EVALUATION OF COMPUTER PROGRAMS NULOAD AND REHAB

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DISCLAIMER

The views, interpretation, analysis, and conclusions expressed or implied in this report are those of the research group. They are not necessarily those of the Texas State Department of Highways and Public Transportation.

ABSTRACT

The purpose of this study is to perform a critical evaluation of the REHAB and NULOAD computer programs. REHAB is currently being used by the Texas State Department of Highways and Public Transportation (DHT) to forecast highway rehabilitation and maintenance funds to keep the road system at an acceptable level of serviceability.

To this end, a complete documentation of the forecasting models is provided and all the significant assumptions are discussed. Recommendations are also suggested for improving the overall predictive capabilities of REHAB and NULOAD. These recommendations include (a) generation of life curves using the Texas highway performance equations, (b) usage of several pavement rehabilitation alternatives, (c) application of new load redistribution methods, and (d) development of a cost analysis methodology.

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CHAPTER 1

INTRODUCTION

This chapter summarizes the fundamental concepts that will be used throughout the report. Specifically, the chapter discusses (a) the scope of the study, (b) the significance of the study, (c) some of the related work, and (d) the proposed general approach.

1.1 Scope of the Study

The global objective of this study is to present recommendations to improve the forecasting capabilities of the REHAB and NULOAD programs. These programs are computer-based procedures used for estimating the rehabilitation requirements of highway systems. In particular, REHAB is being used by the Texas State Department of Highways and Public Transportation (DHT) to forecast the cost and road rehabilitation requirements for a given planning horizon.

By using REHAB or NULOAD, and under the assumption that a particular type of rehabilitation is used, the corresponding rehabilitation cost can be estimated for each pavement category at the state and/or district levels. The proposed methodologies can also be used to assist in the evaluation of the cost impact of changes in truck size, weight, and axle configuration. This is particularly useful to assess the rehabilitation costs induced by a change in legal axle-load limits.

In order to achieve the global objective of the study, the following tasks will be defined and investigated in subsequent chapters:

A. Analysis of the critical assumptions of REHAB and NULOAD.

B. Evaluation of data needs and data availability.

C. Documentation of findings and recommendations.

1.2 Significance of the Study

The Texas State Department of Highways and Public Transportation needs to evaluate the road rehabilitation budget required in each of the periods of a given planning horizon, in order to provide an acceptable level of serviceability to the users of the overall transportation system. Additionally, there is a great need to protect the massive investment in the existing highway system. Since the funds allocated by the State Legislature are insufficient for a total rehabilitation of the overall Texas transportation system, it is clear that sound decision-making procedures are necessary to identify and schedule construction, upkeeping, and rehabilitation projects. This will insure a substantial improvement in the use of available resources.

Currently the DHT is using the REHAB program to estimate the funds required to upkeep the Texas transportation system at an adequate level of serviceability. This program has been modified a few times since its original conception and development in 1976. However, additional modifications must be made to increase the generality and reliability of REHAB as a predicting road rehabilitation cost mechanism. In particular, a substantial amount of data transformation should be eliminated so that the Texas highway data base can be used directly as input for REHAB.

The significance of this study is further emphasized by the current trend of increasingly higher payloads in the distribution of grain output from all agricultural sectors of the state. This particularly affects the low-volume rural roads, which must carry higher axle-loads than those for which they were designed.

1.3 Survey of Related Work

Past work on the development and improvement of computerized methods for estimating road rehabilitation requirements is summarized in the following three reports:

A. The McKinsey report [9], which relates to the original REHAB model.

B. The Updated Documentation report [15], which contains the input/output instructions for the present REHAB model.

C. The Effects of Changes in Legal Load Limits on Pavement Cost report, Volumes I [1] and II [2], which refer to the NULOAD model.

1.3.1 The Original REHAB model

The original Highway Rehabilitation Forecasting Model (REHAB) was jointly developed by the DHT and McKinsey & Company in 1976. The corresponding methodology is explained in Reference [9]. This is a report which contains (a) the fundamental concepts behind the model, (b) a description of the input data requirements, (c) an output description, and (d) a few sample problems to illustrate the calculations involved in the application of the method.

The original method was developed to estimate future road rehabilitation requirements using basic data on lanemileage, pavement age, life expectancy, and rehabilitation costs per lanemile, for each pavement category. Essentially, the original REHAB method can be described as follows, for a planning horizon which is divided in 2-year periods:

A. Determination of lanemile requirements for each pavement category:

Based on total mileage and survivor curves, the extent of road rehabilitation is estimated for the first 2-year period of a planning horizon.

B. Reaging procedure for each pavement category:

All mileage just rehabilitated is reclassified to the first period of the age distribution. All mileage not rehabilitated is moved to the next age group. With the new road age distribution, Step A is repeated and all costs are accumulated.

In order to support further discussion, the input and output portions of the original REHAB method are described below.

<u>Input</u> - Each lanemile of pavement in the state is classified according to (a) system type (Interstate, Farm to Market, Other), (b) pavement type (A.C.P., i.e., asphalt concrete pavement, and mixed bituminous; bituminous - surface treatment; concrete with less than one inch of A.C.P. overlay; and frontage roads), (c) region, (e.g., coastal, West Texas), and (d) rural/urban. The model then requires input concerning the age distribution of lanemiles in each category, the percentage of these lanemiles that is expected to be rehabilitated each period, and the rehabilitation cost per lanemile.

<u>Output</u> - There are two types of output available for each pavement category:

(1) Cost Summary - It consists of the number of lanemiles rehabilitated, the average cost per lanemile, and the total cost for each system, and is totaled for all systems.

(2) Snapshot - It consists of the age distribution of lane-

miles at present and at two 10-year intervals for each pavement category in each system and is totaled for all systems.

1.3.2. The Present REHAB Model

The original REHAB model [9] was modified by the DHT, in 1979, in order to achieve the following two objectives:

A. Analysis of additional rehabilitation costs needed in case of new axle-load legal limits.

B. Analysis of rehabilitation requirements at individual district levels.

The input/output instructions for the present REHAB model are documented in Reference [15] and in Chapter 2 of this report.

1.3.3. The NULOAD Program

Recently, the Federal Highway Administration (FHWA) sponsored a research project to investigate the effects of changes in truck size, weight, and configuration on pavement performance, and to relate these effects to pavement maintenance and rehabilitation costs. The study was conducted by Austin Research Engineers, and the corresponding results have been documented in References [1] and [2]. Reference [1] presents the assumptions, methodology, and data requirements of NULOAD, and Reference [2] is a user's manual for the NULOAD computer program.

A preliminary review of NULOAD has indicated the potential for implementing it to forecast rehabilitation requirements in Texas or for using some of its features in a further modified version of REHAB.

Essentially, NULOAD predicts a life cycle based on present serviceability index (PSI) estimates corresponding to given new axle-load limits.

In this prediction, use is made of traffic forecasts, information on structural cross sections, age of pavements, and the AASHTO equations [6] for pavement performance. Perhaps the strongest feature of NULOAD is its sophisticated, sound, and logical treatment of equivalency factors. On the other hand, the program rather lacks rigor and generality in its economic analysis.

1.4 General Approach

The rest of this report is dedicated to (a) a description of the REHAB program, (b) a discussion of the NULOAD model, (c) a critical evaluation of the NULOAD and REHAB models, and (d) recommendations for the improvement of REHAB and NULOAD. The discussion of REHAB includes a review of its purpose and assumptions, and an in-depth description and analysis of its input, methodology, and output. The study of REHAB is the purpose of Chapter 2.

The discussion of the NULOAD computer program is presented in Chapter 3. It includes a review of its assumptions; a description of its input, methodology, and output; and a comparison with REHAB.

The evaluation of the critical assumptions in REHAB, and the recommendations to improve the overall predictive capabilities of REHAB and NULOAD as forecasting models of road rehabilitation and maintenance requirements is the object of Chapter 4.

Volumes 2 and 3 contain supplementary material needed for the technical completeness of the overall report. Volume 2 complements the discussion of the REHAB model and includes a description of terms, flow charts of REHAB, a printout of the program, and a sample problem. Volume 3 supplements the study of NULOAD and contains a printout of the program and a sample problem.

CHAPTER 2

THE REHAB COMPUTER PROGRAM

The purpose of the present REHAB model is to provide the DHT with key information needed for the allocation of limited funds in the rehabilitation of the overall Texas transportation system during a given planning horizon. An important function of the program is the evaluation of the cost impact due to changes in truck size, weight, and axle configuration. This is particularly useful for assessing the rehabilitation costs induced by a change in legal axle-load limits, which are currently under study by the FHWA and the DHT.

