attribute was calculated for each run performed in step I. Results are shown on Table 2. Minimum standard deviation was found to occur at the four attributes selected in the previous step.

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

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 AND VALIDATION

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. Results from this clustering are presented in Appendix B. There are 5 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 other East Texas districts: 1, 12, 19 and 20. 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 10 are said to possess outlier counties. The presence of outliers counties dictates three possible representations of the results, depending on how the outliers are treated:

Case 1: No regard for district boundaries; outliers allowed to remain in climatic "home" region. See Table 3.

Case 2: No regard for district boundaries; outliers incorporated into region of greatest physical proximity. See Table 4.

Case 3: Respect district boundaries; each district assigned to climatic region identified with majority of member counties; outliers not allowed. See Table 5.

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. Fig. 2 shows the final division of the state according to the results from Case 3. Table 6 shows the average value of each significant attribute for each climatic region.

These final results were reviewed and validated by the Texas State Department of Highways and Public Transportation. Such assessment is supported by the acceptance of the Research Report of the Contract IAC (86-87)-0178 between SDHPT and the Texas Transportation Institute: Improving RENU2 Procedures [7].

Table 3   Climatic Decomposition. CASE 1

Region (R)	Districts	Outlier Counties
1. East Texas	1, 12, 19, 20 10 11	none Wood, Smith (both R-3) Henderson (R-5) Angelina (R-5)
2. West Texas	6, 24 7 8	none Real (R-5), Kinney (R-4) Shackelford, Callahan, Taylor (R-5)
3. Texas Panhandle	4 5 25	none Gains, Davison (R-2) Motley, Childress, Dickens King, Knock (R-2)
4. South Texas	16, 21 13 15	none Colorado, Jackson (R-1) Kerr, Rendall, Bandera Comal (R-5)
5. Central Texas	2, 9, 18 3 14 17 23	none Wilbarger (R-2), Baylor (R-3) Travis (R-4) Walker (R-1), Milam (R-4) San Saba (R-2)

Table 4   Climatic Decomposition. CASE 2

Region (R)	Districts	Outlier Counties
1. East Texas	1, 11, 12, 19, 20 10	none Henderson (R-5)
2. West Texas	6, 24 7 8	none Real (R-5), Kinney (R-4) Shackelford, Callahan, Taylor (R-5)
3. Texas Panhandle	4 5 25	none Gains, Davison (R-2) Dickens, King, Knock (R-2)
4. South Texas	13, 16, 21 15	none Kerr, Rendall, Bandera, Comal (R-5)
5. Central Texas	2, 3, 9, 14, 18, 23 17	none Walker (R-1)

Table 5   Climatic Decomposition. CASE 3

Region (R)	Districts	Outlier Counties
1. East Texas	1, 10, 11, 12, 19, 20	none
2. West Texas	6, 7, 8, 24	none
3. Texas Panhandle	4, 5, 25	none
4. South Texas	13, 15, 16, 21	none
5. Central Texas	2, 3, 9, 14, 17, 18, 23	none.

Table 6   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
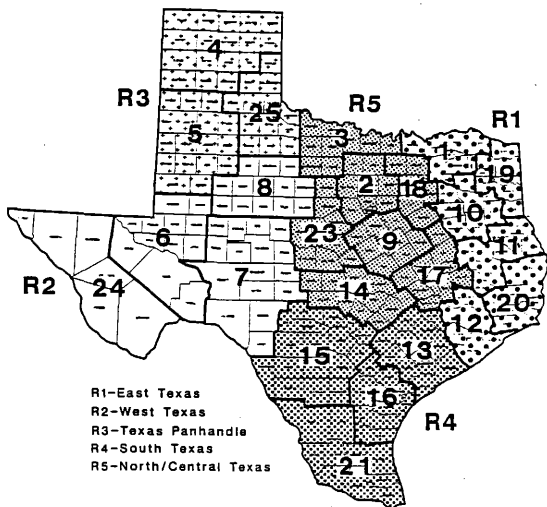
Fig. 2 Homogeneous Climatic Regions

CHAPTER IV

PERFORMANCE/SURVIVOR CHARACTERISTICS OF
PAVEMENT SECTIONS

4.1 PAVEMENT PERFORMANCE FUNCTION

The pavement performance function predicts the deterioration trend of a pavement in terms of PSI (present serviceability index) or the increase in area or severity of a type of distress (such as cracking, rutting, flushing, etc) as the level of traffic loads increases [5]. The life cycle of a pavement is completed when a given terminal performance index (either a minimal PSI value or a maximal distress area or severity) is reached.

The basic pavement performance model used in the RENU programs is expressed as:

$$g(w) = e^{-(\rho/w)^\beta} \qquad (4.1)$$

where:

    w: load applications on the pavement

    g: critical level of performance or pavement damage function

    ρ: scale parameter

    β: shape parameter

4.1.1 Deterioration in terms of PSI

When the pavement performance function predicts deterioration in terms of PSI, the critical level of performance can also be expressed as the ratio of the loss in serviceability after w 18-kip ESALs (Equivalent single axle loads) to a specified

maximum design loss, namely,

$$g(w) = \frac{P_0 - P_t}{P_o - P_f} \tag{4.2}$$

where:

    P_0: initial PSI of the pavement (at $w = 0$)

    P_t: PSI after w 18-kip ESALs

    P_f: lower bound on the PSI

From Equation 4.2 it is possible to express P_t as a function of $g(w)$, as follows:

$$P_t = P_0 - (P_0 - P_f)\, g(w) \tag{4.3}$$

or

$$P_t = P_0 - (P_0 - P_f)\, e^{-(\rho/w)^\beta} \tag{4.4}$$

Fig. 3a shows the form of the loss of PSI (P_t) as a function of the cumulative number of ESALs (w) according to Equation 4.4. Fig. 3b and 3c show, respectively, the influence of parameters ρ and β on the form of the function [5].

4.1.2 Deterioration in terms of distress

Deterioration in terms of distress occurs when pavements are seriously distressed and in need of major rehabilitation before the PSI reaches its terminal value. The most common types of distress are rutting, alligator cracking, patching, flushing, raveling, longitudinal cracks, and transverse cracks.

Pavement distress can be represented by two separate components: area and severity. Area may be expressed either as the percent of the total pavement surface area that is covered by the distress, or total crack length per unit area, or crack
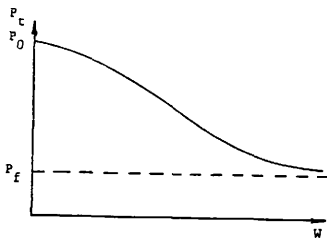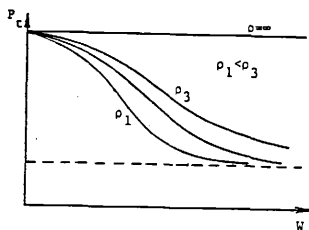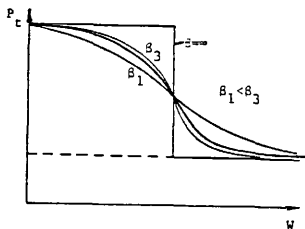
Fig. 3 Pavement Performance Curves

spacing, or similar measures. Severity may be expressed as either an objective or subjective measure. Crack width and crack depth are examples of objective measures. Subjective measures may be assessed by comparing the observed distress with photographs of different levels of severity. Such levels may be described as none, slight, moderate, or severe, and may be given numerical ratings such as 0, 1, 2, and 3, respectively.

Two indices are introduced in order to study pavement deterioration because of distress. Such indices are: Distress area index and Severity index.
Each of these indices represents a number between 0 an 1 which decreases as the level of traffic is increased.

As in the function of deterioration of PSI, the critical level of performance can also be expressed as the ratio of loss of the distress index after w 18-kip ESALs to a specified maximum loss, namely,

$$g(w) = \frac{A_0 - A_t}{A_o - A_f} \quad \text{(area index)} \tag{4.5}$$

where

A_0: initial value of the distress area index ($A_0 \leq 1$)

A_t: distress area index after w 18-kip ESALs

A_f: lower bound on the distress area index

or

$$g(w) = \frac{S_0 - S_t}{S_0 - S_f} \quad \text{(severity index)} \tag{4.6}$$

where

S_0: initial value of the distress severity index ($S_0 \leq 1$)

S_t: distress severity index after w 18-kip ESALs

S_f: lower bound on the distress severity index

These indices can be expressed by a relationship similar to that of Equation 4.4, namely,

$$A_t = A_0 - (A_0 - A_f) e^{-(\rho/w)^\beta} \tag{4.7}$$

$$S_t = S_0 - (S_0 - S_f) e^{-(\rho/w)^\beta} \tag{4.8}$$

To estimate the parameters ρ and β for each of the types of pavement considered the most significant distress type affecting each pavement had to be found. For instance, for flexible pavement types which are asphaltic concrete on aggregate base, asphaltic concrete on bituminous base, and overlaid pavement; the most significant distress types are, respectively, alligator cracking area, alligator cracking severity, and transverse cracking severity [6]. The shapes of typical distress curves are similar to those of Fig. 3.

4.1.3 Procedure for determining performance parameters

The statistical procedure used to determine the constants ρ and β is fully described in [5]. A brief description will be presented here.

For deterioration in terms of PSI the performance function (Equation 4.4) can be expressed as

$$P_0 - P_t = \alpha e^{-(\rho/w)^\beta} \tag{4.9a}$$

where

$$\alpha = P_0 - P_f \tag{4.9b}$$

Taking natural logarithm of Equation 4.9a yields

$$\ln(P_0 - P_t) = \ln(\alpha) - (\rho/w)^\beta \tag{4.10}$$

or

$$\ln(P_0 - P_t) = \ln(\alpha) - \rho^\beta \left(1/w\right)^\beta \quad (4.11)$$

Using the transformation $e^\tau = 1/w$ Equation 4.11 becomes

$$\ln(P_0 - P_t) = \ln(\alpha) - \rho^\beta \left(e^\beta\right)^\tau \quad (4.12)$$

which is equivalent to

$$z = a - bc^\tau \quad (4.13a)$$

where

$$z = \ln(P_0 - P_t) \quad (4.13b)$$

$$a = \ln(\alpha) \quad (4.13c)$$

$$b = \rho^\beta \quad (4.13d)$$

$$c = e^\beta \quad (4.13e)$$

The procedure used to estimate the parameters a, b, and c in Equation 4.13a is the well-known "least squares" method. The corresponding statistical model is defined as

$$z_i = a - bc^{\tau_i} + \varepsilon_i \quad (4.14)$$

where ε_i is the random error corresponding to the value of z_i associated with τ_i.

Assuming a collection of m data points (P_i, w_i) where P_i is the serviceability index corresponding to a traffic load level w_i, and $i = 1, 2, \ldots, m$, the data for solving the regression model can be computed as follows:

(a) $z_i = \ln(P_0 - P_i)$ for $i = 1, 2, \ldots, m$ (P_0 is known)

(b) $\tau_i = \ln(1/w_i)$ for $i = 1, 2, \ldots, m$. With these data and the model of Equation 4.14, it is possible to estimate the value of a, b, and c, which subsequently can

be used to estimate α (and thus P_f), ρ, and β from Equations 4.13c, 4.13d, and 4.13e.

For deterioration in terms of distress the same procedure is followed. The value of the variables of the regression model in Equation 4.13 is

$$z = \ln(A_0 - A_t) \qquad (4.15a)$$

$$a = \ln(A_0 - A_f) \qquad (4.15b)$$

$$b = \rho^\beta \qquad (4.15c)$$

$$c = e^\beta \qquad (4.15d)$$

for distress area. For distress severity the value of such variables is

$$z = \ln(S_0 - S_t) \qquad (4.16a)$$

$$a = \ln(S_0 - S_f) \qquad (4.16b)$$

$$b = \rho^\beta \qquad (4.16c)$$

$$c = e^\beta \qquad (4.16d)$$

Value of the parameters A_f, S_f, ρ, and β may be estimated in the same way as in the PSI case.

4.2 PAVEMENT SURVIVAL FUNCTION

A survival function is a relationship that predicts the percentage of mileage in a given pavement category that does not require rehabilitation when a specified critical performance is reached.

According to the pavement performance function a pavement section reaches its critical performance index after a given number of load applications. By saying

that a given traffic load is reached only at a specific age of the pavement section, load application units can be translated into time units. This way, the survival function is redefined as the relationship that predicts the percentage of mileage in a given pavement category that does not require rehabilitation at a specified time.

The time elapsed until a new pavement section needs a major rehabilitation, or the time between major rehabilitations for an existing pavement section, is known as the service life of the pavement. The statistical distribution of the service life is referred to as a survivor distribution. A particularly used distribution in survivability analysis and reliability is the Weibull distribution [8]. This distribution can be used to predict the survival rate of pavements of a given class at any period of a specified planning horizon.

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:

$$f(w) = \gamma \, \lambda^{\gamma} \, w^{\gamma-1} \, e^{-(\lambda w)^{\gamma}} \qquad (4.17)$$

$$F(w) = 1 - e^{-(\lambda w)^{\gamma}} \qquad (4.18)$$

In the specific application of this distribution to the study of pavement survivability, w represents the number of 18-kip ESALs at which the pavement reaches its critical performance level. The parameters λ and γ are referred to as a "scale parameter" and a "shape parameter", respectively.

The pavement 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,

$$s(w) = e^{-(\lambda w)^{\gamma}} \qquad (4.19)$$

4.2.1 Procedure for Determining Survival Parameters

The Maximum Likelihood Estimation method [8] can be applied to obtain estimates of the parameters λ and γ on the basis of a random sample of traffic loads $w_1, w_2, \ldots, w_n$ (For a specified critical level of performance measured in terms of PSI or distress area/severity indices, this sample can be generated from the pavement performance model, Equation 4.1). The values of w_i can be calculated from solving Equation 4.1 for w; thus we obtain

$$w = \frac{\rho^\beta}{\ln(g_c)} \tag{4.20}$$

where g_c represents the specified critical level of performance. Using Equation 4.20 for n test sections (each with different ρ and β values) the sample $w_1, w_2, \ldots, w_n$ is obtained.

The estimates of λ and γ are the solution to the following non-linear system of equations:

$$\frac{\sum_{i=1}^n w_i^{\hat{\gamma}} \ln(w_i)}{\sum_{i=1}^n w_i^{\hat{\gamma}}} - \frac{1}{\hat{\gamma}} - \frac{1}{n} \sum_{i=1}^n \ln(w_i) = 0 \tag{4.21}$$

$$\frac{1}{\hat{\lambda}^{\hat{\gamma}}} - \frac{1}{n} \sum_{i=1}^n w_i^{\hat{\gamma}} = 0 \tag{4.22}$$

Equation 4.21 can be approximately solved using the Newton-Raphson method [13] to find $\hat{\gamma}$, which in turn is used in Equation (4.22) to find $\hat{\lambda}$.

A graphic procedure to illustrate the generation of survivor curves from performance functions is shown in Fig. 4. Fig. 4a represents the distribution of mileage by level of serviceability index. Fig. 4b corresponds to the performance function and shows the traffic loads, w^*, at which a critical value of serviceability is reached. Fig. 4c shows the probability density function for the mileage in need of rehabilitation. Fig. 4d is the survivor curve which gives the percent of pavement mileage
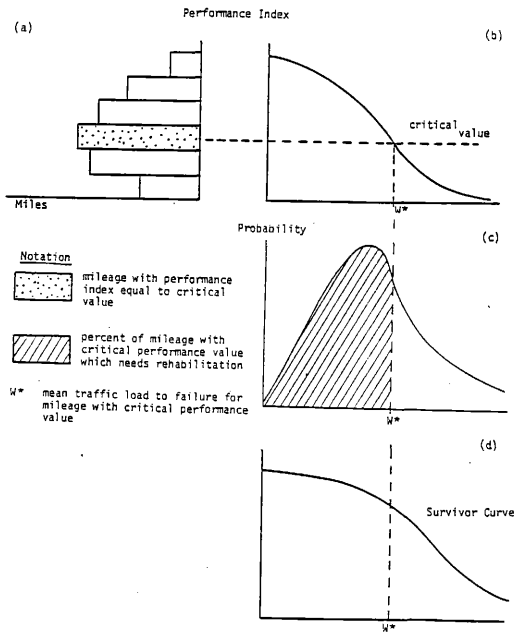
Fig. 4   Procedure to Generate Survivor Curves

with critical performance index which will not fail by the time the traffic load w^*
is reached.

4.3 GENERATION OF PERFORMANCE AND SURVIVAL
PARAMETERS PER CLIMATIC REGION

4.3.1 Flexible Pavements

To find performance and survival parameters for flexible pavements in each
climatic region, the methodology described in Sections 4.1 and 4.2 is followed.

Data Collection

Field measurements from the data base for flexible pavements available at the
Texas Transportation Institute were used [5]. Specifically those data consisted of
values of the present serviceability index (PSI), area and severity indices (A_t and S_t)
for several types of distress, and the corresponding traffic load levels (w) measured
at representative test sections along the entire state.

To find performance and survival parameters for each type of pavement in each
climatic region, the 164 existing test sections were grouped per pavement type and
climatic region. Table 7 shows the number of sections for each pavement type in
each climatic region. The complete set of data may be seen in [5].

Generation of Performance Parameters

Two performance curves for each test section were developed using the method
outlined in Section 4.1.3, one curve for deterioration in terms of PSI and another
one for deterioration in terms of distress. The purpose of the performance function

Table 7   Test Sections per Type of Pavement in Each Region

Pavement Type	Region 1	Region 2	Region 3	Region 4	Region 5
Asphaltic Concrete on Aggregate base	4	9	14	5	4
Asphaltic Concrete on Bituminous base	-	5	24	13	9
Overlays	20	11	16	8	21

is prediction of failure and at the moment of planning the cause of failure (PSI or distress) is unknown; therefore, both curves had to be generated for each test section.

Performance parameters for typical test sections for each pavement type in each climatic region are shown in Table 8. Such parameters correspond to deterioration in terms of PSI. For deterioration in terms of distress, see parameters in Table 9.

Generation of Survival Parameters

Each performance curve developed for each test section was used to generate survivor curves using the method outlined in Section 4.2.1. For each climatic region only the performance curves of the test sections within that region were considered (see Table 7). There are two types of survivor curve, one for deterioration in terms of PSI and another one for deterioration in terms of distress.

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 PSI. The critical performance index referred to in Equation 4.20 is calculated as [6]

$$g_t = \frac{P_0 - P_c}{P_0 - P_f} \tag{4.23}$$

It should be noted that for Equation 4.23 to yield a valid value of g_c it is necessary that $P_c \geq P_f$. Therefore, when considering test sections of a given type of pavement, Equation 4.20 can be used only in the sections having a P_f value less that or equal to the specified value of P_c. All other sections violating this condition cannot be used to generate w values for the maximum likelihood estimation procedure. The three values of P_c considered are 1 (low), 2 (medium), and 3 (high). The results of this analysis are given in Table 10.

Table 8   Representative Performance Parameters for Flexible Pavements (PSI)

Pavement Type	Region 1		Region 2		Region 3		Region 4		Region 5	
	Beta	Rho	Beta	Rho	Beta	Rho	Beta	Rho	Beta	Rho
HOT MIX	0.182	0.116	1.209	0.854	3.170	1.392	0.501	1.324	2.180	1.494
BLACK BASE	0.501*	2.710*	1.209	1.291	3.003	1.996	0.501	2.710	0.742	5.749
OVERLAY	2.313	4.180	0.140	0.013	2.054	0.116	1.658	1.289	0.975	1.245

*Values are estimated on the basis of physical proximity, due to lack of traffic/PSI primary input data.

Table 9   Representative Performance Parameters for Flexible Pavements (Distress)

Pavement Type	Region 1		Region 2		Region 3		Region 4		Region 5	
	Beta	Rho	Beta	Rho	Beta	Rho	Beta	Rho	Beta	Rho
HOT MIX	1.257	1.207	3.219	1.433	2.063	2.430	2.027	0.160	1.876	0.938
BLACK BASE	2.128*	0.496*	6.390*	1.391*	6.390	1.391	2.128*	0.496*	2.128	0.496
OVERLAY	0.685	1.597	3.354	0.921	1.240	0.100	2.111	0.705	5.742	0.476

*Values are estimated on the basis of physical proximity, due to lack of traffic/PSI primary input data.

Table 10 Survivor Parameters for Flexible Pavements (PSI)

Pavement Type	Pc	Region 1		Region 2		Region 3		Region 4		Region 5	
		Gamma	Lambda	Gamma	Lambda	Gamma	Lambda	Gamma	Lambda	Gamma	Lambda
HOT MIX	1	0.670*	0.193*	2.088	0.618	3.041	0.160	0.670*	0.193*	0.670	0.193
	2	1.030	0.078	0.763	0.252	3.476	0.314	1.242	0.184	0.954	0.549
	3	1.216	0.290	1.425	0.658	0.032	0.0001	0.528	0.141	1.268	1.985
BLACK BASE	1	14.128*	0.171*	1.486	1.234	5.522	0.292	1.603	0.072	14.128	0.171
	2	0.933	0.158	0.775	0.537	0.962	0.194	0.700	0.062	0.933	0.158
	3	0.899	0.363	1.154	1.670	0.539	0.117	0.574	0.037	0.899	0.363
OVERLAY	1	0.940	0.125	1.905	0.273	4.980	0.569	2.201*	0.136*	2.201	0.136
	2	1.276	0.221	0.029	0.0003	1.591	0.627	1.718	0.278	1.398	0.134
	3	1.639	0.424	0.632	0.393	1.544	0.004	0.939	0.540	0.787	0.555

*Values are estimated on the basis of physical proximity, due to lack of traffic/PSI primary input data.