The objective of this chapter is to provide a description and documentation of the present REHAB model. In particular, the following four aspects of the program will be considered:

A. Assumptions.

B. Input.

C. Methodology.

D. Output.

2.1 Assumptions of REHAB

The fundamental assumptions of REHAB can be classified according to structural, economic, traffic, and data availability characteristics. A list of the major assumptions in the program is given below:

<u>Structural</u>:

(1) No structural performance equations are considered in the program.

(2) There are only four types of pavement structures: (a) bitu-

minous-surface treatment, (b) A.C.P. and mixed bituminous, (c) concrete with less than one inch of A.C.P . overlay, and (d) frontage roads.

(3) Only one type of rehabilitation or reconstruction is performed.

<u>Economic</u>:

(1) No standard economic analysis is performed; that is, the present worth and/or the annual cost is not computed for a specific rehabilitation alternative, using an interest rate and the salvage value.

(2) A constant annual inflation rate is used.

(3) Maintenance and users travel costs are not considered.

<u>Traffic</u>:

(1) The degree of adjustment of life (survivor) curves is proportional to the ratio of present 18-kip E.S.A.L. (equivalent single axle load) to future 18-kip E.S.A.L. under a new load limit

<u>Data Availability</u>:

(1) The total number of lanemiles for each pavement category is obtained from the automated road inventory file (R12).

(2) The age distribution of center lanemiles, by pavement category, is obtained from the automated road life file (RL1).

(3) Survivor curves, continuous probability functions describing the loss of serviceability for a given pavement type over time, can be transformed into discrete functions by an accurate linear approximation of this loss of serviceability.

(4) Present and proposed 18-kip ESAL's applications are calculated outside REHAB.

(5) Lanemile reconstruction percentages must be specified.

(6) Road rehabilitation and reconstruction costs per lanmile must be specified.

2.2 REHAB's Data Process

The present version of REHAB requires a significant amount of computational work in order to generate the program's input. The output of the program provides essential information concerning the extent of road rehabilitation required under present and proposed legal axle-load limits. The input, basic methodology, and output of REHAB are explained in Sections 2.3., 2.4, and 2.5, respectively. However, a brief description is given here to support the discussion of the REHAB data process.

Figure 2.1 summarizes the computational work required for the input generation, and the basic components of the program's output. The purpose of "Operation A" in this diagram is to generate the number of lanemiles to be rehabilitated. The corresponding results are stored in file (tape) 8.

The first step of the input generation process for REHAB is the classification of each lanemile of pavement according to the following four items:

A. District:

Up to twelve districts can be considered per run.

B. Rural/Urban

C. System type:

(1) Interstate

(2) Farm to Market

(3) Others

D. Pavement type:

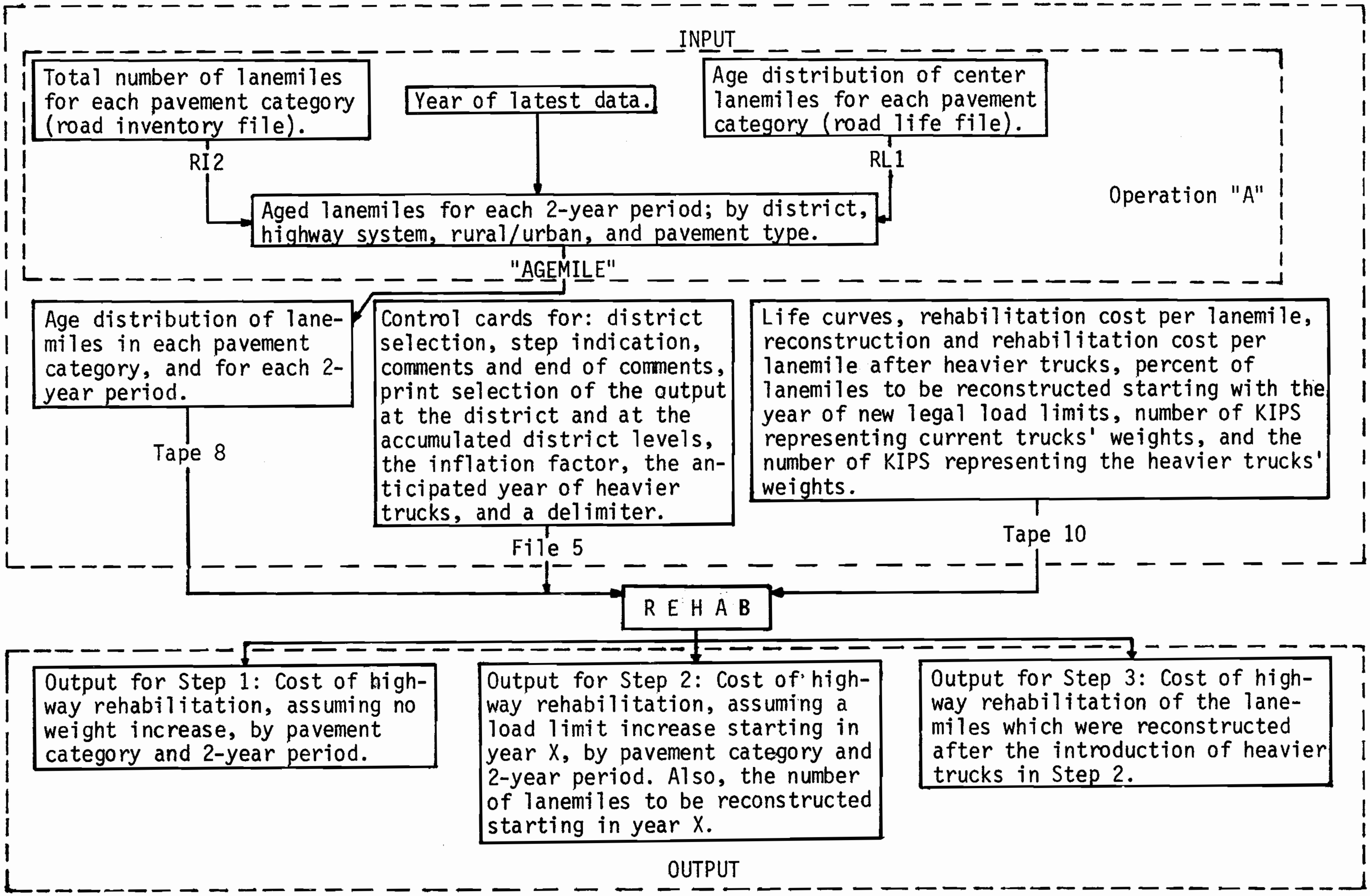


Figure 2.1 General Data Process Flow Chart of REHAB

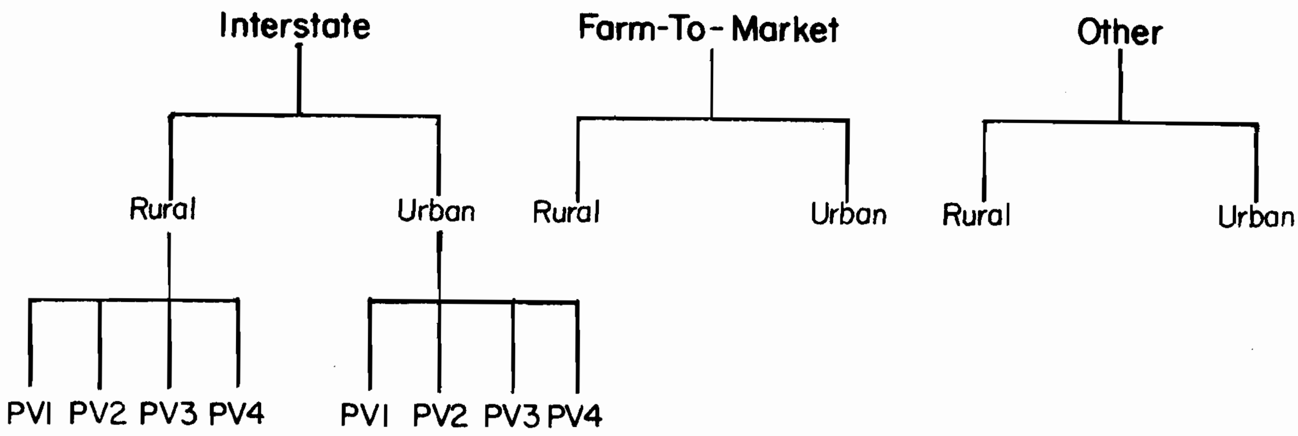
(1) A.C.P. and mixed bituminous

(2) Bituminous-surface treatment

(3) Concrete with less than one inch of A.C.P. overlay

(4) Frontage roads

The corresponding pavement categories are illustrated in Figure 2.2.



PV1: Bituminous Surface Treatment

PV2: A.C.P. and Mixed Bituminous

PV3: Asphalt Concrete w/ less than 1 inch thickness

PV4: Frontage Road

Figure 2.2. Pavement Categories for the REHAB model

For each run of the program, the following three sets of input data are generated:

(1) Control Cards - District selection card, step indicator cards, comments-and-end-of-comments cards, print selection cards for the output at the district

and at the accumulated district levels, inflation factor card, anticipated year of heavier trucks card, and a delimiter card.

(2) Age distribution of lanemiles in each pavement category.

(3) Life curves, rehabilitation cost per lanemile, reconstruction and rehabilitation costs per lanemile after heavier trucks, percent of lanemiles to be reconstructed starting with the year of new legal load limits, number of 18-kip ESAL applications representing current trucks' weights, and number of 18-kip ESAL applications representing the heavier trucks' weights.

As illustrated in Figure 2.1, the output from REHAB consists of three steps:

(1) Output for Step 1 - It consists of the rehabilitation costs under present conditions, and it may be expressed in any combination of the following forms, (a) district detail, (b) district summaries, (c) accumulated district detail, (d) accumulated district summaries, and (e) snapshot at the tenth and twentieth years.

(2) Output for Step 2 - It consists of the rehabilitation costs under new conditions and the number of miles to be reconstructed. The number of lanemiles to be rehabilitated and the costs to do it may be expressed in any combination of the forms mentioned in (1), and the number of miles to be reconstructed is passed directly to Step 3.

(3) Output for Step 3 - It consists of the number of miles to be reconstructed and of the rehabilitation costs of mileage reconstructed after new load limits. This output may be printed in any combination of the forms mentioned in [1].

2.3 Input

This section is divided into three subsections. The first subsection presents the instructions to punch the control cards. The second subsection provides the instructions to produce Tape 8. The last subsection contains the instructions to generate Tape 10.

2.3.1 CONTROL Cards

The control cards for the present REHAB model are input to the program from the card reader (DDNAME = FT05F001). These control cards are sequenced as follows:

Item 1 - District Selection Card

Item 2 - Step Indicator Card (Step 1)

Item 3 - Comment Cards (Step 1)

Item 4 - End-of-Comments Card (Step 1)

Item 5 - Print Selection Card for Output at District Level

Item 6 - Print Selection Card for Output at Accumulated District Level

Item 7 - Inflation Factor Card

Item 8 - Anticipated Year of Rehabilitation Card

*Note: If only the output from Step 1 is wanted, place a Delimiter card here,otherwise continue with Item 9.

Item 9 - Step Indicator Card (Step 2)

Item 10 - Comment Cards (Step 2)

Item 11 - End of Comments Card (Step 2)

Item 12 - Anticipated Year of Heavier Trucks Card

*Note: If output from only Steps 1 and 2 is wanted, place a Delimiter card here; otherwise continue with Item 13.

Item 13 - Step Indicator Card (Step 3)

Item 14 - Comment Cards (Step 3)

Item 15 - End of Comments Card (Step 3)

Item 16 - Delimiter Card

As can be seen from the above sequence and comments, the REHAB model can be terminated at the end of any one of the three steps. However, it should be also noted that execution of each successive step requires the execution of the previous step (s).

Next, the control cards are described and their formats presented.

Item 1 - District Selection Card

A. Description - The entire state can be selected by putting "ALL" in Cols. 45-47. Individual districts can be selected by listing the district numbers beginning in Col. 45 with the format "XX,XX, XX,...ETC". If the individual district option is chosen, a maximum of twelve districts can be selected for a single execution. Leave blank any unneeded columns.

*Note: If regional data are required, simply select those districts which comprise the desired region. Then choose the appropriate print option(s) on Item 6. The output for the summation of all districts will be identical to the regional data.

B. Format -

Cols. 1-42: "SELECT ALL STATE OR INDIVIDUAL DISTRICT =". This is a comment field only.

Cols. 43-44: Blank

Cols. 45-79: Selected Districts

(1) All State - Punch "ALL" in Cols. 45-47.

(2) Individual districts - Indicate selected districts beginning in Col. 45. Each district is a two column field followed by a comma or space.

Col. 80 Blank

Item 2 - Step Indicator Card (Step 1)

A. Description - This card will appear in the heading of the output tabulation for Step 1. A "1" must appear in Col. 39.

B. Format -

Cols. 1-38: "HIGHWAY REHABILITATION FORECAST -- STEP". This is a comment field only.

Col. 39: "1"

Cols. 40-68: "ASSUMES NO WEIGHT LOAD CHANGE." This is a comment field only.

Cols. 69-80: Blank

Item 3 - Comment Cards (Step 1)

A. Description - Any number of cards can be used. They will be printed directly before the output for Step 1. These cards should contain any desired information relevant to Step 1.

B. Format -

Cols. 1-80: Comments

Item 4 - End of Comments Card (Step 1)

A. Description - This card denotes the end of the comments section.

B. Format -

Cols. 1 - 3: "END"

Cols. 4 - 80: "OF COMMENTS FOR STEP 1". This is a comment only.

Item 5 - Print Selection Card for Output at District Level

A. Description - This card will determine the district level stratifications of output produced from the run.

(1) District Detail - If this option is chosen ("YES" punched in Cols. 47-49) the resultant output will contain a breakdown for each district selected (Item 1), by rural for each surface type and by urban for each surface type. If this option is not wanted punch "NO" in Cols. 47-49. See Note*.

(2) District Summaries - Choosing this option ("YES" punched in Cols. 26-28) will result in accumulated totals of all surface types by rural, by urban and by rural plus urban for each district. If this option is not wanted punch "NO" in Cols. 25-28. See Note*.

*Note: Code of "NO" for both options will suppress all output at the district level.

B. Format -

Cols. 1-25: "PRINT DISTRICT SUMMARIES?"

Cols. 26-28: "YES or "NO".

Cols. 31-46: "DISTRICT DETAIL?"

Cols. 47-49: "YES" or "NO".

Cols. 50-80: Blank

Item 6 - Print Selection Card for Output at Accumulated District Level

A. Description - This card will determine the output reports for the data accumulated for all the districts selected in Item 1.

(1) State or Regional Detail - If this option is chosen ("YES" punched in Cols. 65-67), the output will have a breakdown for an accumulation of all chosen districts by rural for each surface type and by urban for each surface type. It this option is not wanted punch "NO" in Cols. 65-67. See Note *.

(2) State or Regional Summaries - If this option is chosen ("YES" punched in Cols. 35-37) the output will have a summation of all surface types by rural, by urban and by rural plus urban for the accumulated data for all selected districts. If this option is not wanted punch "NO" in Cols. 35-37. See Note**.

**Note: Code of "NO" for both options will supress all output at the accumulated district level.

B. Format -

Cols. 1-34: "PRINT STATE OR REGIONAL SUMMARIES?"

Cols. 35-37: "YES" or "NO".

Cols. 38-64: "STATE OR REGIONAL DETAIL?"

Cols. 65-67: "YES" or "NO".

Cols. 68-80: Blank

Item 7 - Inflation Factor Card

A. Description - This card will contain the value of the expected inflation factor for two year increments. A code of 1.000 would indicate no inflation. A code of 1.140 would indicate a 14% increase over a two year period.

B. Format -

Cols. 1-17: "INFLATION FACTOR="

Cols. 18-22: Expected inflation factor punched in the format "X.XXX".

Cols. 23-80: Blank

Item 8 - Anticipated Year of Rehabilitation Card

A. Description - This card will have the first year of rehabilitation in Cols. 1 and 2. This value will normally be one greater than the year of the latest aged LANEMILE Data.

B. Format -

Cols. 1-2: "XX" where XX equals the year of rehabilitation.

Cols. 7-29: "YEAR OF LATEST DATA + 1"

Cols. 30-80: Blank

Item 9 - Step Indicator Card (Step 2)

A. Description - This card will appear in the heading of the output for Step 2.A "2" must appear in Col. 39.

B. Format -

Cols 1-37: "HIGHWAY REHABILITATION FORECAST--STEP". This is a comment field only.

Col. 39: "2"

Cols. 41-78: "HEAVY TRUCKS IN YR X --DO RECONSTRUCTS". This is a comment field only.

Cols. 79-80: Blank

Item 10 - Comment Cards (Step 2)

A. Description - Any number of cards can be used. They will be printed before output for Step 2. These cards should contain any desired information relevant to Step 2.

B. Format -

Cols. 1-80: Comments

Item 11 - End of Comments Card (Step 2)

A. Description - This card must be included to denote the end of the comments' section.

B. Format -

Cols. 1-3: "END"

Cols. 5-26: "OF COMMENTS FOR STEP 2". This is a comment field only.

Cols. 27-80: Blank

Item 12 - Anticipated Year of Heavier Trucks Card.