A similar analysis was carried out for pavement distress using three different critical performance indices. For distress analysis the critical value g_c is directly specified as an input parameter [6]; such critical indices are 0.17, 0.35 and 0.50. Results are shown in Table 11. It should be noted that for each type of pavement only one characteristic of one distress type was considered in the generation of the parameters (see Section 4.1.2), namely,

(a) Hot Mix: Alligator cracking area

(b) Black Base: Alligator cracking severity

(c) Overlays: Transverse cracking severity

4.3.2 Rigid Pavements

The current RENU2 model does not consider performance and survival functions for rigid pavements; therefore a new methodology is presented in this section. Basically there are two types of rigid pavements [7]: Reinforced concrete pavement and Plain concrete pavement.

For each type of pavement the PSI performance function is the same and is given by the following model:

$$P_t = P_0 - (P_0 - P_t)e^{-(\rho/w)^\beta} \tag{4.24}$$

which is the same model for a flexible pavement. The procedure for determining the performance parameters is the same outlined in Section 4.1.3. As seen, the data required to calculate those parameters are a collection of historical data points (P_i, w_i) where P_i is the serviceability index corresponding to a traffic load level w_i. But such data were not available at all; therefore, a model to estimate the value PSI for a given value of w, presented in [9], is used. Such model is given by

Table 11   Survivor Parameters for Flexible Pavements (Distress)

Pavement Type	G_c	Region 1		Region 2		Region 3		Region 4		Region 5	
		Gamma	Lambda	Gamma	Lambda	Gamma	Lambda	Gamma	Lambda	Gamma	Lambda
HOT MIX	0.17	0.177*	0.0002*	0.177	0.0002	0.177	0.0002	1.072	0.960	1.072	0.960
	0.35	2.661	0.949	2.661	0.949	2.574	0.609	2.661	0.949	2.661	0.949
	0.5	2.586	1.047	2.586	1.047	1.313	0.387	0.707	1.085	0.707	1.085
BLACK BASE	0.17	0.177*	0.0002*	0.177*	0.0002*	0.177	0.0002	1.072	0.960	1.072*	0.960*
	0.35	7.216	0.357	7.216	0.357	7.216	0.357	7.216	0.357	7.216	0.357
	0.5	10.758	0.479	10.758	0.479	10.758	0.479	10.758	0.479	10.758	0.479
OVERLAY	0.17	0.177	0.00002	0.177	0.0002	0.177	0.0002	1.072	0.960	1.072	0.960
	0.35	0.387	0.257	0.257	0.256	0.257	0.256	1.394	1.317	1.394	1.317
	0.5	0.661	7.672	7.672	0.913	0.757	0.875	0.614	0.311	0.614	0.311

*Values are estimated on the basis of physical proximity,
due to lack of traffic/PSI primary input data.

$$PSI = 4.46 + AGE * \ln(ESAL + 1)(-0.07825 + 0.03969 * T * AS+$$

$$0.02563 * STAB - 0.0002392 * L) \tag{4.25}$$

where:

PSI: present serviceability index

AGE: time since construction [years]

ESAL: total accumulated 18-kip equivalent single axle load applications since construction [millions]

T: concrete slab thickness [ins]

AS: area of steel reinforcement longitudinality in slab [ins^2/ft. width of slab]

STAB: 1, if subbase is stabilized with cement of asphalt

0, if subbase is unstabilized granular dense graded

L: slab length [ft]

After several points (P_i, w_i) have been generated, the procedure of section 4.1.3 is used to determine ρ and β for deterioration in terms of PSI.

For deterioration in terms of distress, as in the flexible case, the most significant type of distress affecting each pavement had to be found. Typical distress types for rigid pavements are: transverse joint faulting, pumping, patching, joint deterioration, "D" cracking, swells and depressions, and transverse cracking.

Both types of rigid pavements i.e. reinforced and plain, were found to be mostly affected by the same type of distress: Joint deterioration severity [9]. A deteriorated joint is defined as a joint exhibiting blowups, corner breaks, permanent parches, and medium to high severity spallings. Therefore, for each type of pavement the distress

performance function is the same and is given by the following model

$$S_t = S_0 - (S_0 - S_t)e^{-(\rho/w)^\beta} \qquad (4.26)$$

which is the same model for distress in flexible pavements. The procedure for determining the distress performance parameters is also the same outlined in Section 4.1.3. The data required for calculating such parameters are a collection of historical data points (S_i, w_i) where S_i is the joint deterioration severity index corresponding to a traffic load level w_i. Again such data were not available at all; therefore, another model presented in [9] is used to estimate the values of the severity index for given values of w. Such model is given by

$$\ln(DETER + 1) = \ln(ESAL + 1) * AGE\,[0.0011 * FTCYC +$$

$$(0.019 * INCOM * FTCYC * JTSL) + 0.0139] + 0.0429 \qquad (4.27)$$

where

DETER: Joint deterioration severity index

ESAL: Cumulative applied 18-kip equivalent single axle loads [millions]

AGE: Age of pavement [years]

FTCYC: Average annual freeze thaw cycles in the slab

INCOM: 1, if incompressibles are visible in the joints

0, if no incompressibles are visible

JTSL: 1, if the sealant is in medium to high severity

0, if the sealant is in low or better condition

After several points (S_i, w_i) have been generated, the procedure of Section 4.1.3 is used to determine ρ and β for deterioration in terms of distress.

Climatic regions

By conversations with experts in Texas road behavior, at the Texas Transportation Institute, it was concluded that the performance of rigid pavements in regions 1, 3, and 5 is pretty similar; as well as the performance in regions 2 and 4; therefore, only two special climatic regions were considered for rigid pavements:

- Region A (includes regions 1, 3, 5)
- Region B (includes regions 2, 4).

Data Collection

The first step in the data collection was to choose representative rigid pavement section in both regions A and B. The next step was to find the value of the independent variables in the models for calculating the PSI and the distress index values (Equations 4.25 and 4.27). Values of these variables were obtained from the RL1FILE and RIFILE files in the traffic data base at the Texas State Department of Highways and Public Transportation. RL1FILE adn RIFILE are described in Chapter VI. Table 12 summarizes the form and source of each dependent variable in Equations 4.25 and 4.27. With these data, indices for PSI and distress severity were calculated by applying the Equations 4.25 and 4.27 for the five years considered.

Generation of Performance Parameters

Two performance curves were developed for each representative rigid section using the method presented in Section 4.1.3, one curve for deterioration in terms of PSI and another one for deterioration in terms of distress.

Table 12 Sources of Data for Rigid Pavements

Variable	Source
AGE	pavements with 1, 2, 3, 4, and 5 years old were considered
ESAL	RL1FILE file; total value for pavements in each representative section
T	RIFILE file; average value for each representative section
AS	RIFILE file; average value for each representative section
STAB	RIFILE file
L	RIFILE file average value for each representative section
FTCYC	"CLIMDATA" file (See Section 3.2)
INCOM	pavement experts of the Texas Transportation Institute
JTSL	pavement experts of the Texas Transportation Institute

PSI and distress Performance parameters for typical test sections for each rigid pavement type in each special climatic region are shown in Table 13.

Generation of Survival Parameters

Each performance curve developed for each representative section was used to generate survivor curves using the method presented in Section 4.2.1. For each special climatic region only the performance curves of the sections within that region were considered.

For each type of rigid pavement in each special climatic region, the parameters λ and γ were estimated for three different critical levels of PSI. Equation 4.23 was used to find the critical levels; The values of P_c considered were, again, 1, 2, and 3. The results of this analysis are given in Table 14.

In the analysis of pavement distress, three different values of the critical performance index were used; such values were 0.17, 0.35 and 0.50. Results are shown in Table 14.

Table 13   Representative Performance Parameters for Rigid Pavements

Pavement Type	PSI				DISTRESS			
	Region A		Region B		Region A		Region B	
	Beta	Rho	Beta	Rho	Beta	Rho	Beta	Rho
Reinforced	0.189	5.75	0.550	1.930	1.180	7.660	1.260	9.320
Plain	1.510	2.120	0.548	2.070	1.270	15.040	1.260	10.03

Table 14   Survivor Parameters for Rigid Pavements

Pavement Type	P_c	PSI				DISTRESS				
		Region A		Region B		G_c	Region A		Region B	
		Gamma	Lambda	Gamma	Lambda		Gamma	Lambda	Gamma	Lambda
Reinforced	1	4.190	0.339	2.490	0.003	0.17	3.73	0.0278	4.36	0.0103
	2	4.190	0.264	2.490	0.0231	0.35	3.78	0.0344	4.70	0.0323
	3	4.190	0.129	2.490	0.113	0.50	3.90	0.0560	4.77	0.0520
Plain	1	12.07	0.012	0.541	0.0127	0.17	24.03	0.1436	13.29	0.9340
	2	15.39	0.1208	0.737	0.0241	0.35	24.03	0.3609	13.29	0.2347
	3	18.30	0.465	0.936	0.134	0.50	24.03	0.5340	13.29	0.3470

4.3.3 Validation of Results

All the performance and survivor curves for both flexible and rigid pavements, generated for each type of pavement in each climatic region were reviewed and validated by the Texas State Department of Highways and Public Transportation. Such assessment is supported by the acceptance of the Research Report of the Contract IAC (86-87)-0178 between SDHPT and the Texas Transportation Institute: Improving RENU2 Procedures [7].

4.4 CALCULATION OF PROBABILITIES OF FAILURE BASED ON SURVIVAL CURVES

In RENU3 a new procedure to calculate probabilities of failure is introduced. As said before, probabilities of failure are calculated from survivor curves which relate age of pavement to probability of failure. As an illustration assume that the survivor curve for a pavement section is that one of Fig. 5.

The probability that a mile of that pavement section fails in year i is given by $P(i) - P(i - 1)$. The number of mile of age i failing that year will be the product of the total number of miles of that age and the value of $P(i) - P(i - 1)$. The total number of miles of any age failing in year i will be the summation of the number of miles of ages 1, 2, ..., i, $i + 1$, ..., etc. It must be taken into account that the mileage of age j rehabilitated in year i becomes mileage of age 0 after it is rehabilitated. Thus, when calculating the number of miles to fail in year $i+1$, the mileage rehabilitated the previous year must be considered too. This process is best understood through a graphic procedure. A flowchart showing the procedure to calculate the total number of miles failing during the planning horizon, as it is in RENU2, is given in Fig. 6. In this Figure the following notation is used:
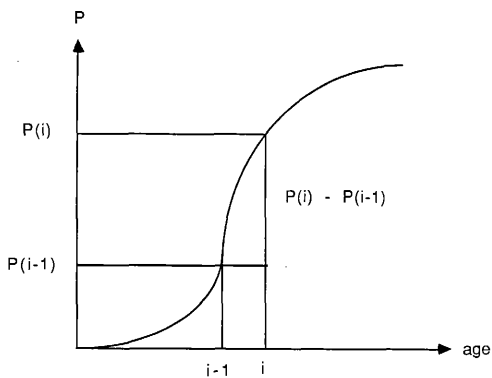
Fig. 5   Probability of Failure Calculation Using a Survivor Curve

NASL = number of years for which lane-mile data is provided (usually 30)

NYAP = number of years in the planning horizon

FAILML(i) = total number of miles to rehabilitate in year i = YMILES(i)

YLM(i) = total number of miles of age i

PR1(k,i) = probability that a mile of age k fails in year i of the planning horizon

PR2(l,i) = probability that a mile rehabilitated in year l of the planning horizon fails in year i of the same horizon.

Both probabilities PR1 and PR2 must be considered separately since the adjustment of the pavement age is made after the calculation of the total number of miles failing in a given year i of the planning horizon (the analysis of all the miles of every age taking year i as reference must be made first).

In RENU3, a new methodology where the adjustment of the pavement age is made simultaneously with the analysis of miles of each age given a specific year of the planning horizon. That is, as the miles of age j failing in year i are calculated, the age of the miles rehabilitated is updated immediately before continuing with the calculation of the analysis of miles of age $j + 1$, of course, taking the same year i as a reference. This way, the idea of the PR2 probabilities used in RENU2 is not needed here. This procedure is also best illustrated through a chart. The flowchart showing the new procedure is given in Fig. 7. In that Figure the following extra notation is used:

PFAIL(k) = probability that a mile of age k fails in the beginning of the planning horizon

PFAILC = cumulative probability of failure

The other variables have the same meaning as those used in Fig. 7.

Results of this procedure were compared to results of the old procedure; both
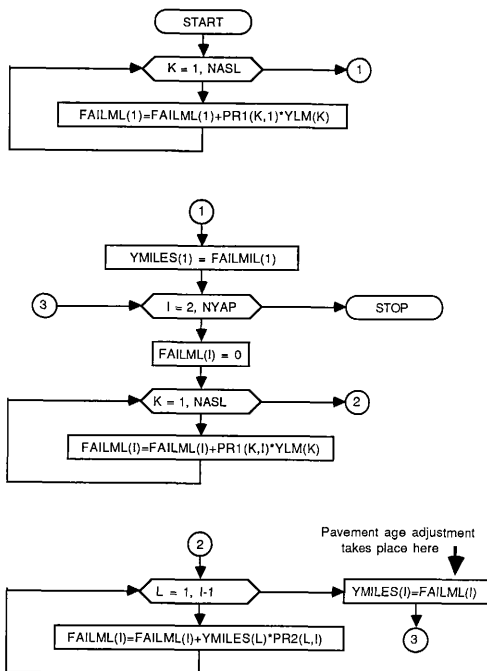
Fig. 6   RENU2 Procedure to Calculate Mileage Failing

START

PFAILC = 0

2 → I = 1, NYAP → STOP

FAILML(I) = 0

K = 1, I+NASL-1 → 1

$$ORIGML = \frac{YLM(K)}{1 - PFAILC}$$

FAILML(I)=FAILM(I)+ORIGML*PFAILC
YLM(K)=YLM(K)-ORIGML*PFAIL(K)

Pavement age adjustment
takes place here ←

PFAILC=PFAILC+PFAIL(K)

1

L = 1, I+NASL → YLM(1) = FAILML(I)

K = I+NASL+2-K
YLM(K) = YLM(K-1)

2
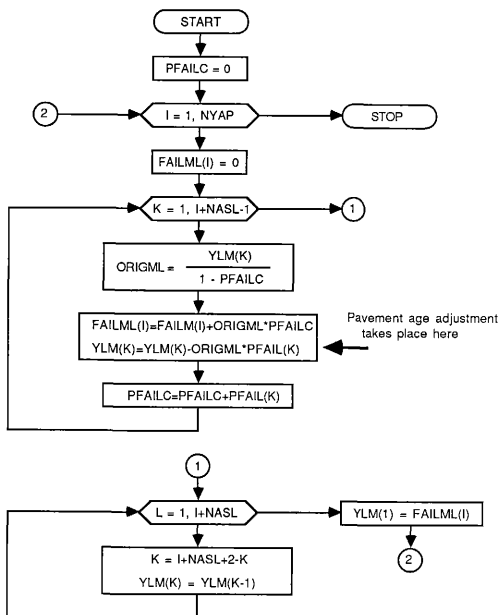
Fig. 7   RENU3 Procedure to Calculate Mileage Failing

results were pretty similar, and it was thought unnecessary to apply statistical test to prove their similarity. However, the new procedure has some advantages over the old procedure. Such advantages are:

1. The new procedure is simpler and therefore easier to follow.

2. The number of calculations is reduced, since with the new procedure only one survivor curve is generated. In the old procedure the number of survivor curves generated is (NASL)*(NYAP).

3. The new procedure represents a more real application of the survivor curves to the calculation of mileage failing.

CHAPTER V

SENSITIVITY TO TRAFFIC MIX AND INTENSITY

Traffic intensity on a pavement section is clearly an important factor in the deterioration of the pavement section. It is expected that the higher the traffic intensity, the heavier the total load applied on the pavement and therefore the shorter the life cycle of the pavement. Also, it is expected that pavement deteriorates faster when the traffic is composed mostly of heavy types of vehicles. Thus a good maintenance and rehabilitation pavement cost model should consider both traffic intensity and composition to be reasonably accurate and reliable.

The RENU2 model considers up to 10 different types of heavy vehicles (see Fig. 8) and performs a specific load analysis for each one; but it was found that it does not consider the traffic intensity. The simplest way to realize this is by analyzing the input data set for the RENU2 model (described in Section 6.1). There is no input variable to enter the value of the traffic intensity into the system. To make sure of the insensitivity of the model to such factor, the model was run for several scenarios with the same axle load and weight distributions and the same performance and survivor parameters, but different traffic intensities. As expected, the model gave the same results for all the scenarios (see Fig. 9).

5.1 RELATION BETWEEN TRAFFIC AND PAVEMENT SURVIVAL

As seen in Equation 4.19, the pavement survival is a function of the load applied on that pavement, this being the only independent variable in that model. This load applied is clearly directly proportional to the traffic intensity; therefore, the total load applied (w) can be defined as a function of the traffic intensity (measured
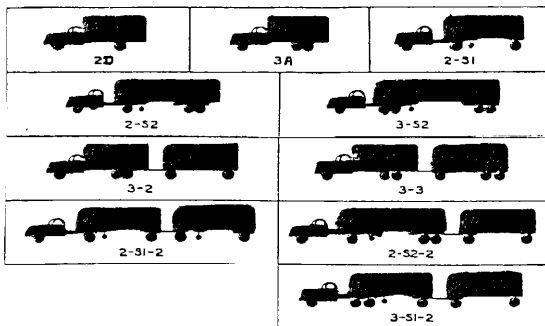
Fig. 8 Truck Types Considered by RENU3
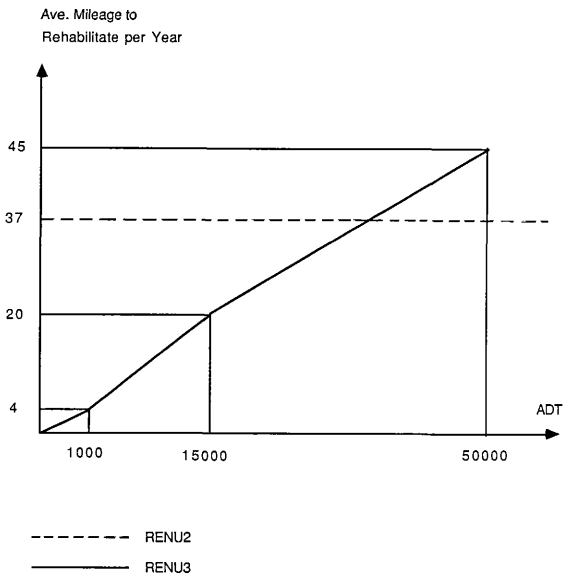
Fig. 9   Comparison of Traffic Intensity Sensitivity between RENU2 and RENU3

in terms of ADT - Average Daily Traffic) value, the traffic mix, and a load equivalency factor. Thus,

$$w = f(ADT, PERC, EF) \qquad (5.1)$$

where $PERC$ represents the mix of vehicles present in the traffic volume, and EF is the load equivalency factor which depends on the traffic composition (vehicle size, weight, and configuration) [2]. A load equivalency factor is defined as a ratio of the number of applications of a standard load which is equivalent in destructive effect to one application of a given load. The computation of an equivalency factor is affected by several factors [2]. Among them are load condition (magnitude, axle configuration, tire spacing), pavement structure (structural properties, physical response, response variable), environmental condition (temperature, moisture), and failure type (PSI loss, distress mode). The methodologies to calculate load equivalence factors proposed by AASHO [15] for single, tandem, and tridem axles, and by the Austin Research Engineers, Inc [2] for steering axles were used in RENU2.

In the current RENU2 model it was very difficult to identify clearly how the value of w was calculated; mainly due to the huge set of subroutines, many of them overlapping. For instance, it happened that in the tracing of such value, a point where the same value is recalculated in a different way was reached. Therefore, it is necessary to find a method to evaluate the traffic load which is clear and easy-to-follow at the same time that the traffic intensity is considered. Such methodology is presented in the following section.

5.2 METHODOLOGY

The method used to compute load equivalency factors in RENU3 is the same one used in RENU2. For detailed description of this method, see [2] and [15]. The overall methodology to calculate the total ESALs applied (w) is presented in Fig.

10. The notation used in that figure is the following.

    n: type of axle load distribution: single, tandem, tridem, or steering

    i: type of truck, i=1,2,...,10

    l: number of intervals in an axle load distribution

Input parameters:

    $AXLE_n(l,i)$: type n axle load distribution for truck type i, with l intervals (input by user)

    $PERC(i)$: percentage of trucks of type i out of the total traffic *(input by user)*

    ADT: average daily traffic (input by user)

    $AXCON_n(i)$: number of axles of type n present in truck type i

    $EF_n(l)$: load equivalency factor for a load l of a type n axle

Other variables:

    $AXLE2_n(l,i)$: type n axle load distribution with l standardized 2-kip intervals, for truck type i

    $CPER2_n(l,i)$: cumulative function of $AXLE2_n(l,i)$

    $MAXLE2_n(l,i)$: list of midpoints of the intervals of the distribution $AXLE2_n(l,i)$

    $TAN18_n(i)$: total load in N-18 kip equivalent loads (ESALs) of a type n axle present in a truck type i

    C: Total ESALs for a given pavement section and given traffic intensity and mix.

5.3 VALIDATION

The same data sets used to prove the insensitivity of RENU2 to traffic intensity were used to prove the sensitivity of RENU3. Some runs were conducted with both models for different traffic intensities in a test section of 500 miles; all other param-

$$\boxed{\begin{array}{c} \text{Calculate } AXLE2_n(l,i); \; n=1,2,3,4 \\ i=1,2,\ldots,10; \; l=1,2,\ldots \end{array}}$$

$$\boxed{\begin{array}{c} \text{Calculate } CPER2_n(l,i); \; n=1,2,3,4 \\ i=1,2,\ldots,10; \; l=1,2,\ldots \end{array}}$$

$$\boxed{\begin{array}{c} \text{Calculate midpoints of intervals in} \\ CPER2_n(l,i); \text{ store them in } MAXLE2_n(l,i) \end{array}}$$

$$\boxed{\begin{array}{c} \text{Using } MAXLE2_n(l,i) \text{ and structural} \\ \text{design data, calculate } EF_n(l) \text{ according} \\ \text{to methods described in [2] and [15]} \end{array}}$$

$$\boxed{\begin{array}{c} TAN18_n(i) = \displaystyle\sum_{l=1} EF_n(l) * CPER2_n(l,i) \\ i=1,2,\ldots,10 \end{array}}$$

$$\boxed{\begin{array}{c} EALPT(I) = \displaystyle\sum_{n=1} TAN18_n(i) * AXCON_n(i) \\ i=1,2,\ldots,10 \end{array}}$$

$$\boxed{C = \displaystyle\sum_{i=1} EALPT(i) * PERC(i)}$$

$$\boxed{W = C * ADT * 365}$$

Fig. 10 RENU3 Procedure to Calculate Total Applied Load

eters remained constant. The results shown in Figure 13 indicate that the number of miles to rehabilitate was higher in the scenarios with high traffic intensities and lower in scenarios with low traffic intensity.