A. Description - This card will have the anticipated year of heavier trucks punched in Cols. 1 & 2. This year cannot exceed 1999.

B. Format -

Cols. 1-2: Year code.

Cols. 4-31: "YEAR X (YEAR OF HEAVY TRUCKS)". This is a comment field only.

Cols. 32-80: Blank

Item 13 - Step Indicator Card (Step 3)

A. Description - This card will appear in the heading of the output tabulation for Step 3. A "3" must appear in Col. 39. All other columns are treated as comments.

B. Format -

Cols. 1-37: "HIGHWAY REHABILITATION FORECAST--STEP"

Col. 39: "3"

Cols. 41-80: "HEAVY TRUCKS IN YEAR X--REHAB RECONSTRUCTS"

Item 14 - comment Cards (Step 3)

A. Description - Any number of cards can be used. They will be printed before the output for Step 3. These cards should contain any information relevant to Step 3.

B. Format -

Cols. 1-80: Comments

Item 15 - End of Comments Card (Step 3)

A. DescriptiOn - This card denotes the end of the comments' section.

B. Format -

Cols. 1-3: "END"

Cols. 4-80: "OF COMMENTS FOR STEP 3". This is a comment field only.

Item 16 - Delimiter Card

A. Description - A Delimiter Card contains a "/*" in Cols. 1-2. This card indicates the end of a data set.

B. Format -

Cols. 1-2: "/*"

Cols. 3-80: Blank

2.3.2 Tape 8

Tape 8 (DDNAME = FT08F001) contains the number of lanemiles of each pavement category of a given district, classified according to pavement age. In the preparation of the age profile, twenty-five 2-year age groups are defined. Each record of Tape 8 is divided into 7 fields as described in Table 2.1.

Table 2.1 Record Description of Tape 8

Field	Field Length	Item Description
1	3	Blank
2	2	District Number
3	1	Rural or Urban
4	2	Highway System
5	3	Pavement Type
6	11	Blank
7	125	Number of lanemiles for the 25 age groups

The description and corresponding formats for each field of the records stored in this file are given below:

Cols. 1-3: Blank

Cols. 4-5: District Number. Each district is a two column field.

Cols. 6: Rural or Urban. (1) Rural - "R" (2) Urban - "U".

Cols. 7-8: Highway System. (1) Interstate - "IH" (2) Farm to Market - "FM" (3) All Others - "OT"

Cols. 9-11: Pavement Type. (1) Bituminous - surface treatment - "PV1".
(2) A.C.P. and mixed bituminous - "PV3".
(3) Concrete with less than one inch of A.C.P. overlay - "PV3".

Cols 12-22: Blank

Cols.23-147: Number of lanemiles in each of the 25 age groups. The number of aged lanemiles for each group is a five-column field.

2.3.3 Tape 10

Tape 10 (DDNAME = FT10F001) contains the life curves, the rehabilitation costs per lanemile, the percent of lanemiles to be reconstructed, the reconstruction and rehabilitation costs per lanemile after changing the legal load limits, and the KIPS representing the current trucks' and the proposed trucks' weights. Each record of Tape 10 is divided into 8 fields as described in Table 2.2.

In Table 2.2 the following notation will be used:

LI: Life curves

CS: Rehabilitation cost per lanemile

RC: Percent of lanemiles to be reconstructed after changing the legal load limits

CN: Reconstruction and rehabilitation costs per lanemile after new legal load limits

K1: KIPS representing current trucks' weights

K2: KIPS representing the weights of the proposed heavier trucks

Table 2.2 Record Description of Tape 10

Field	Field Length	Item Description
1	2	Record Type: LI, CS, RC, CN, K1, K2
2	2	Highway System
3	3	District Number
4	1	Rural or Urban
5	3	Pavement Type
6	65	Data
7	3	Blank
8	1	Sequence Indicator (Defined only for LI)

A detailed description of the format of each field, for each of the six record types mentioned in Table 2.2, is given as follows:

A. Life Curves:

Cols. 1-2: Record Type - "LI"

Cols. 3-4: Highway System*

(1) Interstate - "IH"

(2) Farm to Market - "FM"

(3) All Others - "OT"

Cols. 5-7: District Number*. Each district is a two column field, and a "D" goes in front of the district number.

Col. 8: Rural or Urban*

(1) Rural - "R"

(2) Urban - "U"

Cols. 9-11: Pavement Type *

(1) Bituminous - surface treatment - "PV1 ".

(2) A.C.P. and mixed bituminous - "PV2".

(3) Concrete with less than one inch of A.C.P. overlay "PV3".

(4) Frontage roads "PV4".

Cols. 12-79: Data for the first thirteen age groups. The data for each age group is a five-column field.

Col. 80 Sequence Indicator ("1" or "2"). When coding a continuation record, ("2" in Col. 80) code Cols. 1-11 identical to the first record.

*Note: If any of the columns 3 through 11 are blank, then all codes are used.

B. Rehabilitation Cost per Lanemile:

Cols. 1-2: Record Type - "CS"

Cols. 3-11: Same as for Life Curves.

Cols. 12-16: Cost for the first age group in thousands of dollars*.

Cols. 17-80: Blank

*Note: The cost for future age groups will be generated by applying the inflation factor to the previous cost (Cols. 12-16). Generation of costs for future years is compounded.

C. Percent of Lanemiles To Be Reconstructed After Changing the Legal Load Limits

Cols. 1-2: Record Type - "RC".

Cols. 3-11: Same as for Life Curves.

Cols. 12-16: Percent of lanemiles to be reconstructed starting with the year of heavier trucks. The data is a five-column field, and it must contain one decimal place. For example, 100.0.

Cols. 17-80: Blank

D. Reconstruction and Rehabilitation Costs per Lanemile After New Legal Load Limits

Cols. 1-2: Record Type - "CN"

Cols. 3-11: Same as for Life Curves.

Cols. 12-16: Cost for the first age group in thousands of dollars*.

Cols. 17-80: Blank

*Note: The cost for future age groups will be generated by applying the inflation factor to the previous cost (Cols. 12-16). Generation of costs for future years is compounded.

E. ESAL'S Representing Current Trucks' Weights

Cols. 1-2: Record Type - "K1".

Cols. 3-11: Same as for Life Curves.

Cols. 12-16: 18,000 pound equivalent single axle load applications representing the current truck weights.

Cols. 17-80: Blank

F. ESAL'S Representing the Proposed Trucks' Weights

Cols. 1-2: Record Type - "K2"

Cols. 3-11: Same as Life Curves.

Cols. 12-16: ESAL'S representing the weights of the proposed trucks.

Cols. 17-80: Blank

2.4 Basic Methodology

The basic methodology of REHAB is summarized in Figure 2.3. As can be seen from this flow chart, the first phase of the REHAB methodology is the generation of input data, which was discussed in Section 2.3.

The second phase of the methodology is to calculate the number of lanemiles in need of rehabilitation in the next 2-year period, by pavement category and age group. This is accomplished by multiplying the number of lanemiles in each age group by the corresponding probability of rehabilitation, as indicated by the survivor curve. The total number of rehabilitated lanemiles in the first 2-year period is given by the sum of mileage rehabilitated in each age group.

The remaining lanemiles that were not rehabilitated are reaged by shifting them to the next age group. Those rehabilitated are placed in

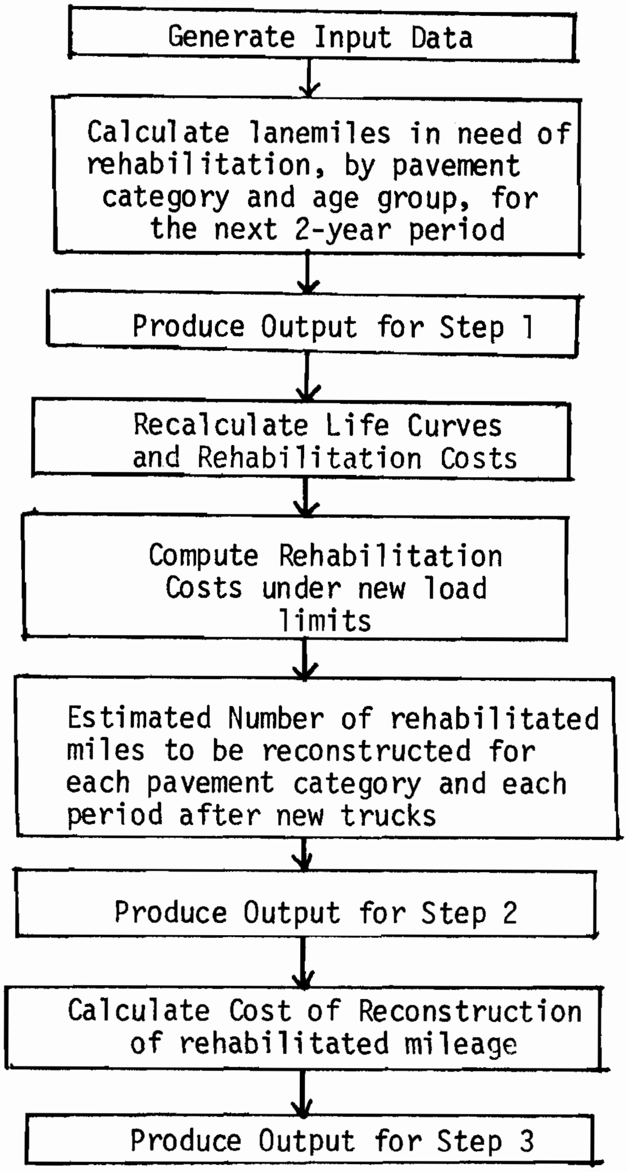


Figure 2.3 Basic Methodology of REHAB

the first age group. Using this new age profile, the procedure is repeated to find the total lanemileage to be rehabilitated in the second 2-year period of the planning horizon, and so on.

Assuming a rehabilitation alternative and a rehabilitation cost per lanemile, the total rehabilitation requirement in each period of the planning horizon can be transformed into a rehabilitation cost. This is the output for Step 1, and it will be further discussed in Section 2.5.

The next phase of the methodology consists of recalculating the life curves and the rehabilitation costs starting the year in which the legal load limits are changed. Figure 2.4 illustrates the basic transformation of the life curves as a result of an increase in the legal load limits. It is assummed that the reduction of the remaining life is proportional to the 18-kip ratio. With the new life curves and the new rehabilitation costs it is possible to repeat the procedure for Step 1

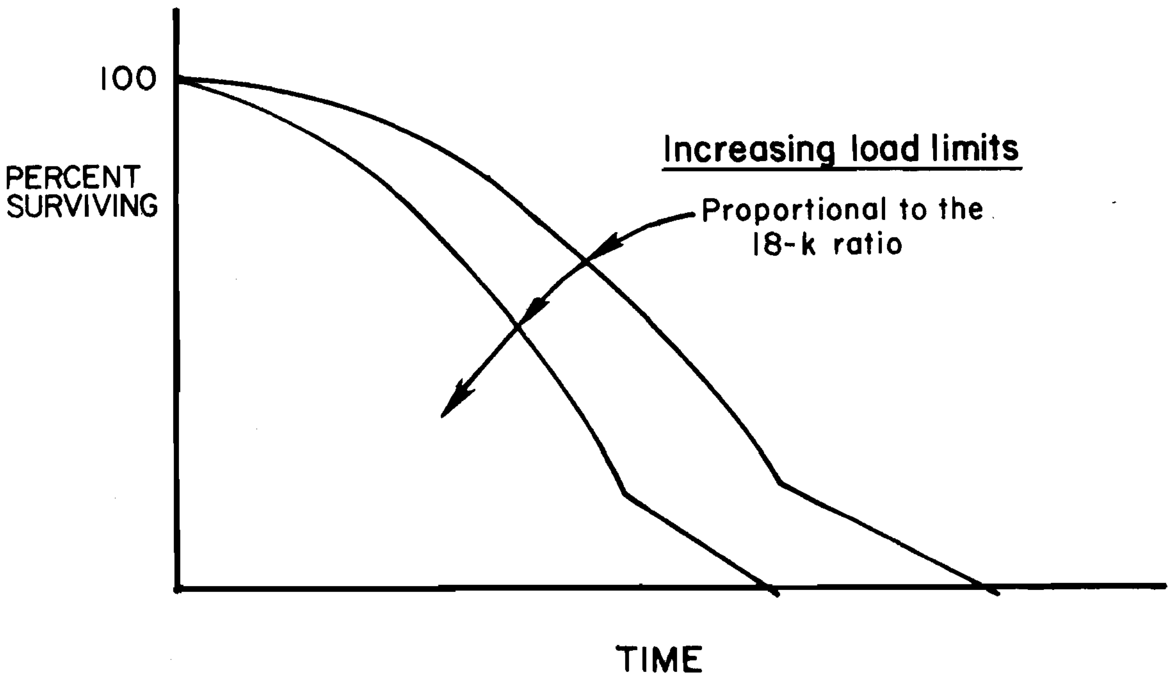


Figure 2.4. Life Curves' Shifting Procedure Use In REHAB

and compute the rehabilitation costs under new load limits. Since a percentage of rehabilitated lanemiles to be reconstructed is known, it is therefore possible to estimate the number of lanemiles to be reconstructed for each pavement category and each period after the year in which new load limits are adopted. This completes the output for Step 2. Figure 2.5 shows the relationship between the costs of Step 1 and Step 2.

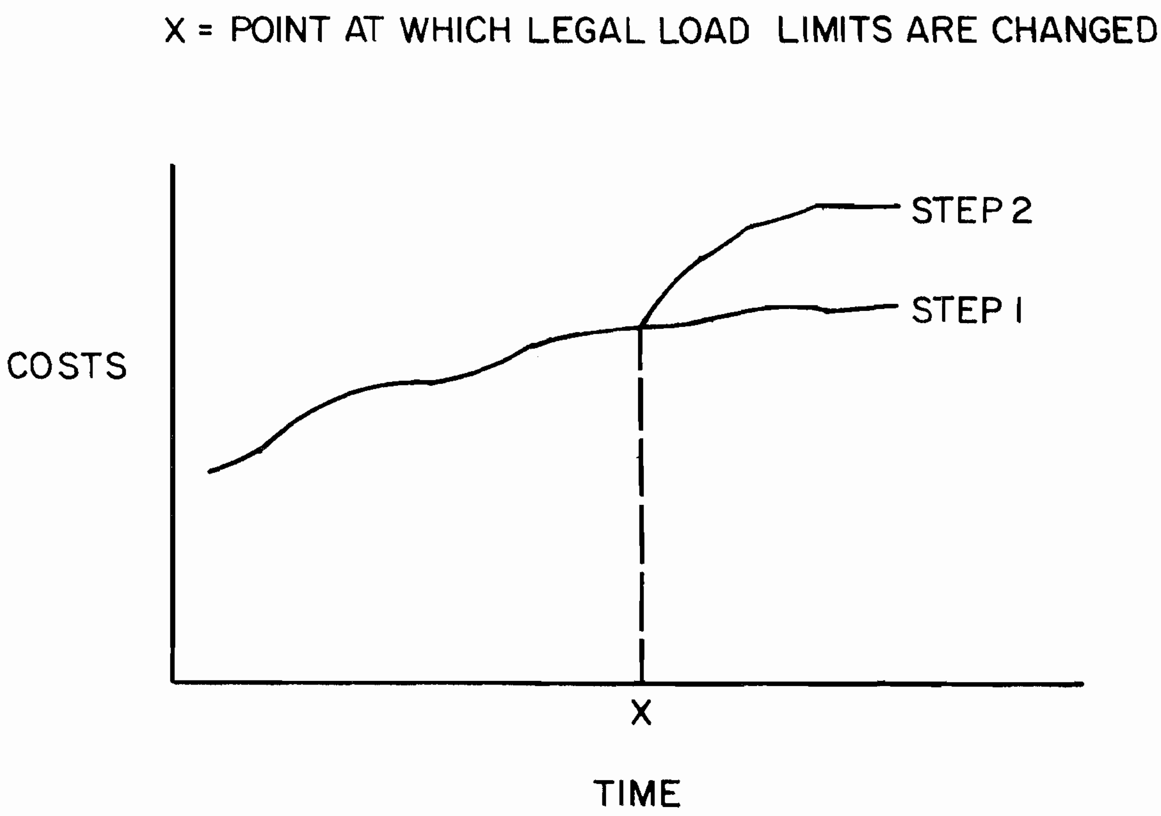


Figure 2.5. Cost Relationship Between Step 1 and Step 2 of REHAB

The last phase of the REHAB methodology consists of calculating the cost of reconstruction of rehabilitated mileage. This is accomplished by multiplying the number of rehabilitated miles in need of reconstruction, which was computed in Step 2, by the cost of reconstruction per lanemile. The output for Step 3 contains the number of lanemiles in need of reconstruction, and the corresponding cost for each pavement category and time period, starting the year in which the legal load limits are changed. This output is further discussed in Section 2.5.

2.5 Output

As previously mentioned, the REHAB program can be terminated and output obtained at the end of any of the three steps of the model. This section has been divided into three subsections to discuss the output of each of these steps.

2.5.1. Output From Step 1

The output of Step 1, which assumes no change in the legal load limits, consists of the following two types of information for each pavement category:

(1) Snapshot - It consists of the age distribution of lanemiles at present and at two 10-year intervals foreach pavement category.