CHAPTER VI

AUTOMATION OF DATA INPUT PROCEDURES

RENU2 requires a meaningful amount of input data to produce the desired output. Currently, such input data are collected manually, making the generation of the input data set a complex and difficult task. As A consequence of this, the following problems arise:

1. The accuracy and reliability of the input data generated manually cannot be assured; therefore, the output is not reliable.

2. It is impossible to make a real run for the entire state.

3. The model is not frequently used.

Due to these problems, the capabilities of the model have not been efficiently used; the implementation of an automated procedure for data input that solves the above problems has become very important for the efficient use of the model. The development of such automated procedure is presented in this chapter.

The objective of this input automation is to minimize the generation of input data by hand. To achieve this, computer software is developed to extract all the possible data from existing data bases, sort them, and transform them to appropriate formats. A central computer program is used to generate the final input file for the improved model. The automation procedure was conducted in the following phases:

1. Review and analysis of the old data input procedure to identify the data that might be taken from each source.

2. Design of the automated system; included in this phase are system definition, definition of main processes, file definition, program definition, and definition of input forms and output reports.

3. Development of software programs

4. Implementation

The documentation phase was conducted simultaneously with each of these tasks. Such documentation consists of the user and maintenance manuals. In Section 6.1 the review and analysis of the old input data is presented; then, in Section 6.2, a general description of the new input procedure is outlined. Description of phases 2 and 3 is one of the purposes of the documentation; therefore, these phases will be covered under the section on documentation, namely, Section 6.3. The last phase, implementation, is presented in the following chapter, Application of the New Methodology.

6.1 OLD DATA INPUT PROCEDURE

The old data input procedure consisted basically of generating the necessary data characterizing a section of the pavement network manually; after the data set was ready, a run of the model was performed. This procedure had to be repeated for each pavement section to be evaluated. The input data set for each pavement section consisted of the following elements:

General Run Parameters: number of years in the analysis period, annual growth rate in ESALs, interest rate used for economic analysis, highway cost index for surfacing, and highway cost index for maintenance materials

System Title: problem and system identification

Flexible Pavement Data: lane width, asymptotic serviceability index, asymptotic serviceability index for overlay, section description (pavement type, highway system, etc). Flexible pavement descriptors: district number, functional classifica-

tion, type of pavement, rural/urban indicator, low/high traffic intensity, estimated time between overlays for distressed pavements, option to use or not use built-in regression models for the parameters of Texas performance equations, minimum overlay thickness for distressed pavements in POTTS (Pavements Older than Terminal Serviceability), desired performance level (low, moderate, high), number of years to overlay mileage in POTTS, and time between seal coats. Also, future mileage added as a result of construction and material code and thickness for each layer

Rigid Pavement Data: lane width, composite support value, type of aggregate (siliceous river gravel or lime stone), modulus of concrete, district number, section description, and material code and thickness for each layer

Mileage Age Distribution: number of years for which lane-mile data are provided, salvage value information, loss factor for pavements in POTTS, mileage by age, material value of existing pavement at the beginning of the analysis period, and rate of loss of value for each pavement age

Truck Information: number of truck types, number of truck types added during analysis period, percent of each truck type which is shifted as a result of a change in axle load limits, AASHTO truck type notation, number of single, tandem, tridem, and steering axles per truck by truck type, truck data by each year (percent of each truck type as a percentage of all vehicles, and percent of all trucks as a percentage of all vehicles), and load limits and load distributions (weight limits, steering weight, axle load distribution for single and tandem, gross vehicle weight and empty vehicle weight distributions)

Performance Data: PSI at initial construction, terminal PSI, PSI after overlay, overlay design life, and average age at terminal PSI

Overlay Data: type of cost unit for asphalt concrete, type of cost unit for base, percent of paved shoulders, average paved shoulder width per lane, average granular shoulder width per lane, cost of AC, cost of granular material, density of compacted AC, density of compacted granular material or turf material, and cost of seal coat per lane mile

Maintenance Data: accelerated or not accelerated routine maintenance indicator, cost data for flexible pavement maintenance: patching, crack sealing, base and surface repair, and cost data for rigid pavement maintenance: cost of failure per lane mile, number of failures at the time of survey, date of survey condition, initial date of planning.

Old Pavement Data: option of process of pavements in POTTS (1: keep them in POTTS, 2: change percent of POTTS to some new target value at end of the analysis period, 3: change POTTS size depending on projected overlay funding, or 4: overlay POTTS in a given time period, then re-age them), funding operating switch (funding under proposed limits is set to funding under present limits or it is not), maintenance cost for these sections, target fraction of POTTS in percent of total lane-miles, percent of total lane miles not expected to be overlaid in the analysis period, percent inflation for projected overlay funding, and annual projected overlay funds

Output Options: (1) provide maintenance and rehabilitation cost differences and cost ratios between proposed and present legal limits, (2) provide all the information

Option 1 plus performance tables, POTTS tables, and summary cost tables, (3) provide all the information of Option 2 plus summary payload and 18-kip ESAL information, and (4) provide all the information of Option 3 plus a listing of the shifted weight distributions resulting from application of the shifting procedure.

Other data such as the survivor parameters were not included in the input data set because they were already included in the source code of the RENU2 program.

Analysis

An exhaustive analysis of the above data showed that some input variables could be dropped from the input data set. The analysis consisted of ascertaining that each input variable was necessary to get the results that the Texas State Department of Highways and Public Transportation (SDHPT) wanted from the cost model. From conversations with technical personnel at SDHPT it was established that:

1. In the old pavement data section, only the third option of process of pavements in POTTS was needed. The other options and the input variables related to them should be dropped.

2. In the output option section, only part of the first option was important. What SDHPT needs are the values of the rehabilitation and maintenance costs for the years in a planning horizon as well as the number of miles to rehabilitate each year.

3. Routine maintenance should not be accelerated (Maintenance data section.

4. The built-in regression models for the parameters of Texas performance equations (Flexible pavement data section) should be discarded.

   The remaining data can be grouped into the following categories: basic run

parameters, pavement design parameters, traffic-related data, unit rehabilitation and maintenance cost parameters, and performance and survival parameters .

Under RENU2 all those data were collected by the user and supplied to the computer manually. As a result of the analysis the following organization of the input data was identified:

1. Data corresponding to the pavement design can be extracted from an existing road data base available at the Texas State Department of Highways and Public Transportation at Austin. The data base consists of the files RIFILE (road inventory data file) and RL1FILE (road life data file). These files are described in detail later.

2. Data corresponding to the traffic on the pavement section can be extracted from an existing traffic data base available at the Texas State Department of Highways and Public Transportation at Austin. Such data base consists of the files WIMOUT85 (weighing-in-motion data file) and VEHICLE.CLASS.1985 (vehicle count and classification data file). Such files are described in detail later.

3. Data corresponding to rehabilitation and maintenance costs can be stored in a separate permanent file due to the semi-permanent characteristic of these cost data; besides, as a result of the climatic decomposition, it was possible to have different cost figures for each climatic region, justifying the creation of a separate file to store all those figures.

4. Data corresponding to survivor parameters can also be stored in a separate file. This is more efficient because when changes on the parameters are needed, the source code of the program is not changed; just the values in the permanent file are changed.

5. Basic run parameters might be supplied by the user; special forms would be

provided to make this task convenient to the user.

6.2 NEW DATA INPUT PROCEDURE

The design of the automated input process is summarized in Fig. 11. The system of automation of data input procedure for the RENU3 model is a set of software programs and files whose objective is to generate a final input file for the model according to specifications given by the user. The relationship between programs and files is illustrated by the diagram in Fig. 12.

The implementation of points 1, 2, and 5 of the analysis is fully described in the following section which corresponds to the documentation of the automated input procedure Implementation of point 3 is achieved through estimating cost figures per climatic region and storing them in a separate permanent file called COSTPAR. The process used is described in Section 6.4, Estimation of Cost Parameters per Climatic Region. For the implementation of point 4, the survivor parameters per climatic region calculated in Chapter 4 (see Tables 10, 11, 13, and 14) are stored in a separate permanent file called SURVPAR. The configuration of this file looks exactly the same as if the Tables 10, 11, 13, and 14 were joined together in that order and including headings and blank lines. This file will be used only in the final run of the RENU3 model. The program will be modified to read the survivor parameters (which were part of the source code in RENU2) from the file SURVPAR (see Section 7.2).
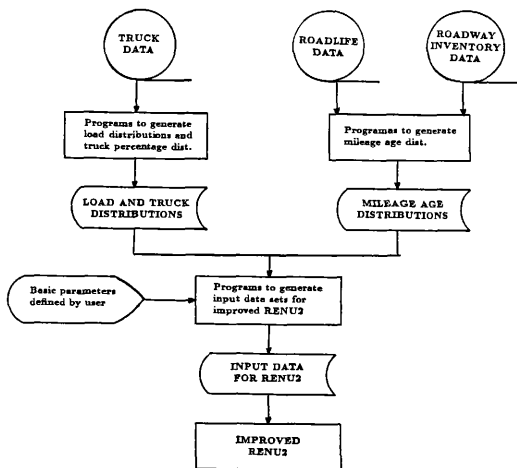
Fig. 11 Proposed Design for Automated Data Input Procedure
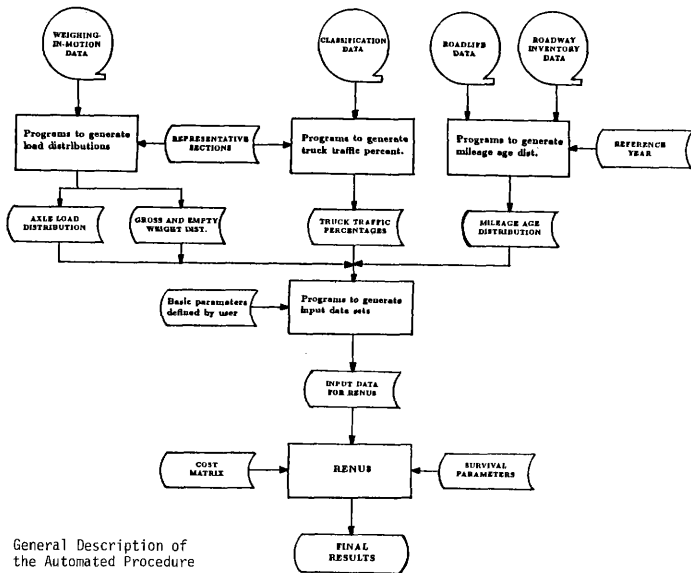
Fig. 12 General Description of
the Automated Procedure

71

6.3 DOCUMENTATION

The purpose of documentation is to assist in the control and use of a computer system, and to provide the communication of specifications and all other necessary information to all people involved with the computer system. The automation of the data input procedure for the RENU3 model has all the characteristics of a regular computer system necessary to provide adequate documentation for the efficient use of such system. Three important areas are considered in the documentation of this system: maintenance documentation, operations documentation, and user documentation. It should be noted that the documentation described in this chapter corresponds to the automated input procedure and not to the RENU3 model itself.

Maintenance Documentation

Adequate maintenance documentation, also referred to as program documentation, is essential for the continued operation and maintenance of the system. The lack of adequate program documentation leads to great efforts in program maintenance in the future; the consequences are even greater if the original programmer does not work with the company that will use the system, as in this case, and employees not involved with the development of the system must maintain it with little or no documentation. For this project, the program documentation manual will contain the following elements:

1. General description of the system

2. Description of files and records

3. Detailed description of each program in the system including flowcharts

These elements are described in detail in Section 1 of Appendix C.

Operation Documentation

The operation manual includes instruction to the computer operator on how to run the system and the programs within the system. The operation documentation manual will contain the following elements:

1. General description of the system
2. Description of runs of main processes including flowcharts and JCL (Job Control Language) programs

This manual is described in Section 2 of Appendix C.

User Documentation

The purpose of the user documentation is to indicate how the system should be used, what information is available in the output, and what information the user should prepare for entry into the system. The user documentation manual will contain the following elements:

1. General description of the system
2. Description of main processes
3. Description of input forms
4. Sample of output

The user manual is described in Section 3 of Appendix C.

6.4 ESTIMATION OF COST PARAMETERS

The mathematical equations used by RENU2 to calculate rehabilitation and maintenance costs are retained by RENU3. However, both programs differ in the following aspects.

1. In RENU3 cost parameters are calculated separately for each climatic region

2. The parameters are calculated by means of a methodology proposed in this section and stored in a permanent file; thus, these data are not included in the main input file but they are read by RENU3 from the cost data file. This will reduce the difficulty of the task of generating the main input file for the user.

6.4.1 Cost Calculation Models

There are three types of costs considered in RENU2:

1. **Rehabilitation cost.** It consists of the cost of asphaltic concrete overlays on the lane-miles failing either by PSI loss or distress types.

2. **Routine maintenance cost.** For flexible pavements routine maintenance consists of pot hole patching, crack sealing and base and surface repair; for rigid pavements it consists of patching, blow-ups, mudjacks and joint sealing.

3. **Preventive maintenance cost.** It consists of the cost of seal coating (for flexible pavements only).

The equations used to calculate each one of these costs [6] are presented below; and the results obtained are presented in Tables 15, 16, 17, and 18.

Rehabilitation

The model used for rehabilitation cost calculation is:

$$TC = C_0 + C_1 V_1 + C_2 V_2 \tag{6.1}$$

where:

$TC =$ rehabilitation cost per lane mile

$V_1 =$ cubic yards of pavement overlay per lane mile

$V_2 =$ cubic yards of unpaved shoulder per lane mile

$C_0 =$ \$ per lane-mile

Table 15   Rehabilitation Costs for Flexible Pavements

Region	C_0 ($/ln-mile)	c_1 ($/yd^3)	c_2 ($/yd^3)
1	5802.62	169.65	103.30
2	2234.97	65.34	39.78
3	1703.45	49.80	30.32
4	4057.68	118.63	72.23
5	5525.20	161.53	98.36

Table 16   Routine Maintenance Costs for Flexible Pavements

Region	Patching[*] ($/yd^2)	Crack-Sealing ($/ft.)	Surface Repair ($/yd^3)
1	58.31	0.19	37.64
2	22.46	0.07	14.50
3	17.12	0.06	11.05
4	40.78	0.13	26.35
5	55.52	0.18	35.84

([*] an average thickness of 4" is assumed)

Table 17   Cost Parameters for Flexible Pavements

	REGION				
	1	2	3	4	5
Traffic ($/ADT)	0.48	0.19	0.14	0.34	0.46
Area ($/yd^2)	0.91	0.35	0.27	0.64	0.87

Table 18   Cost Parameters for Rigid Pavements

REGION	REHABILITATION		MAINTENANCE
	$/Lane Mile	$/yd^3	$/Lane Mile-Failure
A	4344	127	1124.00
B	3147	92	743.00

$C_1 =$ \$ per cubic yard of paved section

$C_2 =$ \$ per cubic yard of unpaved shoulder.

For the calculation of the values of the parameters in Equation 6.1 for flexible pavements, the least-squares regression technique was used. The general form of the regression model is the same of Equation 6.1. The data needed for applying the regression technique were collected from 71 rehabilitation projects on flexible pavements in the entire state. Such data were available at the Texas S.D.H.P.T. at Austin. To find the value of each parameter for each climatic region, the 71 projects were classified into 5 groups according to the region they were located. Then, the least-squares technique was applied to the data from the projects in each region giving as results the figures shown in Table 15.

For rigid pavements, as it is usual in the real world, it was assumed that the overlays made on rigid pavements were flexible overlays. Therefore, the same model and parameters found for flexible overlays are used in the calculation of rehabilitation cost for rigid pavements. For parameters C_0 and C_1 of Equation 6.1 for each "rigid" region (regions A and B), an average of the parameters corresponding to the "flexible" regions included in the "rigid" region was calculated. (region A includes regions 1, 3 and 5; and region B includes regions 2 and 4). Parameter C_0 was dropped of the rigid model because there is not distinction between paved and unpaved shoulders in rigid pavements. Values obtained for parameters C_0 and C_1 for both regions A and B are shown in Table 18 (middle column).

Routine Maintenance

Flexible pavements

Routine maintenance costs were determined from the EAROMAR (Economic Analysis of Roadway Occupancy for Maintenance and Rehabilitation) model, mod-

ified for conditions in Texas [6]. The model is formulated as:

$$C_t = \frac{110C_1 + 1000C_2 + 5C_3}{1 + e^{-(t-10)/1.16}} \qquad (6.2)$$

where:

$C_t =$ maintenance cost in year t per lane mile

$C_1 =$ \$ per square yard of bituminous skin patching

$C_2 =$ \$ per linear foot of crack sealing

$C_3 =$ \$ per cubic yard of bituminous base and surface repair.

For the calculation of values of the parameters in Equation 6.2, statewide es-

timates for such parameters where obtained from the Texas S.D.H.P.T.. Such esti-

mates are: $C_1 = 42.60$, $C_2 = 0.135$, and $C_3 = 27.50$. The criterion used to adjust

these estimates for each region was the proportion of average daily vehicle miles of

the region to the total of the state. The values obtained from such transformation

are shown in Table 16.

Rigid pavements

Routine maintenance costs for rigid pavements are calculated using a method-

ology proposed in [6]. Such methodology is based on the following model:

$$C_t = FAIL_t * UCPF * 0.50 \qquad (6.3)$$

where:

$C_t =$ maintenance cost in year t per lane mile

$UCPF =$ \$ per lane-mile failure, and $FAIL_t$ is defined by

$$FAIL_t = -.381 - .4272X_1 + .018864t^2 + .5532X_2(t - X_1)$$

$$+.0005928tX_3 + X_4 \qquad (6.4)$$

where:

$X_1 =$ date of survey condition (years)

$X_2 =$ number of miles at the time of survey

$X_3 =$ district temperature constant

$X_4 =$ -5.850+1.1856t if type of aggregate is siliceous, 0 otherwise.

The parameter $UCPF$ of Equation 6.3 was calculated for each of both regions A and B from statewide estimates for such parameters, given in [4]. Those estimates were adjusted for each region using the proportion of average daily vehicle miles of the region to the total of the state. The values obtained are shown in Table 18 (right column).

Preventive Maintenance

Flexible pavements

The model used for preventive maintenance cost calculation is:

$$C_s = C_1 ADT + C_2 TSY \qquad (6.5)$$

where:

$C_s =$ total cost of seal coating

$C_1 =$ unit cost contribution from traffic

$ADT =$ average daily traffic

$C_2 =$ $ per square yard of seal coating

$TSY =$ total square yards to coat.

For the calculation of values of the parameters in Equation 6.5, the least-square regression technique was used. The general form of the regression model is the same of Equation 6.5. The data needed for the regression analysis were collected from 565 seal coating projects distributed across the state of Texas. Such data were available at the Texas S.D.H.P.T at Austin. The 565 projects were located in the

corresponding region and the least-squares technique was applied to the data form the projects in each particular region in order to get values of parameters per region. The results are shown in Table 17.

6.4.2 Cost Data File

The cost parameters calculated in the previous section (see Tables 15, 16, 17 and 18) were stored in a permanent disk file called COSTPAR. The configuration of this file is exactly the same as that one of the tables 15, 16, 17, and 18 joined together in the same order and including headings and blank lines. The RENU3 program was modified to read the cost data (which were part of the input data file before) from the file COSTPAR (see Section 7.2).

CHAPTER VII

APPLICATION OF THE METHODOLOGY

An application of the improved RENU2 (or RENU3) model using the automated data input procedure is presented in this Chapter. In Sections 7.1 and 7.2 the new methodology (automated input procedure and RENU3) is applied to the Region 4 of the Texas pavement network to predict the number of miles to rehabilitate in the next 18 years, as well as, the cost of such rehabilitation. Also, the cost of routine and preventive maintenance for that planning horizon will be calculated. The information obtained from the entire process will be very valuable to the budgetary planning process for the Texas road network. In Section 7.2 an analysis of the results is presented. In Section 7.4, another important application is outlined.

7.1 APPLICATION OF THE AUTOMATED INPUT PROCEDURE

The first step in the new methodology was the application of the automated input procedure. The basic parameters used for the application of this procedure were supplied by the Texas State Department of Highways and Public Transportation. They are the following:

       Analysis Period: 18 years

       Annual growth rate in ESALs: 3.35%

       Annual interest rate: 4.0%

       Surfacing cost index: 12.0%

       Maintenance material cost index: 9.0%

       Legal load limits:

         Gross vehicle weight: 80 kips

Single axle load: 20 kips

Tandem axle load: 34 kips

Tridem axle load: 56 kips

Types of trucks considered: 2A, 2D, 3A, 3-S2

Steering axle load limits: 13, 13, 12 and 8 kips, respectively

Performance data:

Distress critical performance level: 1

Asymptotic serviceability index: 3.00

Asymptotic serviceability index for overlay: 3.00

Terminal serviceability index: 3.05

Serviceability index after overlay: 4.70

Number of failures at the time of survey: 3.00 (only for rigid pavements)

Date of survey condition: 1.80 years

Initial date of planning: 9.81 years

For flexible pavements, as said in the User manual, one form F-1 must be filled out for each district. Sample of the first F-1 form filled out for this run is shown in Fig. 13. The basic parameters used for every scenario in each district are the following:

Minimum overlay thickness: 1.00 inch

Maximum overlay thickness: 6.00 inches

Number of years to overlay mileage in POTTS:

- when distress types are the failure mode: 6 years

- when PSI loss is the failure mode: 10 years

Estimated time between seal coats: 10 years

Percent of paved shoulder: 95% for Interstate and State/US, and 5% for FM roads

Region: [04]   FORM F-1: Basic Input Parameters for RENU3
   1   2   - FLEXIBLE PAVEMENTS -

__General Parameters__

NYAP [_18_]   AGR [_3·35_]   RTINT [_4·0_]   XHCIO [_0·12_]   XHCIM [_0·09_]
 1   5   6   10   11   15   16   20   21   25

LOAD LIMITS:

	GVWL	SAL	TAL	TRAL
Present	80.00	20.00	34·00	56·00
Future	120·00	22·40	36·00	56·00
	1 8 9	16 17	24 25	32

TRUCKS CONSIDERED

Type	1	2	3	4	5	6	7	8	9	10
Option	1	1	1	1						
Present Limit	13.00	13.00	12.00	8.00						
Future Limit	16·00	16·00	16·00	16·00						
	1 6	16	24	32	40	48	56	64	72	80

Calculate costs for future Limits? (Load shift procedure): [00]
                                                    1   2
District: [13]
      1   2

			OVERLAYS AND SEAL COATS						ROAD DESCRIPTORS				PERFORMANCE						
1 2	No.	COMBINATION	4 5 XMNDTK	10 14 XMXDTK	16 17 NDEL	18 21 JYR	23 25 IYR	27 32 WLANE	34 38 PPVDSH	40 44 WPSH	46 50 WCSH	52 52 IACR	54 PF	56 PFD	60 64 PTERM	66 70 PIDV	72 76	78 DMIT
	1	1 1 1 1	1.00	6.00	06	010	010			4.75	0·25	1	3.00	3.00	3.05	4·70		
36 Lines	2	1 1 1 2																
	3	1 1 2 1	.															
	:	:																
	:	:																
	36 00	3 3 2 2																

Fig. 13   Sample of an F-1 Form

Average paved shoulder width per lane: 4.75 feets

Average granular shoulder width per lane: 0.25 feets

For rigid pavements, only one form F-2 must be filled out for the entire state. Sample of the form filled out for this run is shown in Fig. 14. The basic parameters used for rigid pavements in every district are:

Minimum overlay thickness: 1.00 inch

Maximum overlay thickness: 6.00 inches

Composite support value (K): 250 pci

Type of aggregate: 2

Materials:

CRC, layer thickness: 8.00 inches

LTB, layer thickness: 6.00 inches

According to the Operation manual (see Appendix C), runs of the following processes were conducted in order to get the complete input data set to run RENU3 for the entire state:

Process 1: Generation of rigid and flexible mileage age distributions (one run)

Process 2: Generation of truck traffic percentages (one run)

Process 3: Generation of axle load and weight distributions (one run)

Process 4: Generation of input file for flexible pavements (five runs, one for each climatic region)

process 5: Generation of input file for rigid pavements (one run).

These runs were conducted in a mainframe system AMDAHL-5805860 at Texas A&M University.

FORM F-2: Basic Input Parameters for RENU3
— RIGID PAVEMENTS —

General Parameters

NYAP	18	AGR	2.00	RTINT	0.02	XHCIO	0.05	XHCIM	0.00
1	5		6	10	11	15	16	20	21	25

LOAD LIMITS:

	GVWL	SAL	TAL	TRAL
Present	80.00	20.00	34.00	56.00
Future	120.00	22.40	36.00	56.00
	1 8	9 16	17 24	25 32

TRUCKS CONSIDERED

Type	1	2	3	4	5	6	7	8	9	10
Option	/	/	/	/						
Present Limit	13.00	13.00	12.00	8.00						
Future Limit	16.00	16.00	16.00	16.00						
	1 8	16	24	32	40	48 56	64	72	80	

Calculate costs for future Limits? (Load shift procedure): 00
| | 1 | 2 |

DISS	3.00	DCON	1.80	DIN	9.81
1	10	11	20	21	25

1 2 DISTRICT	4 OVERLAYS				PAVEMENT DESCRIPTORS				MATERIALS										PERFORMANCE				
									LAYER 1			LAYER 2			LAYER 3								
	4 8 XUNOTIK	10 14 XUUXOTIK	16 PT	18 23 XX	25 29 AGG	31 40 E	42 44 CODE	46 50 TH	52 56 ST	58 60 CODE	62 66 TH	68 72 ST	3 5 CODE	8 11 TH	15 ST	17 IACR	19 23 PF	25 29 PFO	31 35 PTERM	37 41 PIOV
01	1.00	6.00	1	250	2.00	42000	CRC	8.00		LTB	6.00					1	5.00	5.00	5.05	4.70
02			.																	
03																				
:																				
25 00																				

{ 24 Lines

Fig. 14 Sample of an F-2 Form

7.2 APPLICATION OF THE RENU3 MODEL

After the input data files for flexible and rigid pavements were generated, a run of the pavement rehabilitation and maintenance cost model with the improvements described in the previous chapters, and for each input data file was performed. Two runs were performed, one for flexible pavements in Region 4, and another one for rigid pavements in the entire state.

A flowchart describing the run of each process is shown in Figs. 15 and 16. Again, for these processes, a mainframe system AMDHAL-5805860 available at Texas A&M University was used.

The final results from these processes are showed in Tables 19 and 20. Table 19 refers to the results for Region 4, and Table 20 refers to the results for the rigid pavements in the state. The output includes rehabilitation mileage (NPOT stands for mileage mileage out of POTTS, and POT stands for mileage in POTTS), cost of rehabilitation, cost of routine maintenance, and cost of preventive maintenance for each year in the 18-year planning horizon. Also, the net present values of costs of rehabilitation, routine maintenance, and preventive maintenance over the 18-year period are given. It should be noted that no preventive maintenance was considered for rigid pavements.

7.3 ANALYSIS OF RESULTS

From the results obtained, the following statistic data shown in Table 21 can be generated. These results could be generated for the flexible pavements in the other 4 regions to have a total for the entire state.

These final results were presented to the Texas S.D.H.P.T. as the result of a research project conducted at the Texas Transportation Institute by the author of
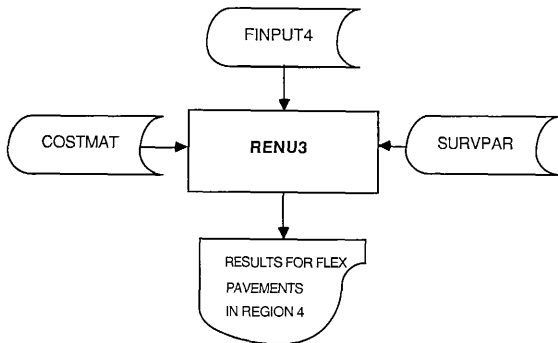
Fig. 15   Flowchart of Run of RENU3 for Flexible Pavements in Region 4
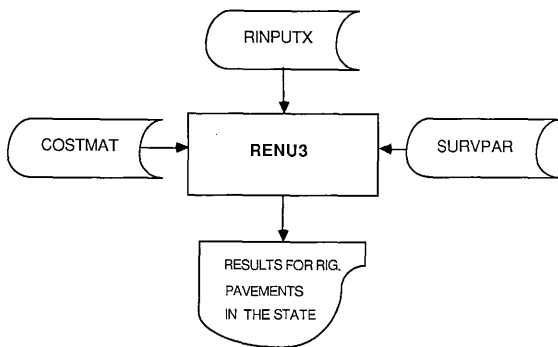
Fig. 16   Flowchart of Run of RENU3 for Rigid Pavements in the State

Table 19. Results of RENU3 for Flexible Pavements in Reg. 4

```
                          COST SUMMARY
                          PRESENT LIMITS
                          REGION :      4


      YEAR          ROUT MAINT          REHAB MILES            REHAB           PREV MAINT
                     COST ($)         NPOT      POT          COST ($)          COST ($)

        1          56872336.00       178.25   1108.09       73198800.00         36444.00
        2          64330800.00       187.44   1108.09       82406160.00         39730.00
        3          72724464.00       191.49   1108.09       92504080.00         43301.00
        4          81970272.00       194.62   1108.09      103785552.00         47205.00
        5          91829808.00       197.39   1108.09      116418896.00         51448.00
        6         101944384.00       199.99   1108.09      130577472.00         56076.00
        7         112146368.00       202.51   1108.09      146451520.00         61122.00
        8         122682480.00       205.00   1108.09      164252208.00         66627.00
        9         134097184.00       207.48   1108.09      184215728.00         72624.00
       10         147104256.00       209.98   1108.09      206606624.00         79156.00
       11         162441680.00       212.50     0.00        27152848.00         86282.00
       12         180586416.00       208.32     0.00        29813376.00         94043.00
       13         201659856.00       206.77     0.00        33141792.00        102514.00
       14         225654864.00       205.86     0.00        36956272.00        111735.00
       15         252626480.00       205.32     0.00        41282624.00        121789.00
       16         282718464.00       205.04     0.00        46172304.00        132752.00
       17         316103680.00       204.94     0.00        51689232.00        144701.00
       18         352882432.00       205.00 ·   0.00        57908720.00        157719.00


TOTAL                              3627.88 11080.91
PRESENT COSTS    2960375040.00     ----------------    1624532740.00       1505268.00
TOTAL LANE MILES                      14708.79
```

Table 20. Results of RENU3 for Rigid Pavements in the State

		COST SUMMARY PRESENT LIMITS RIGID PAVEMENTS			
YEAR	ROUT MAINT COST ($)	REHAB MILES NPOT	POT	REHAB COST ($)	PREV MAINT COST ($)
1	345404416.00	2.20	0.00	57847.00	0.00
2	385952512.00	2.41	0.00	64924.00	0.00
3	429079808.00	2.63	0.00	72624.00	0.00
4	475334912.00	2.86	0.00	80977.00	0.00
5	505124096.00	3.11	0.00	90006.00	0.00
6	559919616.00	3.36	0.00	99775.00	0.00
7	619368448.00	3.63	0.00	110290.00	0.00
8	683818240.00	3.91	0.00	121598.00	0.00
9	753642240.00	4.21	0.00	133759.00	0.00
10	829016064.00	4.51	0.00	146777.00	0.00
11	910759424.00	4.83	0.00	160714.00	0.00
12	999146752.00	5.16	0.00	175605.00	0.00
13	1094659930.00	5.50	0.00	191465.00	0.00
14	1197813500.00	5.85	0.00	208405.00	0.00
15	1309157890.00	6.22	0.00	226403.00	0.00
16	1429281020.00	6.59	0.00	245513.00	0.00
17	1558809600.00	6.98	0.00	265788.00	0.00
18	1698409980.00	7.38	0.00	287279.00	0.00

TOTAL		81.35	0.00		
PRESENT COSTS	15784673300.00			2739769.00	0.00
TOTAL LANE MILES		81.35			

Table 21 Summary Results of Sample Run of RENU3

	Flexible Region 4	Rigid State
Total number of lane miles	26,200	23,600
Total number of miles to rehabilitate	14,709	82
Ave. number of miles to rehabilitate per year	817	4.5
Percentage of miles to rehabilitate (per year)	3.11%	0.02%
Average rehabilitation cost per year	90,251,816	152,210
Rehabilitation cost per mile per year	110,467	33,824
Average routine maintenance cost per year	164.465,270	876,926,270
Average preventive maint. cost per year	83,626	-
Average total cost per year	254,800,712	876,960,094

this thesis, Garcia-Diaz and Afiesimama [7]. S.D.H.P.T. will use those results as a main tool in the rehabilitation and maintenance planning processes for the Texas road network.

7.4 OTHER APPLICATIONS

A very important application of the pavement rehabilitation and maintenance cost model is the analysis of the impact of changing current legal axle load limits. For this, the model uses a load shifting function that modifies the original axle load distributions to reflect a change in such limits. This function establishes the most likely truck traffic distribution that will occur on a highway system after changing the legal axle load limits. This function was not modified but with the improvements on the model, its usefulness will be more evident. With the new model a complete study of the impact of changing such limits in the entire state will be possible. It will be also possible to estimate the total increase on the cost of maintaining the state road network if those limits were changed.

An application of this feature is not presented here since the analysis of changes in legal load limits is beyond the scope of this thesis.

CHAPTER VIII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 SUMMARY

The main focus of interest in this thesis was the improvement of the efficiency and accuracy of the process of estimating rehabilitation/maintenance costs and measuring the impact of changing legal truck axle load limits on those costs. The improved procedure is called RENU3 and retainS all key elements of its predecessor, RENU2, such as:

1. Survivor curves for flexible pavements, for different performance levels and considering both types of failures: PSI loss and distress types.

2. Capability to evaluate the effects of changing legal axle load limits on pavement conditions and rehabilitation/maintenance costs.

3. Pavement age adjustment function that updates the age distribution of the pavement when it is rehabilitated.

4. Cost estimating function that computes costs for rehabilitation and both routine and preventive maintenance in a given planning horizon.

5. Consideration of new mileage added to the system in the future.

Beyond these features, the modified procedure provides enhancement in the following seven areas to improve the efficiency of the RENU2 model. They include:

1. Division of the pavement network into five climatically homogeneous areas.

2. Survivor curves for different performance levels per climatic region and for both rigid and flexible pavements.

3. System sensitivity to ten different types of vehicles and number of trips (traffic volume) for each type of vehicle.

4. A fully automated data input procedure which consists of several computer programs to extract information from other data bases and transform them into the RENU3 input format. This procedure is fully documented.

5. Basic rehabilitation/maintenance cost parameters per climatic area.

6. A simpler and efficient procedure to calculate probabilities of failure based on survivor curves.

7. A better program structure which makes for easier understanding and better system maintenance.

8.2 CONCLUSIONS

RENU3 introduces a good number of significant enhancements to the basic methodology for estimating pavement rehabilitation and maintenance costs in the state of Texas. With the enhanced system, the Texas S.D.H.P.T. will be able to make a very realistic run for the entire state in a very efficient way. The improved accuracy and efficiency of the program should prove valuable to the budgetary planning process for the state road network.

Using statistically sound clustering procedures, the Texas flexible pavement network was demarcated into five climatically homogeneous regions. These regions were further grouped into two rigid pavement sections. Such clustering facilitates the definition of pavement performance and survival parameters along regional lines so that the subsequent evaluation of damage intervention costs reflect varying pavement environmental conditions. This decomposition gave also the basis to analyze rehabilitation and maintenance costs per climatic region, providing a methodology to calculate such costs per region and making the final cost figures more accurate and reliable.

The complete automation of the data input procedures significantly improved

the user-friendliness of the model. With this improvement the model will be more frequently used and will become an important tool for the Texas S.D.H.P.T. in the process of making decisions related to the rehabilitation and maintenance of the entire Texas road network. Other enhancements such as the implementation of sensitivity to traffic volume and the structuring of the program also improve the efficiency of the model.

Finally, with the improvements, RENU3 has the capability to analyze and report data of rehabilitation and maintenance at either state, region, district, or lower levels, and the capability to analyze the impact of changing legal axle load limits at those levels as well.

8.3 LIMITATIONS

Some limitations were found in the development of this theses, all of them related to the gathering of data. Such limitations are:

1. non-availability of enough historical cost data for rehabilitation and routine maintenance of flexible pavements. Due to this lack of information, a model for the routine maintenance cost calculation could not be generated.

2. non-availability of historical cost data for rehabilitation and maintenance of rigid pavements.

3. non-availability of real historical performance data for rigid pavements at all.

4. non-availability of enough classification and weighing-in-motion stations. This is necessary to the assignment of representative stations. For instance, there are only 10 WIM station across the entire state to assign to the many existing scenarios.

8.4 RECOMMENDATIONS FOR FUTURE RESEARCH

Results obtained in this thesis may be improved by the further research into a number of related areas.

First, survivor curves should be developed for rigid pavements using the same methodology as for flexible pavements. To implement this, it is necessary to design a procedure for gathering data in different test rigid pavement sections across the state and for several time periods.

Secondly the procedures for gathering performance, weight, and classification data need to be restructured. Test sections should be re-assigned so that there exist several test sections for any combination of factors such as critical performance levels, region, traffic volume, type of pavement, highway system, etc. Also, stations should be re-assigned so that at least one representative station exist for every combination of the mentioned factors.

Finally, a study of possible integration of RENU3 with other traffic/road cost systems such as PES (Pavement Evaluation System) and others, is recommended to increase the scope of application of RENU3. This way, at some future time the implementation of a fully integrated cost system will be possible.

REFERENCES

[1] Anderberg, M. R., *Cluster Analysis for Applications,* Academic Press, New York (1973).

[2] Austin Research Engineers, Inc., "Effects of Changes in Legal Load Limits on Pavement Costs," Vols. 1 and 2, FHWA Reports 79-73 and 79-74 (July 1978).

[3] Derr, N. and Nagle, R, "An examination of the effect of six types of error perturbation on fifteen clustering algorithms," *Psychometrika,* Vol. 45, No. 3 (September, 1980).

[4] Garcia-Diaz, A., "Documentation of the Modified Computerized Procedure RENU2 to Estimate Pavement Network Rehabilitation and Maintenance Costs," Research Report 992-1, Texas Transportation Institute, Texas A&M University System, College Station, TX (March 1983).

[5] Garcia-Diaz, A., Riggins, M., and Liu. J., "Development of Performance Equations and Survivor Curves for Flexible Pavements," Research Report 284-5, Texas Transportation Institute, Texas A&M University System, College Station, TX (March 1984).

[6] Garcia-Diaz, A., Lytton, R., and Burke, D., "Evaluation of Computer Programs NULOAD and REHAB," Vols. 1, 2, 3, 4, and 5F, Research Report 312-1, Texas State Department of Highways and Public Transportation, Austin, TX (September 1980).

[7] Garcia-Diaz, A., Afiesimama B., and Garcia-Diaz, J. C., "Development and Implementation of a Computerized Procedure for Estimating Pavement Rehabilitation and Maintenance Expenditures," Research Report 129-1, Texas Transportation Institute, College Station, TX (December 1986).

[8] Lee, E. T., *Statistical Methods for Survival Data Analysis,* Lifetime Learning

Publications, Belmont, CA (1980).

[9] Litton, R. L., Scullion, T., Garrett, B. D., and Michalak, C. M., "Effects of Truck Weights on Pavement Deterioration," Research Report RF 4087-2, Texas Transportation Institute, College Station, TX (June 1981).

[10] Texas State Department of Highways and Public Transportation, "Guide to the Highway Rehabilitation Forecasting Model," Texas State Department of Highways and Public Transportation, Austin, TX (1976).

[11] Romesburg, H. C. *Cluster Analysis for Researchers,* Wadsworth, Inc., Belmont, CA (1984).

[12] SAS Institute, *SAS User's Guide: Statistics*, SAS Institute, Cary, NC (1982)

[13] Stark, P. A., *Introduction to Numerical Methods,* Macmillan Publishing Co., Inc., New York (1970).

[14] Texas State Department of Highways and Public Transportation, "Flexible Pavement Deflection Equation Using Elastic Moduli and Field Measurements," Research Report 207-7F, Texas State Department of Highways and Public Transportation, Austin, TX (August 1979)

[15] American Association of State Highway and Transportation Officials, *AASHTO Interim Guide for Design of Pavement Structures*, Washington, DC (1972)

APPENDIX A

DEFINITION OF CLIMATIC TERMS

- **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 change in state of moisture from a liquid to vapor. Unit: inches.

- **Potential Evapotranspiration**. Is the amount of moisture than 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.

- **Thorntwaite Index**. Thorntwaite 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. Such formula is:

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

APPENDIX B

CLUSTERING SAMPLE

SAS

FASTCLUS PROCEDURE

CLUSTER SUMMARY

CLUSTER NUMBER	FREQUENCY	RMS STD DEVIATION	MAXIMUM DISTANCE FROM SEED TO OBSERVATION	NEAREST CLUSTER	CENTROID DISTANCE
1	50	6.3749	23.7679	4	25.0217
2	50	6.3992	35.5496	1	27.9525
3	40	6.7267	35.6811	2	37.9146
4	64	8.2342	29.4826	1	25.0217
5	50	8.5430	36.9385	1	46.4156

STATISTICS FOR VARIABLES

VARIABLE	TOTAL STD	WITHIN STD	R-SQUARED	RSQ/(1-RSQ)
TI	24.223787	10.842533	0.802823	4.071589
AVT	3.986352	1.740819	0.812313	4.328010
FT	25.440983	9.138691	0.873002	6.874120
R	11.307891	5.363208	0.778610	3.516924
OVER-ALL	18.559348	7.630110	0.833653	8.011530

PSEUDO F STATISTIC = 311.97
APPROXIMATE EXPECTED OVER-ALL R-SQUARED = 0.72544
CUBIC CLUSTERING CRITERION = 14.353
WARNING: THE TWO ABOVE VALUES ARE INVALID FOR CORRELATED VARIABLES

CLUSTER MEANS

CLUSTER	TI	AVT	FT	R
1	-10.5495	64.6582	35.4879	31.2404
2	-31.5472	63.4680	48.8748	18.7055
3	-19.6073	58.2700	84.5726	18.5649
4	-15.9550	69.5672	11.5598	31.7039
5	32.4851	65.3661	27.8546	46.8901

CLUSTER STANDARD DEVIATIONS

CLUSTER	TI	AVT	FT	R
1	9.1112	1.4262	7.4444	4.7000
2	7.8453	1.3304	8.6553	5.0562
3	6.1290	1.7673	11.5235	2.7407
4	13.1999	2.0203	6.0205	7.5262
5	14.1038	1.9651	11.9075	4.4393

NOTE: COPYRIGHT (C) 1984 SAS INSTITUTE INC., CARY, N.C. 27511, U.S.A.
NOTE: THE JOB CLUSTER HAS BEEN RUN UNDER RELEASE 5.15 OF SAS AT TEXAS A&M UNIVERSITY (01452001).