(2) Cost Summary - It consists of the number of lanemiles to be rehabilitated, the average rehabilitation cost per lanemile, and the total cost for each highway system. Costs are totaled for all systems, for each 2-year period.

The two types of output from Step 1 can be expressed in any of the following four printing options, for each pavement category:

(1) Detailed Output at the Single District Level - The resultant output by using this printing option will produce a breakdown of the mileage by pavement category and age group, for each district selected.

(2) Summarized Output at the Single District Level - Choosing this option will result in accumulated totals of all pavement types by rural, by urban, and by rural plus urban, for all highway systems and age groups, for each district.

(3) Detailed Output at the Accumulated District Level-If this option is chosen, the output will have a breakdown of the total mileage of all chosen districts by pavement category and age group.

(4) Summarized output at the accumulated distric level - choosing this option will result in totals of all pavement types by rural, by urban, and by rural plus urban, for all highway systems and age groups, for the accumulated data corresponding to the selected districts.

2.5.2 Output From Step 2

The output from Step 2 can be expressed in any of the four printing options mentioned for Step 1. However, the content of the output from Step 2 differs as follows from the information output by Step 1:

A. The content of the output from Step 2 is identical to the output from Step 1 until the year in which new legal load limits are applied. At this point in time, the format of the outputs remain the same, but the numbers will vary due to the recalculation of the survivor curves and the rehabilitation costs.

B. The content of the output of Step 2 also differs from the one of Step 1, because Step 2 generates the number of lanemiles to be constructed starting the year of new load limits and outputs this information directly to Step 3.

2.5.3. Output From Step 3

The output from REHAB's third step consists, for each pavement category, of the number of lanemiles to be reconstructed after the introduction of heavier trucks in Step 2, and of the road rehabilitation cost of the lanemileage reconstructed after new load limits. The output from Step 3 can be expressed in any of the four forms described in Section 2.5.1.

CHAPTER 3

THE NULOAD PROGRAM

The purpose of this chapter is to present a simplified description of NULOAD, to identify the critical assumptions of the program, and to compare the basic methodologies followed by NULOAD and REHAB.

3.1 General Description

The overall objective of NULOAD is to determine the effects of changes in truck size, weight, and configuration on pavement performance and to relate those effects to pavement maintenance and rehabilitation requirements. Once these requirements are established, the corresponding costs are estimated. In this way, the final purpose of the program is to inject sufficient information into the decision-making process concerning the allocation of limited funds in the upkeeping and rehabilitation of a transportation system during a given planning horizon. Figure 3.1 shows the basic methodology followed by the NULOAD program.

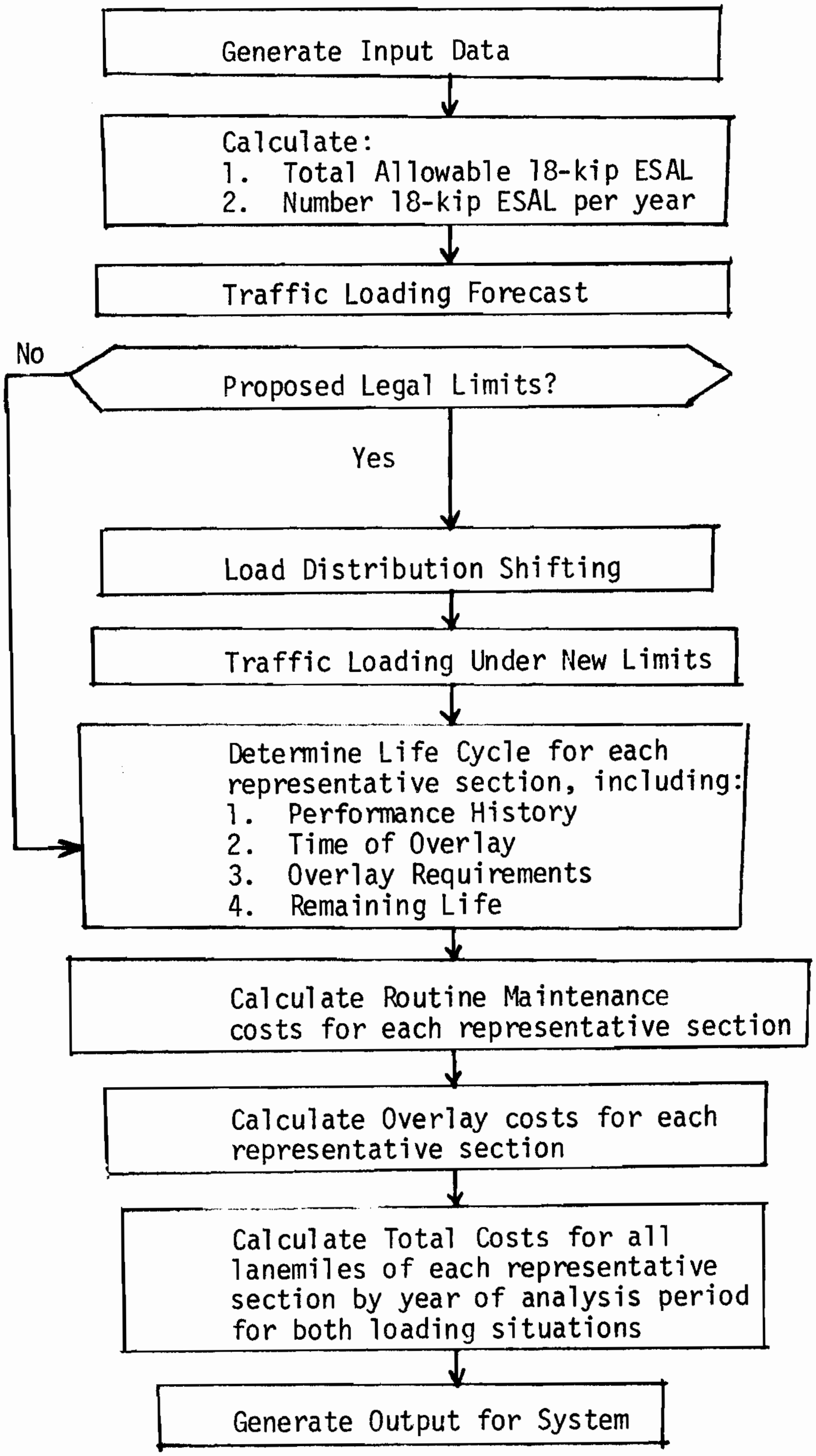


Figure 3.1. Basic Methodology of NULOAD

The input data for NULOAD can be classified according to the following categories:

A. Traffic and load survey

B. Performance prediction variables

C. Economic cost prediction data

D. Program controls

Each of the above categories will be subdivided into specific data requirements in the next section.

3.2 Assumptions of NULOAD

The fundamental assumptions of NULOAD can be classified according to structural, economic, traffic, maintenance, and data availability characteristics.

Structural

(1) Response Variable: pavement failure is assumed to be independent of environmental conditions, since the AASHTO regional factor is considered by many agencies as insufficient.

(2) The Performance Equation: the AASHTO Interim design guide equations for flexible and rigid pavements are assumed to apply to pavement performance in states other than Illinois.

(3) Rehabilitation Activity: rehabilitation is defined in terms of overlays only, excluding other reasonable rehabilitations alternatives for the state of Texas, as well as other states in the nation. The thickness of overlays is assumed to be a function of only type of pavement and the ride condition.

(4) Single Tires: the effect of single tires is separated to compute equivalency factors.

Economical

(1) Overlay Costs: the program assumes that unit costs are independent of thickness.

(2) Salvage Value: salvage value is addressed from a purely structural point of view, not including other elements such as geometry and safety.

(3) Inflation Effects: inflation effects are not directly considered. Budget levels, however, are assumed to be dependent on inflation rates.

Traffic

In order to predict what will happen to the distribution of gross vehicle weights for the various types of trucks after a law change, National Cooperative Highway Research Program (NCHRP) researchers [11] examined measured GVW (gross vehicle weight) distributions before and after size and weight law changes. A pattern existing in these data show a shift to heavier trucks with a small shift on the empty weight portion of the distribution. A shift approximately proportional to the ratio of the practical maximum gross weight under the new law to the practical maximum gross weight under the old law exists on the loaded weight portion of the distribution. Figure 3.2 illustrates this trend.

Maintenance

(1) Maintenance Costs of Roads Other than Freeways: the predictive equations have been developed for only multilane-freeways. If a road does not belong to this category, its maintenance cost is estimated as a percentage of the cost as if the road were a freeway.