NOTE: CPUID   VERSION = 82 SERIAL = 000261 MODEL = 0580 .

NOTE: SAS OPTIONS SPECIFIED ARE:
      SORT=4

```
1             OPTIONS NODATE,NONUMBER;
2             DATA CLIMA;
3                INFILE FT;
4                INPUT DN $ 1-2 CN $ 3-5 @12 TI 8.3 @64 (PE1-PE12) (+2 8.3 +8)
5                     @280 (R1-R12) (+2 8.3 +8) @1576 (FT1-FT12) (+2 8.3 +8)
6                     @2656 (AVT1-AVT12) (+2 8.3 +8) @496 (MC1-MC12) (+2 8.3 +8)
6                     @928 (AE1-AE12) (+2 8.3 +8) @1782 (WFT1-WFT12) (+2 8.3 +8)
8                     @2008 (DP1-DP12) (+2 8.3 +8) @2224 (MDCP1-MDCP12) (+2 8.3 +8)
9                     @2440 (MMT1-MMT12) (+2 8.3 +8);
10                   R=SUM(OF R4-R8);
11                   FT=SUM(OF FT1-FT12);
12                AVT1=MEAM(AVT1,AVT2,AVT11,AVT12);
13                AVT2=MEAN(AVT6,AVT7);
14                N1C=MIN(OF MC1-MC12);
15                M2C=MAX(OF MC1-MC12);
16                   AE=SUM(OF AE1-AE12);
17                   WFT=SUM(OF WFT1-WFT12);
18                   DP=SUM(OF DP1-DP12);
19                   MMT=MAX(OF MMT1-MMT12);
20                   PE=MEAN(PE1-PE12); MDCP=MEAN(MDCP1-MDCP12);
21                OUTPUT; KEEP DN CN TI AVT1 AVT2 FT R N1C M2C AE WFT DP MMT PE
22                   MDCP;
```

NOTE: INFILE FT IS:
      DSNAME=USR.W151.NR.FROMTAPE,
      UNIT=DISK,VOL=SER=USER59,DISP=SHR,
      DCB=(BLKSIZE=2871,LRECL=2871,RECFM=FB)

NOTE: 254 LINES WERE READ FROM INFILE FT.
NOTE: DATA SET WORK.CLIMA HAS 254 OBSERVATIONS AND 15 VARIABLES. 168 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.75 SECONDS AND 184K.

```
23            PROC STANDARD DATA=CLIMA MEAN=-8.99 STD=24.99 OUT=TI;;
```
NOTE: THE DATA SET WORK.TI HAS 254 OBSERVATIONS AND 15 VARIABLES. 168 OBS/TRK.
NOTE: THE PROCEDURE STANDARD USED 0.16 SECONDS AND 216K.

```
24            PROC STANDARD DATA=CLIMA MEAN=49.26 STD=5.37 OUT=AVT;
```
NOTE: THE DATA SET WORK.AVT HAS 254 OBSERVATIONS AND 15 VARIABLES. 168 OBS/TRK.
NOTE: THE PROCEDURE STANDARD USED 0.16 SECONDS AND 216K.

```
25            PROC STANDARD DATA=CLIMA MEAN=38.34 STD=25.44 OUT=FT;
```
NOTE: THE DATA SET WORK.FT HAS 254 OBSERVATIONS AND 15 VARIABLES. 168 OBS/TRK.
NOTE: THE PROCEDURE STANDARD USED 0.16 SECONDS AND 216K.

```
26            PROC STANDARD DATA=CLIMA MEAN=14.29 STD=3.997 OUT=R;
```
NOTE: THE DATA SET WORK.R HAS 254 OBSERVATIONS AND 15 VARIABLES. 168 OBS/TRK.
NOTE: THE PROCEDURE STANDARD USED 0.16 SECONDS AND 216K.

```
27            DATA MATCH;
```

SAS

FASTCLUS PROCEDURE

REPLACE=FULL RADIUS=0 MAXCLUSTERS=5 MAXITER=10 CONVERGE=0.02

INITIAL SEEDS

CLUSTER	TI	AVT	FT	R
1	9.808	59.996	68.106	31.130
2	-46.114	64.847	53.969	10.144
3	-22.019	55.442	106.850	16.738
4	-19.086	71.567	2.600	30.746
5	38.530	68.481	8.512	55.683

MINIMUM DISTANCE BETWEEN INITIAL SEEDS = 53.86

ITERATION CHANGE IN CLUSTER SEEDS

	1	2	3	4	5
1	24.6335	19.8979	19.2636	15.34	21.0849
2	6.25676	1.03634	2.39377	1.53016	0.644792
3	4.11457	1.10627	1.07802	2.53051	0
4	1.22347	0.701946	1.02274	0.972384	0
5	1.32657	0.276974	0.776939	0.355982	0.616215
6	0.885153	0.287377	0.914899	0	0

CLUSTER LISTING

OBS	CN	CLUSTER	DISTANCE FROM SEED	OBS	CN	CLUSTER	DISTANCE FROM SEED
1	001	5	20.71524	24	024	4	14.04556
2	002	2	8.481872	25	025	1	9.561468
3	003	5	21.72686	26	026	4	20.12342
4	004	4	12.11838	27	027	1	7.961301
5	005	1	8.376372	28	028	4	12.31366
6	006	3	4.703081	29	029	4	22.24647
7	007	4	7.114045	30	030	1	11.35433
8	008	4	22.61077	31	031	4	16.60881
9	009	3	18.12934	32	032	5	17.9039
10	010	1	3.325726	33	033	3	2.201726
11	011	4	8.615861	34	034	5	26.85016
12	012	2	16.45268	35	035	3	12.90349
13	013	4	3.786402	36	036	5	18.88378
14	014	1	12.66713	37	037	5	6.789193
15	015	4	1.954408	38	038	2	6.914669
16	016	1	6.786442	39	039	1	16.99133
17	017	2	2.327865	40	040	3	7.018129
18	018	1	6.258111	41	041	2	7.65435
19	019	5	24.36253	42	042	1	8.137394
20	020	5	22.32493	43	043	5	19.06336
21	021	4	23.47569	44	044	3	17.75532
22	022	4	24.8937	45	045	4	24.57477
23	023	3	3.840493	46	046	4	8.174144

102

SAS

FASTCLUS PROCEDURE

OBS	CN	CLUSTER	DISTANCE FROM SEED	OBS	CN	CLUSTER	DISTANCE FROM SEED
47	047	1	5.908912	101	101	5	7.455052
48	048	2	15.79014	102	102	5	30.45699
49	049	5	30.19452	103	103	5	7.583695
50	050	1	6.498654	104	104	3	24.72245
51	051	2	8.096018	105	105	2	11.80107
52	052	2	12.61124	106	106	4	12.04774
53	053	3	8.32184	107	107	3	4.438836
54	054	3	8.603697	108	108	1	23.7679
55	055	2	15.15364	109	109	4	28.74386
56	056	3	18.65368	110	110	1	8.205421
57	057	4	17.99393	111	111	3	6.084167
58	058	2	15.60349	112	112	1	4.977066
59	059	3	3.35206	113	113	5	36.93852
60	060	5	27.22068	114	114	5	18.96684
61	061	1	18.98981	115	115	2	10.65647
62	062	4	8.030951	116	116	2	15.27218
63	063	2	6.982282	117	117	5	16.02764
64	064	4	15.75891	118	118	3	13.15348
65	065	3	3.008248	119	119	2	8.779577
66	066	4	15.28489	120	120	1	8.914499
67	067	4	14.5268	121	121	4	26.93342
68	068	1	12.5639	122	122	5	8.427688
69	069	2	11.17355	123	123	1	16.7107
70	070	1	20.19575	124	124	5	21.21969
71	071	1	12.17634	125	125	4	20.42479
72	072	2	25.54964	126	126	4	10.16436
73	073	1	4.023765	127	127	1	6.937463
74	074	4	14.84813	128	128	2	15.33831
75	075	5	26.83319	129	129	4	2.993109
76	076	4	10.58203	130	130	1	20.68817
77	077	2	5.083746	131	131	1	8.536249
78	078	3	6.890714	132	132	2	9.953143
79	079	3	16.49289	133	133	1	10.15224
80	080	5	27.59635	134	134	2	8.748998
81	081	5	17.97314	135	135	2	11.83831
82	082	5	24.4284	136	136	4	18.63031
83	083	4	10.06536	137	137	4	13.17608
84	084	2	19.9195	138	138	2	8.996406
85	085	5	31.06402	139	139	5	18.71637
86	086	2	15.52314	140	140	3	4.791008
87	087	4	13.08231	141	141	4	12.55232
88	088	2	5.574587	142	142	4	18.525
89	089	4	7.603668	143	143	4	15.88259
90	090	4	3.434453	144	144	4	8.928846
91	091	3	3.671155	145	145	1	21.22974
92	092	5	17.85253	146	146	5	14.63042
93	093	5	4.132434	147	147	1	22.26571
94	094	4	24.82205	148	148	3	9.633687
95	095	4	1.923385	149	149	4	5.090414
96	096	3	1.797683	150	150	1	12.384
97	097	2	10.04766	151	151	3	17.67856
98	098	1	2.807304	152	152	3	14.83041
99	099	3	8.452727	153	153	3	17.63375
100	100	3	16.43736	154	154	4	21.6121

FASTCLUS PROCEDURE

OBS	CN	CLUSTER	DISTANCE FROM SEED		OBS	CN	CLUSTER	DISTANCE FROM SEED
155	155	5	6.913116		209	209	1	14.55087
156	156	2	8.643893		210	210	6	8.150964
157	157	1	12.20393		211	211	3	18.64486
158	158	4	25.2878		212	212	3	8.804403
159	159	4	16.90334		213	213	1	4.305322
160	160	1	11.09286		214	214	4	29.48263
161	161	4	7.47697		215	215	1	11.17336
162	162	4	15.63173		216	216	2	2.675648
163	163	4	5.961116		217	217	2	7.520768
164	164	2	11.52164		218	218	2	11.02559
165	165	2	11.81193		219	219	3	8.72242
166	166	4	7.799383		220	220	1	10.0496
167	167	1	12.34559		221	221	1	13.49914
168	168	2	8.685999		222	222	2	12.52945
169	169	1	10.82621		223	223	3	9.759116
170	170	5	22.52046		224	224	2	14.42641
171	171	3	5.261606		225	225	6	27.38857
172	172	5	2.059362		226	226	2	8.724827
173	173	2	10.43405		227	227	4	2.57279
174	174	5	8.91635		228	228	6	14.91623
175	175	1	17.21949		229	229	6	5.078094
176	176	6	13.11364		230	230	5	13.35704
177	177	2	13.28506		231	231	3	17.41653
178	178	4	10.11913		232	232	4	16.1232
179	179	5	11.59773		233	233	2	28.60186
180	180	3	15.72873		234	234	5	15.82424
181	181	5	16.62061		235	235	4	9.15328
182	182	1	8.601433		236	236	5	24.93161
183	183	6	7.085041		237	237	6	20.70151
184	184	1	5.25727		238	238	2	15.54985
185	185	3	12.65852		239	239	4	18.12948
186	186	2	14.22666		240	240	4	20.63411
187	187	5	8.308413		241	241	4	22.42853
188	188	3	4.07364		242	242	3	10.28253
189	189	3	28.83663		243	243	1	10.82576
190	190	5	11.99586		244	244	1	13.58559
191	191	3	3.336857		245	245	4	16.11045
192	192	2	5.385188		246	246	4	8.35398
193	193	1	13.78471		247	247	4	3.434358
194	194	5	20.25361		248	248	2	15.06198
195	195	2	19.82955		249	249	1	9.379822
196	196	4	11.28079		250	250	3	35.68107
197	197	3	11.14394		251	251	3	6.503899
198	198	1	19.08223		252	252	1	17.45952
199	199	1	9.066244		253	253	4	28.34482
200	200	2	6.503882		254	254	4	17.37437
201	201	5	2.577651					
202	202	5	6.969851					
203	203	5	4.680879					
204	204	5	7.662383					
205	205	4	8.146241					
206	206	1	13.51729					
207	207	2	8.075279					
208	208	2	12.5711					

TEXAS COUNTIES
STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

CO NO	COUNTY NAME	DIST NO	CO NO	COUNTY NAME	DIST NO	CO NO	COUNTY NAME	DIST NO	CO NO	COUNTY NAME	DIST NO
1	ANDERSON	10	65	DONLEY	25	129	KARNES	16	192	REAGAN	7
2	ANDREWS	6	66	KENEDY	21	130	KAUFMAN	18	193	REAL	7
3	ANGELINA	11	67	DUVAL	21	131	KENDALL	14	194	RED RIVER	1
4	ARANSAS	13	68	EASTLAND	23	132	KENT	8	195	REEVES	6
5	ARCHER	3	69	ECTOR	6	133	KERR	14	196	REFUGIO	16
6	ARMSTRONG	4	70	EDWARDS	7	134	KIMBLE	7	197	ROBERTS	4
7	ATASCOSA	15	71	ELLIS	18	135	KING	25	198	ROBERTSON	17
8	AUSTIN	13	72	EL PASO	24	136	KINNEY	7	199	ROCKWALL	18
9	BAILEY	5	73	ERATH	2	137	KLEBERG	16	200	RUNNELS	7
10	BANDERA	15	74	FALLS	9	138	KNOX	3	201	RUSK	10
11	BASTROP	14	75	FANNIN	1	139	LAMAR	1	202	SABINE	11
12	BAYLOR	3	76	FAYETTE	13	140	LAMB	5	203	SAN AUGUSTINE	11
13	BEE	16	77	FISHER	8	141	LAMPASAS	23	204	SAN JACINTO	11
14	BELL	9	78	FLOYD	5	142	LA SALLE	15	205	SAN PATRICIO	16
15	BEXAR	15	79	FOARD	3	143	LAVACA	13	206	SAN SABA	23
16	BLANCO	14	80	PORT BEND	12	144	LEE	14	207	SCHLEICHER	7
17	BORDEN	8	81	FRANKLIN	1	145	LEON	17	208	SCURRY	8
18	BOSQUE	9	82	FREESTONE	17	146	LIBERTY	20	209	SHACKELFORD	8
19	BOWIE	19	83	FRIO	15	147	LIMESTONE	9	210	SHELBY	11
20	BRAZORIA	12	84	GAINES	6	148	LIPSCOMB	4	211	SHERMAN	4
21	BRAZOS	17	85	GALVESTON	12	149	LIVE OAK	16	212	SMITH	10
22	BREWSTER	24	86	GARZA	5	150	LLANO	14	213	SOMERVELL	2
23	BRISCOE	25	87	GILLESPIE	14	151	LOVING	6	214	STARR	21
24	BROOKS	21	88	GLASSCOCK	7	152	LUBBOCK	5	215	STEPHENS	23
25	BROWN	23	89	GOLIAD	16	153	LYNN	5	216	STERLING	7
26	BURLESON	17	90	GONZALES	13	154	MADISON	17	217	STONEWALL	8
27	BURNET	14	91	GRAY	4	155	MARION	19	218	SUTTON	7
28	CALDWELL	14	92	GRAYSON	1	156	MARTIN	8	219	SWISHER	5
29	CALHOUN	13	93	GREGG	10	157	MASON	14	220	TARRANT	2
30	CALLAHAN	8	94	GRIMES	17	158	MATAGORDA	13	221	TAYLOR	8
31	CAMERON	21	95	GUADALUPE	15	159	MAVERICK	15	222	TERRELL	6
32	CAMP	19	96	HALE	5	160	MC CULLOCH	23	223	TERRY	5
33	CARSON	4	97	HALL	25	161	MC LENNAN	9	224	THROCKMORTON	3
34	CASS	19	98	HAMILTON	9	162	MEDINA	15	225	TITUS	19
35	CASTRO	5	99	HANSFORD	4	163	MENARD	7	226	TOM GREEN	7
36	CHAMBERS	20	100	HARDEMAN	25	164	MIDLAND	6	227	TRAVIS	14
37	CHEROKEE	10	101	HARDIN	20	165	MILAM	17	228	TRINITY	11
38	CHILDRESS	25	102	HARRIS	12	166	MILLS	23	229	TYLER	20
39	CLAY	3	103	HARRISON	19	167	MITCHELL	8	230	UPSHUR	10
40	COCHRAN	5	104	HARTLEY	4	168	MONTAGUE	3	231	UPTON	6
41	COKE	7	105	HASKELL	8	169	MONTGOMERY	12	232	UVALDE	15
42	COLEMAN	23	106	HAYS	15	170	MOORE	4	233	VAL VERDE	7
43	COLLIN	18	107	HEMPHILL	4	171	MORRIS	19	234	VAN ZANDT	10
44	COLLINGSWORTH	25	108	HENDERSON	10	172	MOTLEY	25	235	VICTORIA	13
45	COLORADO	13	109	HIDALGO	21	173	NACOGDOCHES	11	236	WALKER	11
46	COMAL	15	110	HILL	9	174	NAVARRO	9	237	WALLER	12
47	COMANCHE	23	111	HOCKLEY	5	175	NEWTON	20	238	WARD	6
48	CONCHO	7	112	HOOD	2	176	NOLAN	8	239	WASHINGTON	17
49	COOKE	3	113	HOPKINS	1	177	NUECES	16	240	WEBB	21
50	CORYELL	9	114	HOUSTON	11	178	OCHILTREE	4	241	WHARTON	12
51	COTTLE	25	115	HOWARD	8	179	OLDHAM	4	242	WHEELER	25
52	CRANE	6	116	HUDSPETH	24	180	ORANGE	20	243	WICHITA	3
53	CROCKETT	7	117	HUNT	1	181	PALO PINTO	2	244	WILBARGER	3
54	CROSBY	5	118	HUTCHINSON	4	182	PANOLA	10	245	WILLACY	21
55	CULBERSON	24	119	IRION	7	183	PARKER	2	246	WILLIAMSON	14
56	DALLAM	4	120	JACK	3	184	PARMER	5	247	WILSON	15
57	DALLAS	18	121	JACKSON	13	185	PECOS	6	248	WINKLER	6
58	DAWSON	8	122	JASPER	20	186	POLK	11	249	WISE	2
59	DEAF SMITH	4	123	JEFF DAVIS	24	187	POTTER	4	250	WOOD	10
60	DELTA	1	124	JEFFERSON	20	188	PRESIDIO	24	251	YOAKUM	5
61	DENTON	18	125	JIM HOGG	21	189	RAINS	1	252	YOUNG	3
62	DE WITT	13	126	JIM WELLS	16	190	RANDALL	4	253	ZAPATA	21
63	DICKENS	25	127	JOHNSON	2				254	ZAVALA	15
64	DIMMIT	15	128	JONES	8						

```
                                    SAS
                CANONICAL DISCRIMINAT ANALYSIS OF CLIMATIC CLUSTERS

                      CANONICAL DISCRIMINANT ANALYSIS

              254 OBSERVATIONS       253 DF TOTAL
                4 VARIABLES          249 DF WITHIN CLASSES
                5 CLASSES              4 DF BETWEEN CLASSES

              CLUSTER   FREQUENCY    WEIGHT   PROPORTION

                 1          50         50     0.196850
                 2          50         50     0.196850
                 3          40         40     0.157480
                 4          64         64     0.251969
                 5          50         50     0.196850


                        UNIVARIATE STATISTICS

VARIABLE      MEAN      TOTAL STD    WITHIN STD   BETWEEN STD   R-SQUARED   RSQ/(1-RSQ)        F       PROB > F

TI        -8.99999213   24.22379658  10.84253329  24.21868531   0.802823      4.072       253.456      0.0
AVT       64.79417717    3.88635166   1.74081931   4.00899601   0.612313      4.328       269.419      0.0
FT        38.34095669   25.44098343   9.13889066  26.52405025   0.873002      6.874       427.914      0.0
R         30.12379528   11.30799085   5.36320780  11.13361403   0.778610      3.517       218.929      0.0

              AVERAGE R-SQUARED:   UNWEIGHTED =   0.816687      WEIGHTED BY VARIANCE =   0.833653


                             CLASS MEANS

              CLUSTER         TI            AVT            FT             R

                 1        -10.54952000   64.65817667   35.48794000   31.24040000
                 2        -31.54724000   63.45804333   48.97484000   18.70546000
                 3        -19.60732500   58.27005000   84.57260000   19.55492500
                 4        -15.95500000   69.56724740   11.55984375   31.70392187
                 5         32.48506000   65.36608333   27.85460000   46.85006000

                                                    EIGENVALUES OF INV(E)*H
                    ADJUSTED     APPROX      SQUARED                    = CANRSQ/(1-CANRSQ)
         CANONICAL  CANONICAL   STANDARD    CANONICAL
         CORRELATION CORRELATION  ERROR    CORRELATION   EIGENVALUE   DIFFERENCE   PROPORTION   CUMULATIVE

    1     0.950226   0.949004   0.006103    0.902929      9.3017       6.4358      0.7464       0.7464
    2     0.861017   0.859480   0.016261    0.741349      2.8662       2.6414      0.2300       0.9763
    3     0.428456   0.419043   0.051328    0.183574      0.2249       0.1549      0.0180       0.9944
    4     0.295663      .       0.058760    0.065364      0.0699         .         0.0056       1.0000
```

106

CANONICAL DISCRIMINANT ANALYSIS

TESTS OF HO: THE CANONICAL CORRELATION IN THE CURRENT ROW AND ALL THAT FOLLOW ARE ZERO

	LIKELIHOOD RATIO	APPROX F	NUM DF	DEN DF	PR > F
1	0.01915862	124.5543	16	752.18	0.0
2	0.19736611	63.3283	9	601.284	0.0
3	0.76306100	17.9522	4	496	0.0001
4	0.93463640	17.4138	1	249	0.0001

MULTIVARIATE TEST STATISTICS AND F APPROXIMATIONS
S=4   M=-0.8   N=122.8

STATISTIC	VALUE	F	NUM DF	DEN DF	PR > F
WILKS' LAMBDA	0.01915862	124.554	16	752.18	0.0
PILLAI'S TRACE	1.893216	55.940	16	996	0.0
HOTELLING-LAWLEY TRACE	12.46269	190.446	16	978	0.0
ROY'S GREATEST ROOT	9.301685	579.030	4	249	0.0