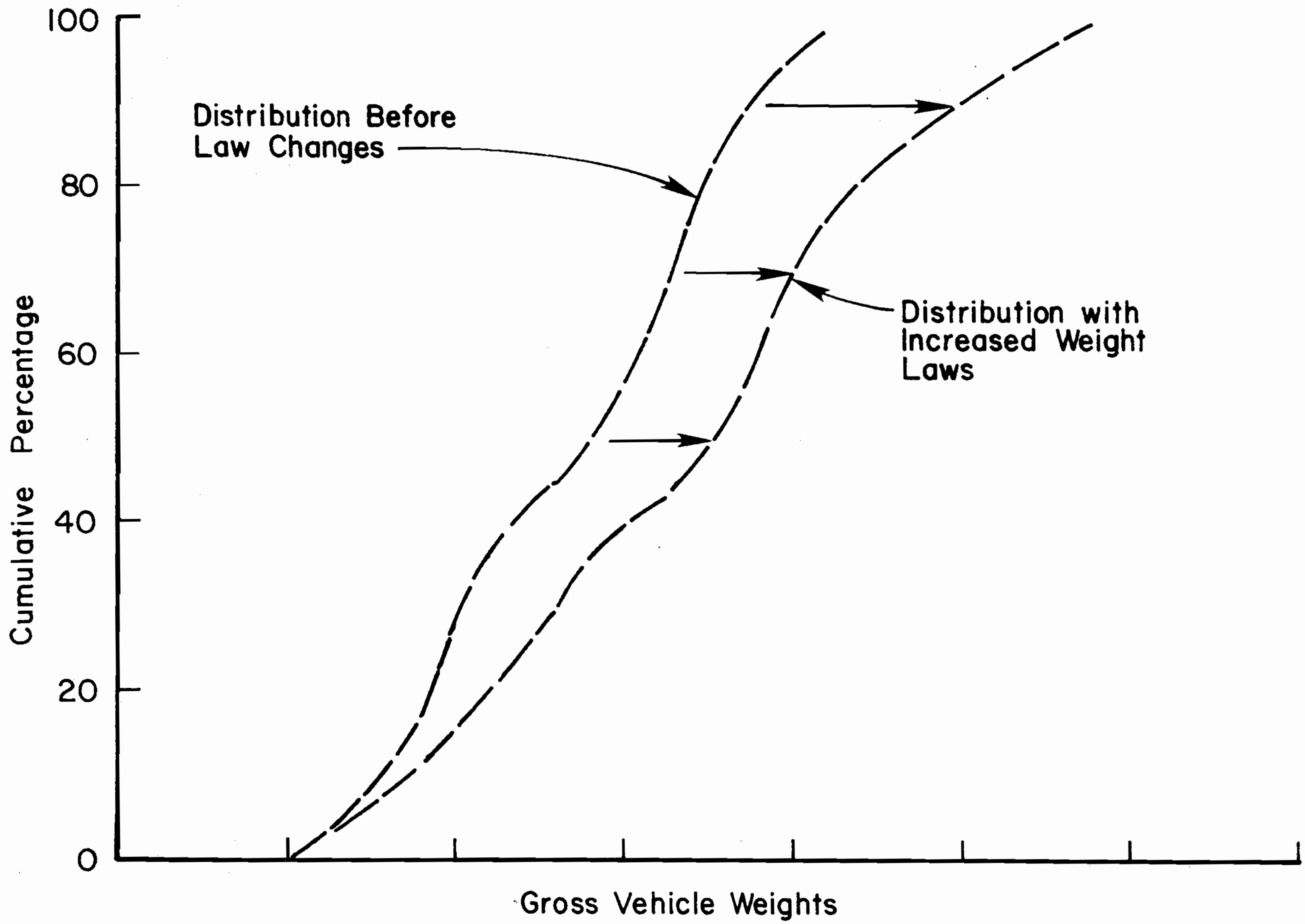


Figure 3.2 Typical Historical Shifts In Gross Weight Distributions

(2) Maintenance Predictive Models: if the historical maintenance option is not chosen, the model uses existing predictive equations to estimate the amount of maintenance required for flexible pavements, rigid pavements, mudjacking concrete pavements, and blowups per year.

(3) Accelerated Maintenance: maintenance costs increases between two PSI levels are the same for both present and new axle-load limits, but time is shorter for the new limits. Figure 3.3 illustrates this assumption.

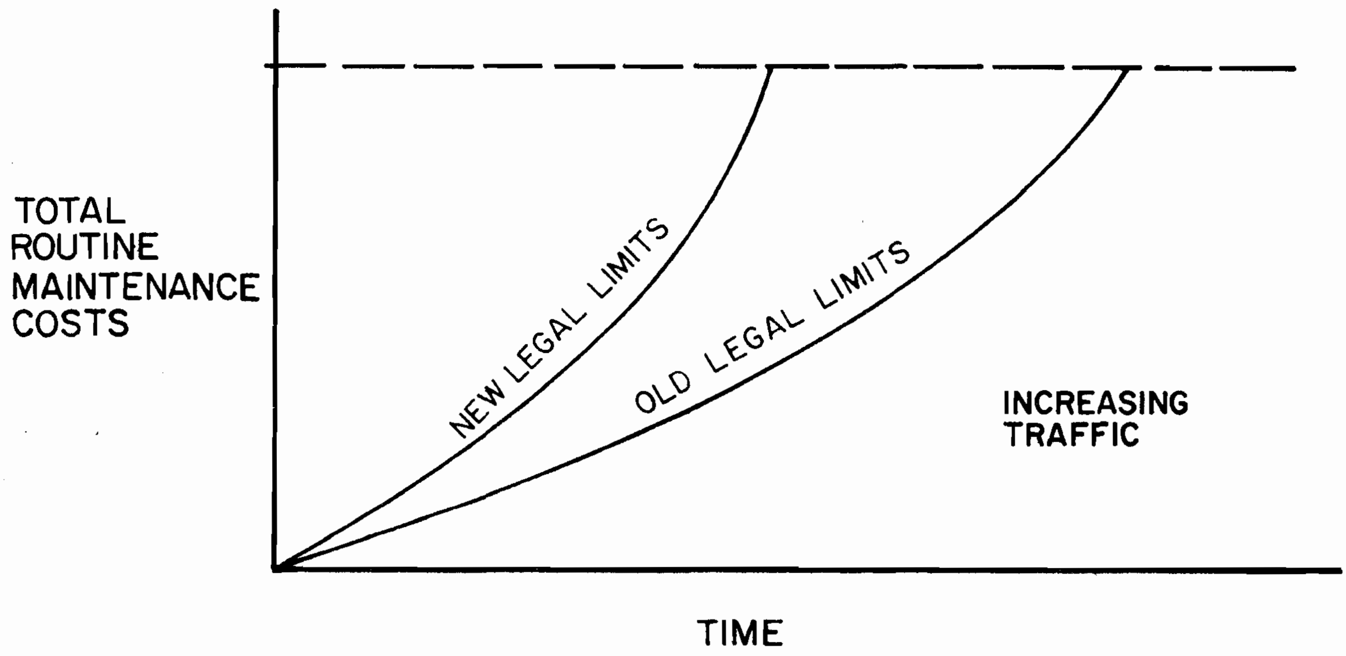


Figure 3.3. NULOAD's Accelerated Maintenance Assumption

Data Availability

(1) Traffic and Load Survey Information:

percent of each truck type projection for years of planning horizon. Information comes from W-4 and W-5 tables.

Systems are classified as interstate rural, other rural, all rural, all urban, all system.

(2) Performance Prediction Variables:

Highway network statistics: number of lanemiles, age, PSI values, for each structural design section.

Design Section Structure: lane widths, regional factors, material types, layer thicknesses, soil support values layer coefficients; for portland cement concrete and composite pavements, composite soil support values, elastic modulus of concrete, and concrete flexural strength.

Pavements Older than Terminal Serviceability: lanemiles of pavement which at the time of evaluation have serviceability values lower than the system terminal PSI. Data needed include: percent of lanemiles remaining below terminal PSI at end of analysis period, percent total lanemiles never overlain, percent of inflation used in obtaining predicted overlay funding levels, and annual projected overlay funds.

(3) Economic Cost Prediction Data:

Data needed for application of maintenance models (FHWA EAROMAR models).

Historical Maintenance Data.

Overlay Costs: geometric, cost, placement data.

3.3 REHAB-NULOAD Comparison

Both NULOAD and REHAB were developed to perform the same function. There are different approaches and assumptions in each program. NULOAD is a complete computer program that uses the AASHTO interim guide performance equations to predict "survivor curves". On the other hand, REHAB uses "survivor curves" directly developed from the TTI flexible pavement data base and from some assumptions concerning pavements not in the data base. Both programs incorporate assumptions in the areas of economics, maintenance costs, and redistribution patterns of truck weights when there is a change in truck weight limits. In practice, REHAB requires a significant amount of hand calculations or use of data entered from the DHPT data base. On the other hand, NULOAD is self-contained and requires no additional amount of data manipulation. The major differences between the outputs of the two programs will be largely explained by the differences in the assumptions concerning maintenance costs and weight redistribution, and by the use of the AASHTO interim guide equations.