NOTE: F STATISTIC FOR ROY'S GREATEST ROOT IS AN UPPER BOUND

TOTAL CANONICAL STRUCTURE

	CAN1	CAN2	CAN3	CAN4
TI	0.6232	0.7806	-0.0445	0.0161
AVT	0.6042	-0.6430	0.2258	0.0867
FT	-0.9052	0.4236	0.0123	-0.0313
R	0.8118	0.4867	-0.0906	0.3093

BETWEEN CANONICAL STRUCTURE

	CAN1	CAN2	CAN3	CAN4
TI	0.6609	0.7502	-0.0213	0.0046
AVT	0.8478	-0.5187	0.1074	0.0246
FT	-0.9206	0.3904	0.0057	-0.0086
R	0.8743	0.4760	-0.0440	0.0896

SAS
CANONICAL DISCRIMINAT ANALYSIS OF CLIMATIC CLUSTERS

CANONICAL DISCRIMINANT ANALYSIS

WITHIN CANONICAL STRUCTURE

	CAN1	CAN2	CAN3	CAN4
TI	0.4373	0.8941	-0.0905	0.0350
AVT	0.5783	-0.6374	0.4710	0.1935
FT	-0.7814	0.6046	0.0313	-0.0849
R	0.8378	0.5261	-0.1741	0.6355

STANDARDIZED CANONICAL COEFFICIENTS

	CAN1	CAN2	CAN3	CAN4
TI	1.7783	1.8800	1.4537	-2.6634
AVT	0.3119	0.2786	4.5474	0.7511
FT	-2.3940	1.5223	4.2116	1.9186
R	-0.4220	-0.0218	-0.8243	3.4386

RAW CANONICAL COEFFICIENTS

	CAN1	CAN2	CAN3	CAN4
TI	0.073450617	0.077611678	0.060010885	-0.109951696
AVT	0.078250028	0.069993437	1.140749039	0.188416985
FT	-0.094100850	0.059837366	0.165543435	0.075415065
R	-0.037316154	-0.001924756	-0.081737588	0.304170638

CLASS MEANS ON CANONICAL VARIABLES

CLUSTER	CAN1	CAN2	CAN3	CAN4
1	0.1023	-0.3026	-0.8117	0.2692
2	-2.3344	-1.1843	-0.1722	-0.4419
3	-5.2460	1.5075	0.4375	0.2119
4	2.3238	-1.8117	0.4649	0.1250
5	3.4545	2.6000	0.0388	-0.1568

SAS
PLOT OF CANONICAL VARIABLES IDENTIFIED BY CLUSTER

PLOT OF CAN2*CAN1   SYMBOL IS VALUE OF CLUSTER

NOTE: 29 OBS HIDDEN
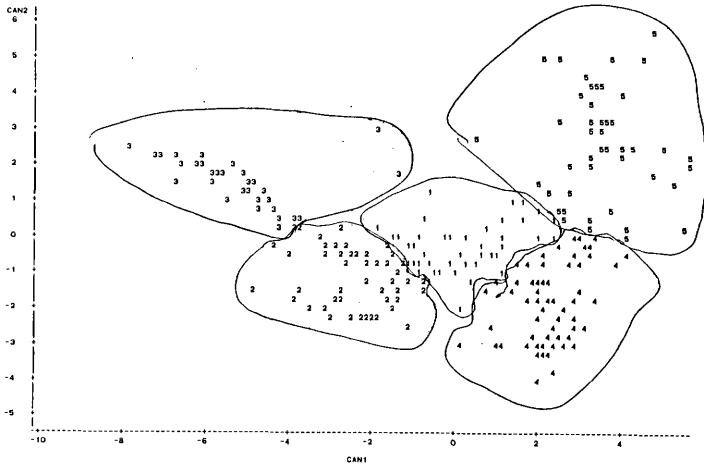
APPENDIX C

DOCUMENTATION OF THE INPUT PROCEDURE

C.1 MAINTENANCE MANUAL

GENERAL DESCRIPTION OF THE SYSTEM

The system of automation of data input procedure for the RENU3 model is a set of software programs and files whose objective is to generate a final input file for the model according to specifications given by the user. The relationship between programs and files is illustrated by the diagram in Fig. 12.

DESCRIPTION OF FILES

The files involved in the system are classified into two types:

A. Original data files

B. Files created by the package

A brief description of the files in each group and their corresponding records follows. The name of each file referred to as in Fig. 12 is shown between parenthesis after its actual name.

A. Original Data files

1. RIFILE (roadway inventory data)

This file contains roadway characteristics and traffic data for the designated under maintenance State Highway System and the Federal-Aid System. RIFILE is a monthly updated accounting of the physical qualities and system designations of these routes, organized by county, control section, beginning and ending milepoints. See record description in Table 22.

Table 22   Record Description of File RIFILE

Record format: Fixed blocked
Record size: 256
Block size: 5120

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
FILNUM	C	1	1		file identification number
DISTRI	C	2	2		district number
COUNTY	C	4	3		county number
CONTRL	C	7	4		SHD control number
SECTIO	C	11	2		SHD section number
BEGMPT	Z	13	5	3	Beginning milepoint [1/1000 mile]
ENDMPT	Z	18	5	3	Ending milepoint [1/1000 mile]
SUBFIL	C	23	1		Sub-file identification number
LGTSEC	Z	24	5	3	Length of section [1/1000 mile]
HWYSYS	C	29	2		Designated highway system
HWYNUM	C	31	4		Designated highway number
HWYSTA	C	35	1		Highway status
ROWWID	C	36	3		Right-of-way width [feet]
HWYDES	C	39	1		Highway design type
ROADBD	C	40	3		Road-bed width
BASTYP	C	43	1		Base type
SURWID	C	44	3		Surface width
SURCOM	C	47	1		Comb. of 2 or more surf. types
SURTYP	C	48	2		Surface type
NUMBLN	C	51	2		Number of mail lanes
SHLTYP	C	54	2		Shoulder type
MPDATE	C	56	4		Date of last milepoint change
ADMSYS	C	60	2		Administrative system
FEDRES	C	62	2		Type of federal reservation
FEDAID	C	64	2		Designated federal aid system
FUNCCL	C	66	1		Functional classification
URBRUR	C	67	1		Urban-rural classification
CONLNK	C	68	1		Interstate travelway flag

Table 22 Continued

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
MAISEC	C	69	2		Maintenance section number
CLASS	C	71	2		Maintenance class code
RESLOD	C	73	2		Restricted load limit
SP-SYS	C	75	2		Special systems
TRUCKS	C	77	1		Trucks or commercial vehicles
CITNUM	C	78	5		City number
URBANO	C	83	5		Urban area number
HPMS	C	88	12		Hpms
YRCADT	C	120	2		Yr of current Annual ADT (AADT)
ADTCYR	C	122	6		AADT, current year
ADTYR1	C	128	6		AADT for 1 year prior to current
ADTYR2	C	134	6		AADT for 2 years prior to current
ADTYR3	C	140	6		AADT for 3 years prior to current
ADTYR4	C	146	6		AADT for 4 years prior to current
ADTYR5	C	152	6		AADT for 5 years prior to current
ADTYR6	C	158	6		AADT for 6 years prior to current
ADTYR7	C	164	6		AADT for 7 years prior to current
ADTYR8	C	170	6		AADT for 8 years prior to current
ADTYR9	C	176	6		AADT for 9 years prior to current
VEH-MI	C	182	8		Vehicle miles daily (current yr)
D-YR	C	190	2		Estimated design year (current+20)
INCFAC	Z	192	4	2	20-year ADT increase factor
ESTADT	C	196	6		Estimated design year AADT
EST-VM	C	202	8		Est. design year vehicle miles
KFACTO	Z	210	3	1	% design hour is of 24-hour ADT
DIRDIS	C	213	2		% ADT in direction of heviest flow
TRKADT	Z	215	3	1	% trucks in ADT
TRKDHV	Z	218	3	1	% trucks in design hour volume
ATHWLW	C	221	3		Average ten heaviest wheel loads
ATHWLA	C	224	2		% tandem axles in ATHWLW
TNWLGT	C	226	5		No. wheel loads ¿ 8000 pounds
FLEX-K	C	231	5		No. 18-kip wheel applications (flex)
RIGI-K	C	236	5		No. 18-kip wheel applications (rig)
DHV	C	241	6		DHV factor

2. RL1FILE (roadlife data)

The Road Life file contains active as well as historical records , pertaining to the R. O. W. (right of way), construction costs and miles constructed, and maintainance of all highways on the state maintained system. In general these records contain type and cross section of base and surface, kind of work performance, miles constructed and cost. These records are broken out by county, control section, job number, cross section, rural or urban, etc. See record description in Table 23.

3. WIMOUT85 (weighing-in-motion data)

This file contains weighing-in-motion data collected at specific stations in the state, during the year 1985. The records contain information about the station, the type of vehicle weighed, the weight of its axles, spacing between axles, and the gross vehicle weight. Each record contains information about one vehicle weighted at a specific station. See record descrition in Table 24.

4. VEHICLE.CLASS.1985 (classification data)

This file contains vehicle classification data gathered at specific count stations in the state, during the year 1985. The records contain information about the station, and the number and type of vehicles counted at such station during a given time interval (usually one hour). Each record contains information about what and how many vehicles traveled over by a specific station during one hour. See record description in Table 25.

5. STATIONS (representative stations)

This file contains the representative station codes for all the scenarios within every district. There are two types of stations for each scenario: the weighing-in-

Table 23 Record Description of File RL1FILE

Record format: Fixed blocked
Record size: 206
Block size: 2060

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
DISTRI	C	1	1		district number
COUNTY	C	4	3		county number
CONTRL	C	7	4		SHD control number
SECTIO	C	11	2		SHD section number
JBNM	C	13	3		SHD job number
CDNM	C	16	2		SHD number to describe a project
CC	C	18	1		Card control
MP1	Z	19	5	3	Beginning milepoint [1/1000 mile]
MP2	Z	24	5	3	Ending milepoint [1/1000 mile]
TRCL	C	29	1		Travel class of roadway
HS	C	30	2		Highways system
RU	C	32	2		Administrative system
FAS	C	34	2		Federal aid system
YRML	C	36	4		Year and month let
YRMC	C	40	4		Year and month job complete
YROS	C	44	2		Year taken on system
PJCL	C	46	3		Project class
SFTP	C	49	2		Surface type
KW	C	51	6		Kind of work
SX	C	57	4		Cross section of surface
BX	C	61	5		Cross section of base
SHLTA	C	66	3		Type of shoulders
FLX	C	69	7		Surface description
CONC	C	76	1		Continuous or jointed concrete
ROW	C	77	4		Right-of-way width
MC	C	81	1		Mileage class
MB	Z	83	5	3	Mileage built [1/1000 mile]

Table 23 Continued

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
SBO	C	87	6		Subgrade description
MIRE	Z	93	5	3	Miles remaining [1/1000 mile]
HWNO	C	98	4		HIghway number
NOA	C	102	1		Blank field
CITYNO	C	103	5		City number
BLANKF	C	108	8		Blank field
NOIT	C	116	2		Number of items
ITTC	C	118	2		Item number
DOTC	Z	120	8		Total cost [$]
ITTS	C	128	2		Item number 04
DOTS	Z	130	8		Total cost for item 04 [$]
ITRI	C	138	2		Item number 05
DORI	Z	140	8		Total cost for item 05 [$]
ITSA	C	148	2		Item number 06
DOSA	Z	150	8		Total cost for item 06 [$]
ITGR	C	158	2		Item number 10
DOGR	Z	160	8		Total cost for item 10 [$]
ITS	C	168	2		Item number 20
DOS	Z	170	8		Total cost for item 20 [$]
ITB	C	178	2		Item number 30
DOB	Z	180	8		Total cost for item 30 [$]
ITM	C	188	2		Item number 88
DOM	Z	190	8		Total cost for item 88 [$]
ITROW	C	198	2		Item number 89
DOROW	Z	200	8		Total cost for item 89 [$]

Table 24 Record Description of File WIMOUT85

Record format: Fixed blocked
Record size: 80
Block size: 3200

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
FILNUM	C	1	1		truck weight record code
STATE	C	2	2		state code
FUNCLS	C	4	2		functional classification
STATID	C	6	3		station identification number
DIRTRA	C	9	1		direction of travel
DATE	C	10	6		date of measuring
HOUR	C	18	2		hour of measuring
VEHCOD	C	18	6		vehicle type code
BODENG	C	24	5		body and engine type
REGWGT	C	29	4		registered weight
BLANKF	C	33	3		blank field
COMCOD	C	36	5		commodity code
LDSTCD	C	41	1		load status code
TOTWGT	Z	42	4		total weight of truck [1000's pounds]
AAXWGT	Z	46	3		A-axle weight [100's pounds]
BAXWGT	Z	49	3		B-axle weight [100's pounds]
CAXWGT	Z	52	3		C-axle weight [100's pounds]
DAXWGT	Z	55	3		D-axle weight [100's pounds]
EAXWGT	Z	58	3		E-axle weight [100's pounds]
AB-SPC	Z	61	3	2	(A-B) axle spacing [feet]
BC-SPC	Z	64	3	2	(B-C) axle spacing [feet]
CD-SPC	Z	67	3	2	(C-D) axle spacing [feet]
DE-SPC	Z	70	3	2	(D-E) axle spacing [feet]
WHLBAS	Z	73	4	2	total wheelbase [feet]
RECORD	Z	77	3		record serial number
CONTIN	C	80	1		continuation indicator

Table 24 Continued

CONTINUATION RECORD

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
		1	28		same as cols 1-28 of face recd.
FAXWGT	Z	29	3		F-axle weight [100's pounds]
GAXWGT	Z	32	3		G-axle weight [100's pounds]
HAXWGT	Z	35	3		H-axle weight [100's pounds]
IAXWGT	Z	38	3		I-axle weight [100's pounds]
JAXWGT	Z	41	3		J-axle weight [100's pounds]
KAXWGT	Z	44	3		K-axle weight [100's pounds]
LAXWGT	Z	47	3		L-axle weight [100's pounds]
MAXWGT	Z	50	3		M-axle weight [100's pounds]
EF-SPC	Z	53	3	2	(E-F) axle spacing [feet]
FG-SPC	Z	56	3	2	(F-G) axle spacing [feet]
GH-SPC	Z	59	3	2	(G-H) axle spacing [feet]
HI-SPC	Z	62	3	2	(H-I) axle spacing [feet]
IJ-SPC	Z	65	3	2	(I-J) axle spacing [feet]
JK-SPC	Z	68	3	2	(J-K) axle spacing [feet]
KL-SPC	Z	71	3	2	(K-L) axle spacing [feet]
LM-SPC	Z	74	3	2	(L-M) axle spacing [feet]
RECORD	Z	77	3		record serial number
CONTIN	C	80	1		continuation indicator

Table 25: Record Description of File VEHICLE.CLASS.1985

Record format: Fixed blocked
Record size: 80
Block size: 3200

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
FILNUM	C	1	1		vehicle class. record code
STATE	C	2	2		state code
FUNCLS	C	4	2		functional classification
STATID	C	6	3		station identification number
DIRTRA	C	9	1		direction of travel
DATE	C	10	6		date data were gathered
HOUR	C	16	2		hour data were gathered
INSTST	Z	18	5		in-state passenger cars - std
INSTSM	Z	23	5		in-state passenger cars - small
OUSTST	Z	28	5		out-state passenger cars - std
OUSTSM	Z	33	5		out-state passenger cars - small
MOTOSC	Z	38	3		motor scooters and motorcyles
CBUSES	Z	41	4		commercial buses
SBUSES	Z	45	3		school and nonrevenue buses
N2PTRC	Z	48	4		2P, panel and picuck trucks
N2STRC	Z	52	4		2S, other 4-tire trucks
N2DTRC	Z	56	4		2D, 2-axle, 6-tire trucks
N3ATRC	Z	60	3		3A, 3-axle trucks
N2S1TR	Z	63	3		2S1, 2-ax tractor, 1-ax trailer
N2S2TR	Z	66	4		2S2, 2-ax tractor, 2-ax trailer
N3S2TR	Z	70	4		3S2, 3-ax tractor, 2-ax trailer
BLANKF	C	74	2		blank field
RECORD	Z	76	4		record serial number
CONTIN	C	80	1		continuation indicator

Table 25 Continued

CONTINUATION RECORD

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
		1	17		same as cols 1-17 of face recd.
V1CODE	Z	18	6		vehicle type code
V1COUN	Z	24	4		vehicle count for above type
V2CODE	Z	28	6		vehicle type code
V2COUN	Z	34	4		vehicle count for above type
V3CODE	Z	38	6		vehicle type code
V3COUN	Z	44	4		vehicle count for above type
V4CODE	Z	48	6		vehicle type code
V4COUN	Z	54	4		vehicle count for above type
V5CODE	Z	58	6		vehicle type code
V5COUN	Z	64	4		vehicle count for above type
BLANKF	C	68	8		blank field
RECORD	Z	76	4		record serial number
CONTIN	C	80	1		continuation indicator

motion station and the count station. The records are broken out by district, road system, pavement type, traffic level, rural-urban status, and representative station. See record description in Table 26.

6. YEARIN (reference year) This one two-digit record file contains the reference year for which the age lane mile distributions will be generated.

B. Files Created by the Package

1. CLS1985

This file is the sorted version of files VEHICLE.CLASS.1985. Sorting key is the station number. The record configuration is the same of that one in Table 25.

2. TRUCKS (truck traffic percentages)

This file contains the percentages of each type of truck with respect to the total traffic for each scenario within every district. Each record contains the district number, the scenario code, and the percentages for the ten types of trucks considered by the system. See record descriptions in Table 27.

3. LOADDIS (axle load distributions - 1)

This file contains the single and tandem axle load distributions for every weighing-in-motion station. There are two types of records in this file. One type corresponds to the identification of the station. The other type corresponds to the values of the distributions; each of these records contains the frequencies of axles for each one of the ten types of trucks, considering a given number of weight intervals. Records in this file are arranged in this way: one identification record, twenty distribution records, one identification record, twenty distribution records, and so on. See record descriptions in Table 28.

Table 26 Record Description of File STATIONS

Record format: Fixed blocked
Record size: 10
Block size: 6230

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
DISTRI	C	1	2		district number
DESCOM	C	3	2		scenario code
COUNST	C	5	3		count station identification number
WEIGST	C	8	3		WIM station identification number

Table 27 Record Description of File TRUCKS

Record format: Fixed blocked
Record size: 66
Block size: 6160

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
DISTRI	C	1	2		district number
COMNUM	C	3	4		scenario code
PER(1)	Z	7	6		percentage of truk type 1
PER(2)	Z	13	6		percentage of truck type 2
PER(3)	Z	19	6		percentage of truck type 3
PER(4)	Z	25	6		percentage of truck type 4
PER(5)	Z	31	6		percentage of truck type 5
PER(6)	Z	37	6		percentage of truck type 6
PER(7)	Z	43	6		percentage of truck type 7
PER(8)	Z	49	6		percentage of truck type 8
PER(9)	Z	55	6		percentage of truck type 9
PER(10)	Z	61	6		percentge of truck type 10

4. LOADS (axle load distributions - 2)

This file contains the representative single and tandem axle load distributions for each scenario in every district. There are two types of records in this file. One type corresponds to the identification of the distribution; that is, the district number, the scenario code, and the type of distribution (single or tandem). The other type corresponds to the values of the distributions; each of these records contains the frequencies of axles for each one of the ten types of trucks, considering a given number of weight intervals. Records in this file are arranged in this way: one identification record, ten distribution records, one identification record, ten distribution records, and so on. See record descriptions in Table 29.

5. GVEMDIS (gross and empty weight dist. - 1)

This file contains the gross and empty weight distributions for every weighing-in-motion station. There are two types of records in this file. One type corresponds to the identification of the station. The other type coresponds to the value of the distributions; each of these records contains the frequencies for each one of the ten types of trucks, considering a given number of weight intervals. Records in this file are arranged in this way: one identification record, twenty distribution records, one identification record, twenty distribution records, and so on. See record descriptions in Table 30.

6. GVEMPT (gross and empty weight dist. - 2)

This file contains the representative gross and empty weight distributions for each scenario in every district. There are two types of records in this file. One type corresponds to the identification of the distribution; that is, the district number, the scenario code, and the type of distribution (gross or empty). The other type corresponds to the values of the distributions; each of these records contains the

Table 28 Record Description of File LOADDIS

Record format: Fixed blocked
Record size: 120
Block size: 6120

RECORD TYPE 1

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
STATID	C	1	3		station identification number
BLANKF	C	4	117		blank field

RECORD TYPE 2

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
WGT(1)	Z	1	8		frequency of axle loads for a type of truck in interval 1
WGT(2)	Z	9	8		frequency of axle loads for a type of truck in interval 2
WGT(15)	Z	113	8		frequency of axle loads for a type of truck in inteval 15

Table 29 Record Description of File LOADS

Record size: 120
Block size: 6120

RECORD TYPE 1

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
DISTRI	C	1	2		district number
COMNUM	C	3	4		scenario code
DISTTY	C	7	1		distribution type
BLANKF	C	8	112		blank field

RECORD TYPE 2

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
WGT(1)	Z	1	8		frequency of axle loads for a type of truck in interval 1
WGT(2)	Z	9	8		frequency of axle loads for a type of truck in interval 2
WGT(15)	Z	113	8		frequency of axle loads for a type of truck in inteval 15

Table 30 Record Description of File GVEMDIS

Record format: Fixed blocked
Record size: 112
Block size: 6160

RECORD TYPE 1

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
STATID	C	1	3		station identification number
BLANKF	C	4	109		blank field

RECORD TYPE 2

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
WGT(1)	Z	1	4		frequency of gross or empty trucks for a type of truck in interval 1
WGT(2)	Z	5	4		frequency of gross or empty trucks for a type of truck in interval 2
WGT(28)	Z	109	4		frequency of gross or empty trucks for a type of truck in inteval 28

frequencies of each one of the ten types of trucks, considering a given number of weight intervals. Records in this file are arranged in this way: one identification record, ten distribution records, one identification record, ten distribution records, and so on. See record descriptions in Table 31.

7. FAGEDIS (mileage age distribution - 1)

This file contains the flexible lane-mile age distribution and the average ADT (average dayly traffic) for each scenario in every district. These records contain the number of lane-miles which are older than one, two, three, ... , twenty-nine, and thirty and more years. The records are broken out by district and scenario code. See record description in Table 32.

8. RAGEDIS (mileage age distribution - 2)

This file contains the rigid lane-mile age distribution and the average adt for each district. These records contain the number of lane-miles which are older than one, two, three, ... , twenty-nine, and thirty and more years. The records are broken out by district. See record description in Table 33.

9. FCARDSX (basic parameters - 1)

Actually this file represents one of a set of five files: FCARDS1, FCARDS2, FCARDS3, FCARDS4, and FCARDS5. Each of these files contains the basic run parameters for flexible pavements within the respective climatic region (last digit in the file-name). Configuration of this file is exactly the same as the configuration of Form F-1 (See Fig. 32).

10. RCARDS (basic parameters - 2)

This file contains the basic run parameters for rigid pavements in the entire

Table 31 Record Description of File GVEMPT

Record size: 112
Block size: 6160

RECORD TYPE 1

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
DISTRI	C	1	2		district number
COMNUM	C	3	4		scenario code
DISTTY	C	7	1		distribution type
BLANKF	C	8	105		blank field

RECORD TYPE 2

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
WGT(1)	Z	1	4		frequency of gross or empty trucks for a type of truck in interval 1
WGT(2)	Z	5	4		frequency of gross or empty trucks for a type of truck in interval 2
WGT(28)	Z	109	4		frequency of gross or empty trucks for a type of truck in inteval 15

Table 32 Record Description of File FAGEDIS

Record format: Fixed blocked
Record size: 133
Block size: 6118

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
BLANKF	C	1	1		blank field
DISTRI	C	2	2		district number
DESCOM	C	4	4		scenario code
AGE(1)	Z	8	4		one-year old lane-miles
AGE(2)	Z	12	4		two-year old lane-miles
AGE(30)	Z	124	4		thirty and more years old lane-miles
ADTSEC	Z	128	6		average daily traffic

Table 33   Record Description of File RAGEDIS

Record format: Fixed blocked
Record size: 133
Block size: 6118

Field Name	Field Type	Field Location	Field Length	Dec Pl.	Field Description
BLANKF	C	1	1		blank field
DISTRI	C	2	2		district number
BLANKF	C	4	4		blank field
AGE(1)	Z	8	4		one-year old lane-miles
AGE(2)	Z	12	4		two-year old lane-miles
AGE(30)	Z	124	4		thirty and more years old lane-miles
ADTSEC	Z	128	6		average daily traffic

state. Configuration of this file is exactly the same as that one of Form F-2 (See Fig. 33).

11. FINPUTX (input data for RENU3 - 1)

This file represents one of a set of five files: FINPUT1, FINPUT2, FINPUT3, FINPUT4, and FINPUT5. Each of these files contains the final input data set for program RENU3 when running for flexible pavements in a specific climatic region (last digit in the file-name).

12. RINPUT (input data for RENU3 - 2)

This file contains the final input data set for program RENU3 when running for rigid pavements in the entire state.

DESCRIPTION OF PROGRAMS

The programs in the automated system are classified into the following groups.

1. Programs to generate truck traffic percentages
2. Programs to generate load distributions
3. Programs to generate mileage age distributions
4. Programs to generate final input data sets.

The programs in each group are described below.

1. Programs to generate truck traffic percentages

SORT1

The purpose of this SAS program is to sort the vehicle classification data file, VEHICLE.CLASS.1985, by station number. The sorted file is stored in the file CLS1985 which is used by program TRUCKCOB. Because sorting is the only op-

eration in this program, only a SAS macro-command called "SORT" is used. See general flowchart in Fig. 17.

TRUCKCOB

This COBOL program generates percentages of each type of truck for a given scenario or representative count station. Such percentages are stored in the file TRUCKS. See general flowchart in Fig. 18.

2. Programs to generate load distributions

LOADCOB

This COBOL program generates the following load distributions for each station in file WIMOUT85 using weighint-in-motion data files:

1. Single axle weight distribution
2. Tandem axle weight distribution
3. Gross vehicle weight distribution
4. Empty vehicle weight distribution

Such distributions are stored in the files LOADDIS and GVEMDIS. See general flowchart in Fig. 19.

LOADCOB2

This program assigns the distributions found in LOADCOB to each scenario in every district. Distributions assigned to a particular scenario are those corresponding to the scenario's representative station. Distributions per scenario per district are stored in files LOADS and GVEMDIS. See general flowchart in Fig. 20.

```
        ┌──────────┐
        (   START   )
        └──────────┘
              │
              ▼
        ┌──────────────┐
        │   Read file   │
        │VEHICLE.CLASS.1985│
        └──────────────┘
              │
              ▼
        ┌──────────────┐
        │     SORT      │
        │ Acending key: │
        │ Station Number│
        └──────────────┘
              │
              ▼
        ┌──────────────┐
        │Output of SORT:│
        │  file  CLS1985│
        └──────────────┘
              │
              ▼
        ┌──────────┐
        (   STOP    )
        └──────────┘
```
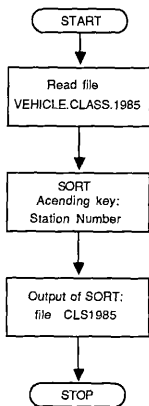
Fig. 17 General Flowchart of Program SORT1
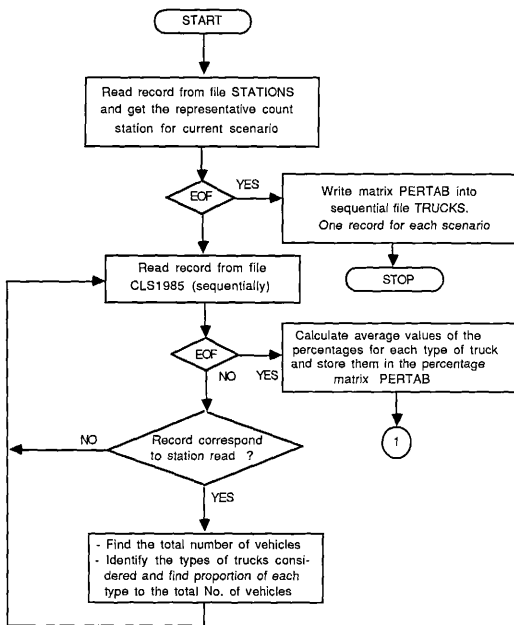
Fig. 18 General Flowchart of Program TRUCKCOB
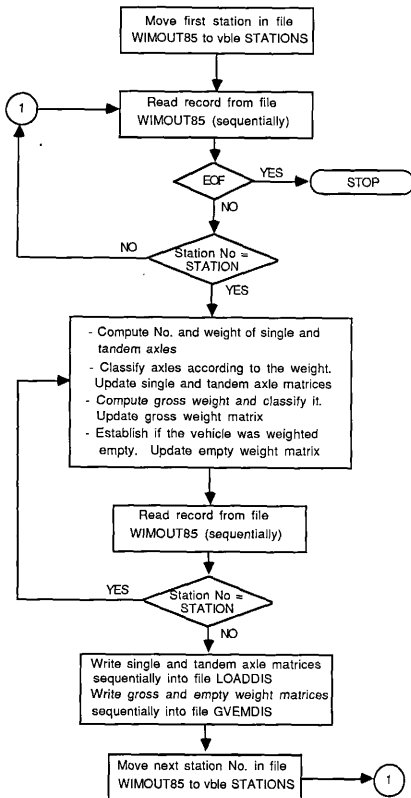
Fig. 19 General Flowchart of Program LOADCOB
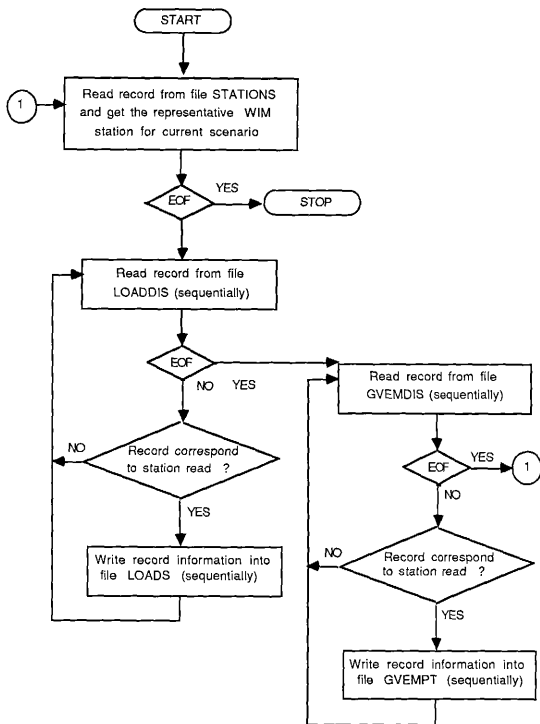
Fig. 20   General Flowchart of Program LOADCOB2

3. Programs to generate mileage age distributions

FAGECOB

This program prorates RIFILE flexible lane-miles by age using the RL1FILE, generating a flexible lane-mile age distribution per scenario in every district. Flexible mileage age distributions are stored in file FAGEDIS. See general flowchart in Fig. 21.

RAGECOB

This program prorates RIFILE rigid lane-miles by age using the RL1FILE, generating a rigid lane-mile age distribution per district. Rigid mileage age distributions are stored in file RAGEDIS. See general flowchart in Fig. 22.

4. Programs to generate final input data sets

FINPRENU

This program generates the input file for RENU3 when running for flexible pavements in a given climatic region or part of it. The input file generated is stored in one of the files FINPUTX. See general flowchart in Fig. 23.

RINPRENU

This program generates the input file for RENU3 when running for rigid pavements in the entire state or part of it. The input file generated is stored in file RINPUT. See general flowchart in Fig. 24.
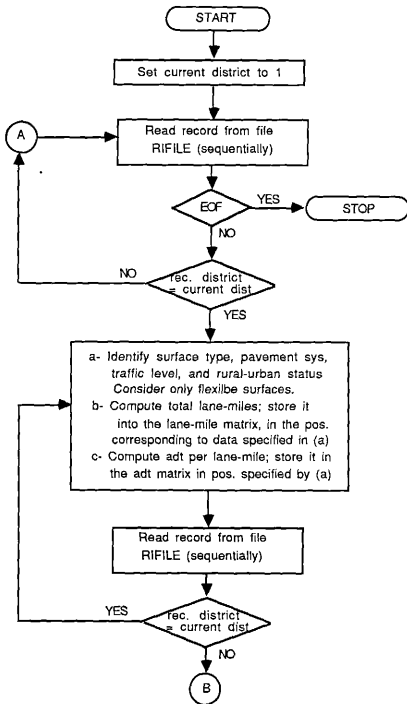
Fig. 21   General Flowchart of Program FAGECOB
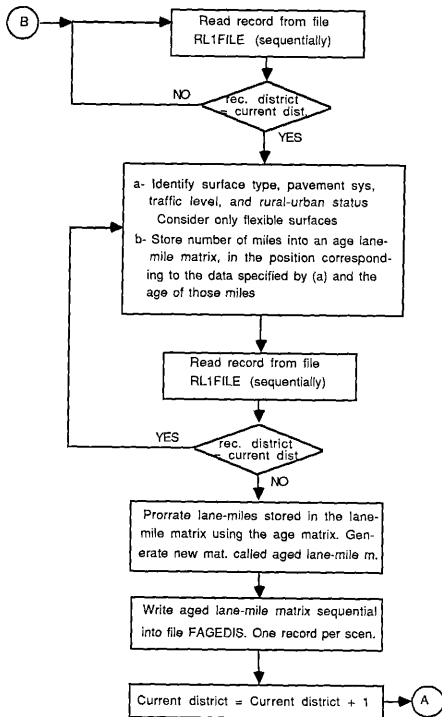
Fig. 21 Continued
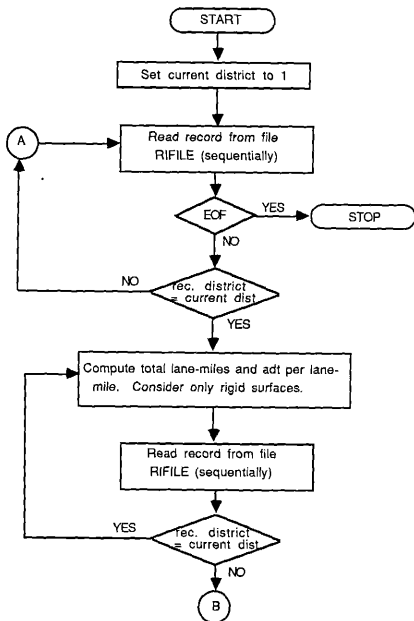
Fig. 22 General Flowchart of Program RAGECOB
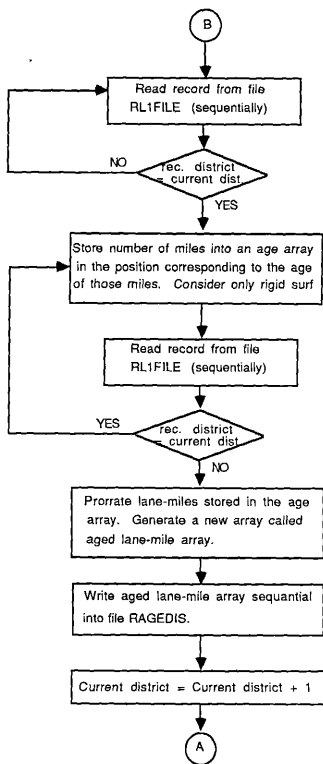
Fig. 22 Continued
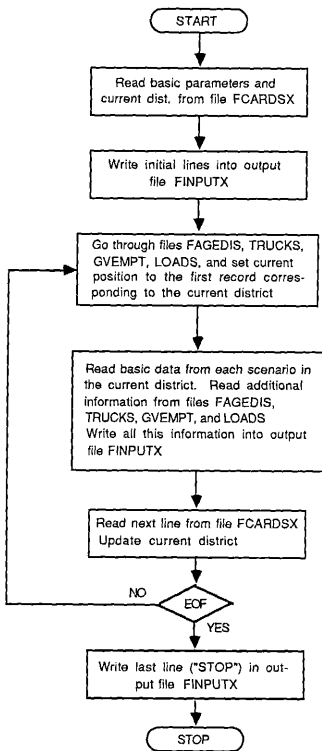
Fig. 23   General Flowchart of Program FINPRENU
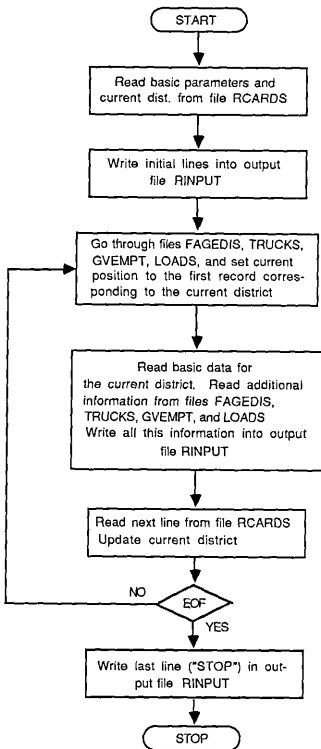
Fig. 24 General Flowchart of Program RINPRENU

C.2 OPERATIONS MANUAL

GENERAL DESCRIPTION OF THE SYSTEM

The diagram of Fig. 12 is modified to show the general description of the system from the point of view of the operator. The new diagram is showed in Fig. 25.

DESCRIPTION OF RUNS OF MAIN PROCESSES

The main processes of the system are outlined in Figure 31. A brief description of each process, a flowchart indicating the files and the programs involved in that process, and the JCL corresponding to that process are given in this section. When running each process the operator should make sure that the data files and the program files specified in the chart of that process are already loaded in the computer system.

PROCESS 1. Generation of mileage age distributions.

The purpose of this process is to generate rigid and flexilbe mileage age distributions for each scenario in each district. The flowchart corresponding to this process is shown in Fig. 26. The JCL commands for this process are the following.

```
//(Job Card)
//STEP1 EXEC COBVSCLG
//COB.SYSIN     DD DSN=FAGECOB, DISP=OLD
//GO.RL1FILE    DD DSN=RL1FILE, DISP=OLD,
//                 UNIT=(TAPE9,,DEFER), VOL=SET=volnum, LABEL=(n,SL),
//GO.RIFILE     DD DSN=RIFILE, DISP=OLD,
//                 UNIT=(TAPE9,,DEFER), VOL=SET=volnum, LABEL=(n,SL),
```
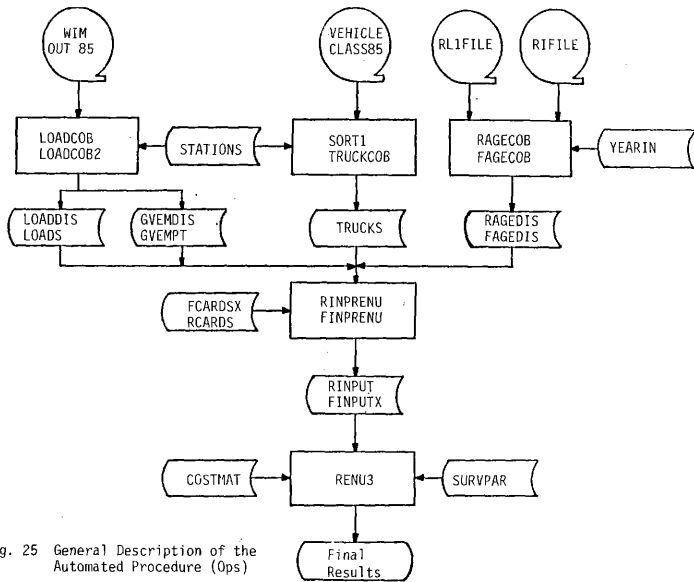
Fig. 25 General Description of the
Automated Procedure (Ops)
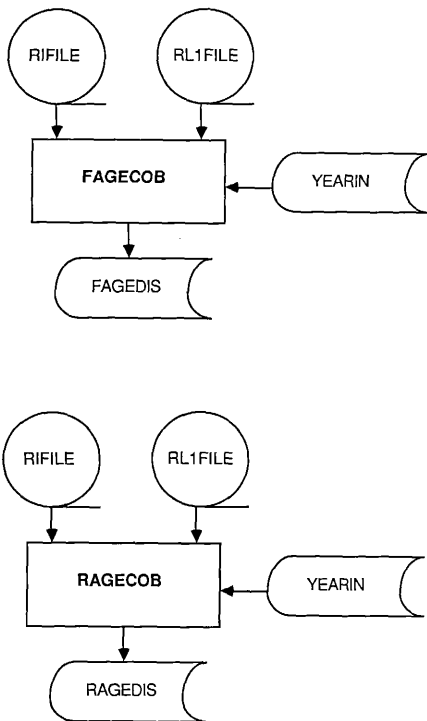
Fig. 26   Flowchart of Process 1

```
//GO.YEARIN      DD DSN=YEARIN, DISP=OLD
//GO.FAGEDIS     DD DSN=FAGEDIS, DISP=(NEW,CATLG,DELETE),
//               UNIT=SYSDA, SPACE=(TRK,(100,50),RLSE),
//               DCB=(LRECL=133,BLKSIZE=6118,RECFM=FB)
//STEP2 EXEC COBVSCLG
//COB.SYSIN      DD DSN=RAGECOB, DISP=OLD
//GO.RL1FILE     DD DSN=*.STEP1.STEP.GO.RL1FILE
//GO.RIFILE      DD DSN=*.STEP1.STEP.GO.RIFILE
//GO.YEARING     DD DSN=*.STEP1.STEP.GO.YEARIN
//GO.RAGEDIS     DD DSN=RAGEDIS, DISP=(NEW,CATLG,DELETE),
//               UNIT=SYSDA, SPACE=(TRK,(100,50),RLSE),
//               DCB=(LRECL=133,BLKSIZE=6118,RECFM=FB)
```

PROCESS 2. Generation of truck traffic percentages.

The purpose of this process is to generate percentages of truck traffic per type of truck for each scenario in each district. The flowchart corresponding is shown in Fig. 27. The JCL commands for this process follow.

```
//(Job Card)
//STEP1 EXEC SAS
//SAS.SYSIN      DD DSN=SORT1, DISP=OLD
//GO.INFILE      DD DSN=VEHICLE.CLASS.1985, DISP=OLD,
//               UNIT=(TAPE9,,DEFER),VOL=SER=volnum, LABEL=(n,SL)
//GO.FILE        DD DSN=CLS1985, DISP=(NEW,PASS),
//               UNIT=SYSDA,SPACE=(TRK,(500,50),RLSE),
//               DCB=(LRECL=80,BLKSIZE=3200,RECFM=FB)
//STEP2 EXEC COBVSCLG
```
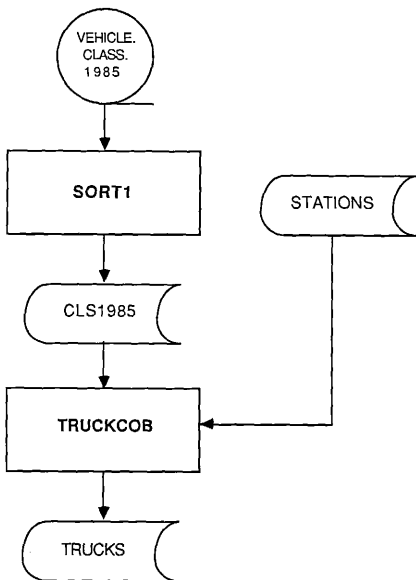
Fig. 27   Flowchart of Process 2

```
//COB.SYSIN     DD DSN=TRUCKCOB, DISP=OLD
//GO.CLS985     DD DSN=CLS1985, DISP=OLD
//GO.STATIONS   DD DSN=STATIONS, DISP=OLD
//GO.TRUCKS     DD DSN=TRUCKS, DISP=(NEW,CATLG,DELETE),
//              UNIT=SYSDA,SPACE=(TRK,(100,50),RLSE),
//              DCB=(LRECL=66,BLKSIZE=6160,RECFM=FB)
```

PROCESS 3. Generation of axle load and weight distributions.

The purpose of this process is to generate the axle load, gross and empty weight distributions per type fo truck for each scenario in every district. The flowchart of the process is shown in Fig. 28. JCL commands are the following.

```
//(Job Card)
//STEP1 EXEC COBVSCLG
//COB.SYSIN     DD DSN=LOADCOB, DISP=OLD
//GO.TRWEIGHT   DD DSN=WIMOUT85, DISP=OLD,
//              UNIT=(TAPE9,,DEFER),VOL=SER=volnum,LABEL=(num,SL),
//GO.LOADDIS    DD DSN=LOADDIS, DISP=(NEW,PASS),
//              UNIT=SYSDA, SPACE=(TRK,(50,5),RLSE,
//              DCB=(LRECL=120,BLKSIZE=6120,RECFM=FB)
//GO.GVEMDIS    DD DSN=GVEMDIS, DISP=(NEW,PASS),
//              UNIT=SYSDA, SPACE=(TRK,(50,5),RLSE),
//              DCB=(LRECL=112,BLKSIZE=6160,RECFM=FB)
//STEP2 EXEC COBVSCLG
//COB.SYSIN     DD DSN=LOADCOB2, DISP=OLD
//GO.STATIONS   DD DSN=STATIONS, DISP=OLD
//GO.LOADDIS    DD DSN=LOADDIS, DISP=OLD
```
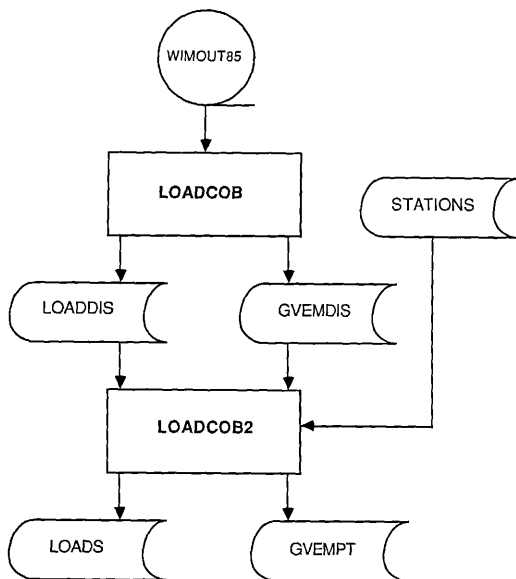
Fig. 28   Flowchart of Process 3

```
//GO.GVEMDIS    DD DSN=GVEMDIS, DISP=OLD
//GO.LOADDIST   DD DSN=LOADS, DISP=(NEW,CATLG,DELETE),
//              UNIT=SYSDA, SPACE=(TRK,(100,50),RLSE),
//              DCB=(LRECL=120,BLKSIZE=6120,RECFM=FB)
//GO.GVEMDIST   DD DSN=GVEMPT, DISP=(NEW,CATLG,DELETE),
//              UNIT=SYSDA, SPACE=(TRK,(100,50),RLSE),
//              DCB=(LRECL=112,BLKSIZE=6160,RECFM=FB)
```

PROCESS 4. Generation of input file for a flexible pavement run.

The purpose of this process is to generate the final input data set for a run of
RENU3 considering flexible pavements in a region or part of it. The flowchart of
this process is shown in Fig. 29. The JCL commands are the following.

```
//(Job Card)
//STEP1 EXEC FORTVCLG, LANGLV=66
//FORT.SYSIN     DD DSN=FINPRENU, DISP=OLD
//GO.FT07F001    DD DSN=GVEMPT, DISP=OLD
//GO.FT08F001    DD DSN=TRUCKS, DISP=OLD
//GO.FT09F001    DD DSN=LOADS, DISP=OLD
//GO.FT11F001    DD DSN=FCARDSX, DISP=OLD
//GO.FT12F001    DD DSN=FAGEDIS, DISP=OLD
//GO.FT10F001    DD DSN=FINPUTX, DISP=(NEW,CATLG,DELETE),
//               UNIT=SYSDA,SPACE=(TRK,(100,50),RLSE),
//               DCB=(LRECL=80,BLKSIZE=6400,RECFM=FB)
```

PROCESS 5. Generation of input file for a rigid pavement run.

The purpose of this process is to generate the final input data set for a run of
RENU3 considering rigid pavements in the state or part of it. Flowchart co-
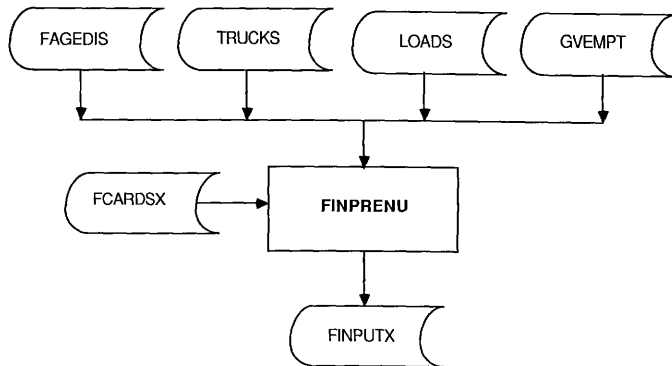
Fig. 29   Flowchart of Process 4

rresponding to this process is shown in Fig. 30. JCL commands are the following.

```
//(Job Card)
//STEP1 EXEC FORTVCLG, LANGLV=66
//FORT.SYSIN      DD DSN=RINPRENU, DISP=OLD
//GO.FT07F001     DD DSN=GVEMPT, DISP=OLD
//GO.FT08F001     DD DSN=TRUCKS, DISP=OLD
//GO.FT09F001     DD DSN=LOADS, DISP=OLD
//GO.FT11F001     DD DSN=RCARDS, DISP=OLD
//GO.FT12F001     DD DSN=RAGEDIS, DISP=OLD
//GO.FT10F001     DD DSN=RINPUT, DISP=(NEW,CATLG,DELETE),
//                UNIT=SYSDA,SPACE=(TRK,(100,50),RLSE),
//                DCB=(LRECL=80,BLKSIZE=6400,RECFM=FB)
```

C.3 USER MANUAL

GENERAL DESCRIPTION OF THE SYSTEM

From the point of view of the user the automation of the input procedure for RENU3 is a set of computational process whose final objective is the generation of the input data file for RENU3 according to some basic parameters supplied by him (the user). Such processes are the following.

1. Generation of rigid and flexible mileage age distributions
2. Generation of truck traffic percentages
3. Generation of axle load and weight distributions
4. Generation of input file for flexible pavements
5. Generation of input file for rigid pavements

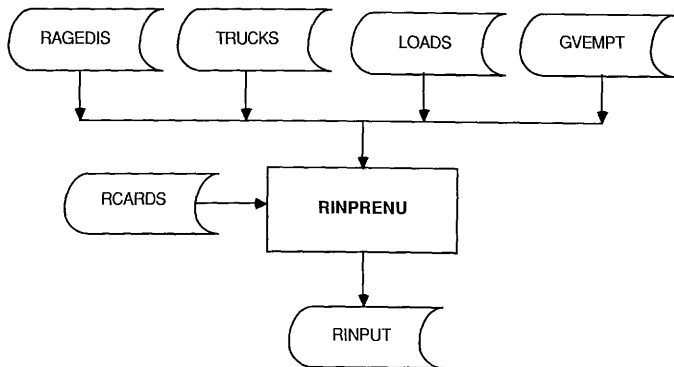According to this classification the general system can be represented by the chart

Fig. 30   Flowchart of Process 5

in Fig. 31.

DESCRIPTION OF MAIN PROCESSES

1. Generation of rigid and flexible mileage age distributions

The purpose of this process is to generate new flexible mileage age distributions per scenario in every district, and rigid mileage age distributions per district. This process must be performed when there is any change in one of the following files:

- RIFILE

- RIL1FILE

- YEARIN

To run ti, ask operator to run process number one of the operation manual.

2. Generation of truck traffic percentages

The purpose of this process is to generate representative percentages of truck traffic per type of truck for each scenario in every district. This process must be performed whenever there is a change in one of the following files:

- VEHICLE.CLASS.1985

- STATIONS (count stations)

To run it, ask operator to run process number two of the operation manual.

3. Generation of axle load and weight distributions

The purpose of this process is to generate the following distributions per type of truck for each scenario in each district.

- single axle load distribution

- tandem axle load distribution

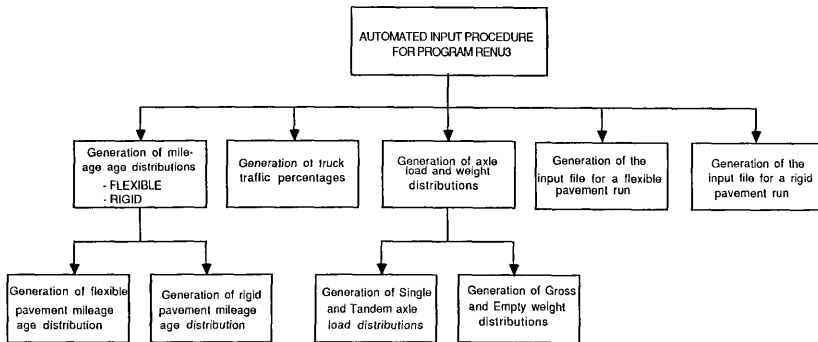- gross vehicle weight distribution

```
        ┌─────────────────────────────┐
        │  AUTOMATED INPUT PROCEDURE  │
        │      FOR PROGRAM RENU3      │
        └─────────────────────────────┘
```

| Generation of mileage age distributions - FLEXIBLE - RIGID | Generation of truck traffic percentages | Generation of axle load and weight distributions | Generation of the input file for a flexible pavement run | Generation of the input file for a rigid pavement run |

| Generation of flexible pavement mileage age distribution | Generation of rigid pavement mileage age distribution | | Generation of Single and Tandem axle load distributions | Generation of Gross and Empty weight distributions |

Fig. 31   General Description of the Automated System (User Manual)

- empty vehicle weight distribution

This process must be performed whenever there is a change in one of the following files:

- WIMOUT85
- STATIONS (weighing-in-motion stations)

To run it, ask operation to run process number three of the operation manual.

4. Generation of input file for a flexible pavement run

The purpose of this process is to generate the final input data set for a run of RENU3 considering flexible pavements in a region or part of it. For the run of this process the user must fill out the standard form F-1 (see DESCRIPTION OF INPUT FORMS next). Then, the user must create a regular file using the computer editor or any word processor to store the data in such form; instructions to store such data in the file are given in the section "Description of input form F-1". After creating that file under the corresponding name (see DESCRIPTION OF FILES, file FCARDSX) the user will ask the operator to run process number four of the operation manual.

5. Generation of input file for a rigid pavement run

The purpose of this process is to generate the final input data set for a run of RENU3 considering rigid pavements in the state or part of it. For the run of this process the user must fill out the standard form F-2 (see DESCRIPTION OF INPUT FORMS next). Then, the user must create a regular file to store the data in such form; instruction to store such data in the file are given in the section "Description of input form F-2". After creating that file under the corresponding name (see DESCRIPTION OF FILES, file RCARDS) the user will ask the operator to run process number five of the operation manual.

DESCRIPTION OF INPUT FORMS

There are two input forms for the user to enter data into the system:

1. Form F-1: to enter basic run parameters for a flexible pavement run of RENU3

2. Form F-2: to enter basic run parameters for a rigid pavement run of RENU3

Detailed description of each form follows.

1. Description of input form F-1

(See sample of form F-1 in Fig. 32)

REGION	Number of climatic region
NYAP	Analysis period [years]
AGR	Annual growth rate in ESALs
RTINT	Annual interest rate
XHCIO	Surfacing cost index
XHCIM	Maintenance material cost index

LOAD LIMITS

GVWL	Gross vehicle weight limit [kips]
SAL	Single axle legal load limit [kips]
TAL	Tandem axle legal load limit [kips]
TRAL	Tridem axle legal load limit [kips]

The first line corresponds to present limits and the second one to proposed limits.

TRUCKS CONSIDERED:

There are ten possible types of trucks (see Fig. 8):

1. 2D	6. 2-S2

Region: [____] 1 2   FORM F-1: Basic Input Parameters for RENU3
                        — FLEXIBLE PAVEMENTS —

General Parameters

NYAP [____]   AGR [____]   RTINT [____]   XHCIO [____]   XHCIM [____]
     1   5   8   10   13   17   20   24   27   31

LOAD LIMITS:

	GVWL	SAL	TAL	TRAL
Present				
Future				
	8 9	16 17	24 25	32

TRUCKS CONSIDERED

Type	1	2	3	4	5	6	7	8	9	10
Option										
Present Limit										
Future Limit										
	1	8	16	24	32	40	48	56	64	72	80

Calculate costs for future Limits? (Load shift procedure): [____] 1 2

District: [____] 1   2

		OVERLAYS AND SEAL COATS					ROAD DESCRIPTORS				PERFORMANCE						
1 2		4 8	10 14	16 17	18 21	23 25	27 32	34 38	40 44	46 50	52 52	54 58	60 64	66 70	72 76	78
No.	COMBINATION	XMNOTK	XMXOTK	NOEL	JYR	EYR	WLANE	PPVDSH	WFSH	WGSH	IACR	PF	PFO	PTERM	PIOV	OMIT
1	1 1 1 1															
2	1 1 1 2															
3	1 1 2 1															
:	:															
36	3 3 2 2															
00																

36 Lines

Fig. 32 F-1 Data Input Form

2. 3A	7. 3-S1
3. 3-S2	8. 3-S3
4. 2-S1-2	9. 3-S1-2
5. 2-S1	10. 2-S2-2

Option: 1 (consider that type of truck), or 2 (do not consider it)

Present: Present steering axle weight limit for that type of truck

Future: Future steering axle weight limit for that type of truck

COST CALCULATION FOR FUTURE LIMITS:

1: Use load shifting procedure

0: Do not use load shifting procedure

Both options should be used when impact of changing leagl load limits is to be measured in terms of cost. In such case, two runs are made. In the first one, do not use load shifting procedure, and in the second one do consider it leaving the other data as they were in the first run.

DISTRICT: District number

One form F-1 must be filled out for each district for the following part of the form only.

COMBINATION CODE

First column:	1 = Interstate, 2 = Farm-to-Market, 3 = State/US
Second column:	1 = Hot Mix, 2 = Black Base, 3 = Overlaid
Third column:	1 = Rural, 2 = Urban
Fourth column:	1 = Low Traffic, 2 = High Traffic

OVERLAYS AND SEAL COATS:

XMNOTK   Minimum overlay thickness [inches]

XMXOTK	Maximum overlay thickness [inches]
NDEL	Number of years to overlay mileage in POTTS when distress
	types are the failure mode
JYR	Time between seal coats
IYR	Number of years to overlay mileage in POTTS when PSI
	loss is the failure mode

ROAD DESCRIPTORS:

WLANE	Lane width [feet] (default value is 12)
PPVDSH	Percent of paved shouldet (default value is 95 for
	Interstate and State/US, and 5 for FM)
WPSH	Average paved shoulder width per lane [feet]
WGSH	Average granular shoulder width per lane [feet]

PERFORMANCE:

IACR	Distress critical performance level (1, 2 or 3)
PF	Asymptotic serviceability index
PF0	Asymptotic serviceability index for overlay
PTERM	Terminal serviceability index
PIOV	Serviceability index after overlay

| OMIT | 1 (omit combination), or 0 (include combination) |

To run the program a file with the data from this form must be created. When creating such file, note the following:

(1) Each line in form F-1 corresponds to one line in the file; column numbers are specified in each line of the form.

(2) The combination code should not be included in the file. Only the corresponding number in columns 1 and 2 should be entered.

(3) When an input-variable value for a combination ia the same as for the previous combination, the column space should be left blank; the program automatically assumes previous value for that variable.

(4) Enter "00" in columns 1 and 2 at the end of each district data set. The last district data set should have an additional "00" line to mark the end of data input.

1. Description of input form F-2

(See sample of form F-2 in Fig. 33)

NYAP	Analysis period [years]
AGR	Annual growth rate in ESALs
RTINT	Annual interest rate
XHCIO	Surfacing cost index
XHCIM	Maintenance material cost index

LOAD LIMITS

GVWL	Gross vehicle weight limit [kips]
SAL	Single axle legal load limit [kips]
TAL	Tandem axle legal load limit [kips]
TRAL	Tridem axle legal load limit [kips]

The first line corresponds to present limits and the second one to proposed limits.

TRUCKS CONSIDERED:

There are ten possible types of trucks (see Fig. 8):

FORM F-2: Basic Input Parameters for RENU3
— RIGID PAVEMENTS —

General Parameters

NYAP [   ]   AGR [   ]   RTINT [   ]   XHCIO [   ]   XHCIM [   ]
1   5   6   10   13   17   20   24   27   31

LOAD LIMITS:

	GVWL	SAL	TAL	TRAL
Present	.			
Future				

1   8 9   16 17   24 25   32

TRUCKS CONSIDERED

Type	1	2	3	4	5	6	7	8	9	10
Option										
Present Limit										
Future Limit										

1   8   16   24   32   40   48   56   64   72   80

Calculate costs for future Limits? (Load shift procedure): [   ]
1   2

DISS [   ]   DCON [   ]   DIN [   ]
1   10   11   20   21   25

1 2	4	OVERLAYS		PAVEMENT DESCRIPTORS				MATERIALS									PERFORMANCE				
DISTRICT								LAYER 1			LAYER 2			LAYER 3							
4	8 10 14	16	18 23	25 28	31 40	42 44	45 50	52 56	58 60	62 68	69 72	1	3 5	8 11 15	17 17	18 23	25 28	31 35	37 41
	XUNOTK	XMXOTK	PT	XK	AGO	E	CODE	TH	ST	CODE	TH	ST	CODE	TH	ST	IAGR	PF	PFD	PTERM	PNOV
24 Lines			.																	
00																				

Fig. 33 F-2 Data Input Form

1. 2D	6. 2-S2
2. 3A	7. 3-S1
3. 3-S2	8. 3-S3
4. 2-S1-2	9. 3-S1-2
5. 2-S1	10. 2-S2-2

Option: 1 (consider that type of truck), or 2 (do not consider it)

Present: Present steering axle weight limit for that type of truck

Future: Future steering axle weight limit for that type of truck

COST CALCULATION FOR FUTURE LIMITS:

  1: Use load shifting procedure

  0: Do not use load shifting procedure

Both options should be used when impact of changing legal load limits is to be measured in terms of cost. In such case, two runs are made. In the first one, do not use load shifting procedure, and in the second one do consider it leaving the other data as they were in the first run.

DISS   Number of failures at the time of survey

DCON   Date of survey condition [years]

DINT   Initial date of planning

DISTRICT   District number

OVERLAYS:

XMNOTK   Minimum overlay thickness [inches]

XMXOTK   Maximum overlay thickness [inches]

PAVEMENT DESCRIPTORS:

PT	Type of rigid pavement:
	1: Jointed reinforced concrete
	2: Plain concrete (unreinforced)
XK	Composite support value (K) [pci]
AGG	Type of aggregate

MATERIALS:

Three layers are considered

CODE:	ACP: Asphalt Concrete Pavement	SAB: Sand Asphalt Base
	ATB: Asphalt Treated Base	LTB: Lime Treated Base
	AGB: Aggregate Base	Aggregate Subbase
	CTB: Cement Treated Base	LTS: Lime Treated Subbase
	CRC: Cont. Reinforced Pavement	JCP: Jointed Concrete
TH	Layer thickness [inches] (layer thickness for
	representative sections used in left blank)
ST	Structural coefficient (if blank, default is used)

PERFORMANCE:

IACR	Distress critical performance level (1, 2 or 3)
PF	Asymptotic serviceability index
PF0	Asymptotic serviceability index for overlay
PTERM	Terminal serviceability index
PIOV	Serviceability index after overlay

To run the program a file with the data from this form must be created. When

creating such file, note the following:

(1) Each line in form F-2 corresponds to one line in the file; column numbers are specified in each line of the form.

(3) When an input-variable value for a combination ia the same as for the previous combination, the column space should be left blank; the program automatically assumes previous value for that variable.

(4) Enter "00" in columns 1 and 2 at the end of the data set to mark the end of data input.

DESCRIPTION OF OUTPUT

Output of the system is stored in one single file, FINPUTX or RINPUT, depending on which type of pavement the run of RENU3 is made for (See "DESCRIPTION OF FILES"). Each file contains essentially the same information outlined in Section 6.1.

The RENU3 program has the characteristic of printing as part of the output, all the input data set, printing each line with the same format and in the same order of input.

VITA

Juan Carlos Garcia-Diaz, son of Joaquin Garcia and Lucrecia Diaz, was born on November 24, 1963 in Bucaramanga, Colombia. He completed his secondary education at the National Technical Institute of Commerce, Bucaramanga, Colombia. He then entered the Industrial University of Santander in the same city, and graduated with a B.S. degree in *Systems Engineering* in 1985. His undergraduate thesis was the implementation of a transformer load management system and the automation of the divisions of services and operations of the Santander Utilities Company in Colombia. Simultaneously with his studies, he worked as Accounting assistant and as system analyst. In January 1986, he started his M.S. degree in the Industrial Engineering Department of Texas A&M University; and after graduation, he plans to pursue a Doctoral degree. His permanent mailing address is Calle 34 No. 30-26, Bucaramanga, Colombia.