The results from the comparison of the two programs are summarized in Tables 3.1, 3.2, and 3.3. Table 3.1 compares the input requirements; Table 3.2 compares the output requirements; and Table 3.3 compares REHAB and NULOAD from the following standpoints:

1. Use of AASHTO Equations
2. Use of Survivor Curves
3. Road Rehabilitation
4. Road Maintenance
5. Equivalency Factors
6. Axle Load Distribution
7. Salvage Value
8. Interest Rate

Table 3.1 Input Description

REHAB	NULOAD
1. Road Inventory File: Total number of lanemiles for each pavement category.	1. Serviceability Criteria
2. Road Life File: Age distribution of lanemiles by pavement category	2. Structural Characteristics
3. Life Curves	3. Soil Support Values
4. Rehabilitation Costs	4. Regional Factors
5. Reconstruction Costs	5. Traffic Data
6. Reconstruction Percentages	6. Age-lanemile Distribution
7. Traffic Data	7. Maintenance and Rehabilitation Data

Table 3.2 Output Description

REHAB	NULOAD
1. Rehabilitation costs under present conditions (Step 1)	1. Predicted Cost Ratios by section, system, or total.
2. Rehabilitation costs under new conditions, and miles to be reconstructed (Step 2)	2. Resulting Cost Difference between present and new conditions.
3. Rehabilitation costs of mileage reconstructed after new load limits (Step 3).	3. Remaining Life in terms of 18-kip ESAL's.

Table 3.3 REHAB-NULOAD Comparison

Item	REHAB	NULOAD
1. AASHTO Equations		AASHO Equations are used to determine the number of 18-kip ESAL that a typical pavement structure will sustain before reaching terminal PSI.
2. Survivor Curves	Directly input into the program. The curves are used to determine the number of lanemiles to be rehabilitated.	Survivor curves are used to determine the time during the analysis period when mileage of a certain age require timely overlay.
3. Rehabilitation	One type of rehabilitation is defined. Cost of rehabilitation = cost per mile X number of miles.	Only one type of rehabilitation (overlay). Cost of rehabilitation = cost of overlay plus shoulder cost. One overlay for any representative section is allowed.
4. Maintenance		Routine maintenance includes work related to pavement condition. There are two options: FHWA EAROMAR models, and historical data.
5. Equivalency Factors		These factors are used in the calculation of number of 18-kip ESAL.
6. Axle Load Distribution	ESAL's representing current and heavy truck weights are directly input into the program.	The axle load distributions for present load limits are shifted in order to evaluate the effect of legal load limit changes on future truck weight distributions.
7. Salvage Value		Defined as value of existing roadway plus value of overlay. It is calculated from both a structural standpoint and a monetary standpoint.
8. Interest Rate		A constant annual rate is used.

CHAPTER 4

CRITICAL EVALUATION AND RECOMMENDATIONS

The purpose of this chapter is to evaluate the assumptions of REHAB and to recommend specific improvements in the forecasting capabilities of both REHAB and NULOAD. For NULOAD (Section 3.2) and REHAB (Section 2.1), the assumptions were classified according to structural design, economic analysis, traffic conditions, maintenance (only used in NULOAD), and data availability. In the discussion of the assumptions of REHAB, the critical aspects are classified according to data availability, road rehabilitation, road maintenance, and economic analysis.

In order to propose an overall course of action to be assessed by the DHT, the following alternatives can be considered:

Alternative 1:

(1) Modify NULOAD to produce reports for the state legislative body. These reports will aid final decision-making concerning rehabiliation and maintenance funding levels.

(2) Modify NULOAD again for interaction with the state highway data base.

Alternative 2:

(1) Modify REHAB to produce reports for the legislators.

(2) Modify REHAB again for interaction with the data base.

Alternative 3:

Develop a hybrid forecasting model which combines the most attractive features of both NULOAD and REHAB. For the implementation of this alternative, both Alternative 1 and Alternative 2 must be carefully examined. Alternative 3 seems to be the best course of action. The corresponding research proposal for its development and implementation is given in

Appendix C.

Section 4.1 discusses the critical assumptions of REHAB. Section 4.2 identifies the recommended modifications for NULOAD. Finally, Section 4.3 recommends modifications for REHAB.

4.1 Discussion of Critical Assumptions in REHAB

The critical aspects of REHAB to be discussed can be classifed as follows:

A. Data Availability

B. Road Rehabilitation

C. Road Maintenance

D. Economic Analysis

4.1.1 Data Availability

In order to successfully run the present REHAB model, a substantial amount of data transformation is required. This limitation significantly affects the readiness and overall usefulness of the program.

Age profiles for each pavement category in each district must be externally computed using information from the road inventory file (RI2) and the road life file (RL1) before being input to REHAB.

Two other critical activities that must be completed before using REHAB are (a) generation of the survivor curves and (b) development of a shifting procedure to predict what will happen to the distribution of gross vehicle weights for the various types of trucks after a law change.

4.1.2. Road Rehabilitation

The REHAB program presently considers only one type of road rehabilitation. The total rehabilitation cost is computed by multiplying the number of lanemiles in need of rehabilitation by the cost of rehabilitation per lanemile.

One specific rehabilitation alternative is currently used for interstate, farm to market and other road types. The assumption of one rehabilitation technique severely restricts the choice of investment possibilities under limited funding.

4.1.3 Road Maintenance

The current version of the REHAB model does not include the calculation and analysis of road maintenance costs. Since maintenance costs represent a significant portion of the total transportation cost, the current output of the program is insufficient for final decision-making concerning the allocation of limited funds.

4.1.4 Economic Analysis

The present REHAB program does not perform any kind of economic analysis, which limits its scope since no mechanism is available to compare the cost impact of several possible rehabilitation alternatives. The lack of such a mechanism is due to not considering the rate of interest and the salvage value to estimate present values of annual costs.

4.2. Recommended Modifications for NULOAD.

The recommended changes in NULOAD seek to improve the forecasting capability of the program for typical conditions of Texas highways. Although a high number of minor modifications could be implemented, the most significant changes are listed below:

A. Use of Texas performance structural equations.

B. Use of the highway cost index in the economic analysis.

C. Use of a modified load redistribution procedure.

D. Use of a maintenance cost methodology for roads other than A.C.P.

4.2.1. Use of Texas Performance Structural Equations

4.2.1.1 Performance Equations in NULOAD at Present

Both the flexible and rigid pavement performance equations used in NULOAD were developed at the AASHTO Road Test and are part of the AASHTO Interim Design Guide. In their simplest form, both equations are as given below

$$g = \left(R\frac{W_{18}}{\rho}\right)^{\beta}$$

where

W_{18} = the number of 18-kip equivalent single axle loads that have passed over a pavement

g = the damage ratio which is discussed in detail below

β = a power which differs between rigid and flexible pavements and which depends upon the layer thickness, AASHTO layer coefficients of each layer, and the configuration of wheel loadings applied.

ρ = the total number of 18-k equivalent single axle loads that will cause the amount of damage represented by the damage ratio, g. The quantity ρ depends upon layer thicknesses, layer coefficients, and wheel configurations.

R = the regional climatic factor.

The damage function, g, is a ratio of serviceability indexes, as given below:

$$g = \frac{P_i - P_n}{P_i - P_t}$$

where

P_n = the present serviceability index at the present time, n years after construction or major rehabilitation

P_i = the initial serviceability index

P_t = the terminal serviceability. These are shown in Fig. 4.1.

The damage function is a number that begins at 0.0 when the pavement is new and becomes 1.0 when the pavement reaches its terminal serviceability index. The number of 18-kip equivalent single axle loads (ESAL) required to reduce the serviceability index to P_n is

$$W_n = \frac{\rho\, g^{1/\beta}}{R}$$

The number of 18-kip ESAL that remain to be carried by the pavement is

$$W_r = \frac{\rho}{R}\left(1 - g^{1/\beta}\right)$$

The annual number of 18-kip ESAL that have caused the damage thus far is w_n, as given below.

$$w_n = \frac{i W_n}{\left[(1 + i)^n - 1\right]}$$

where n = the number of years since the pavement was constructed or rehabilitated

i = the annual growth rate in 18-k ESAL

$$r = \frac{\ell n \left[\dfrac{W_r\, i}{W_n} + (1 + i)^n\right]}{\ell n\,(1 + i)} - n$$

If growth rate is zero, the equations are as follows:

$$w_n = \frac{W_n}{n}$$

and

$$r = \frac{Wr}{w_n}$$

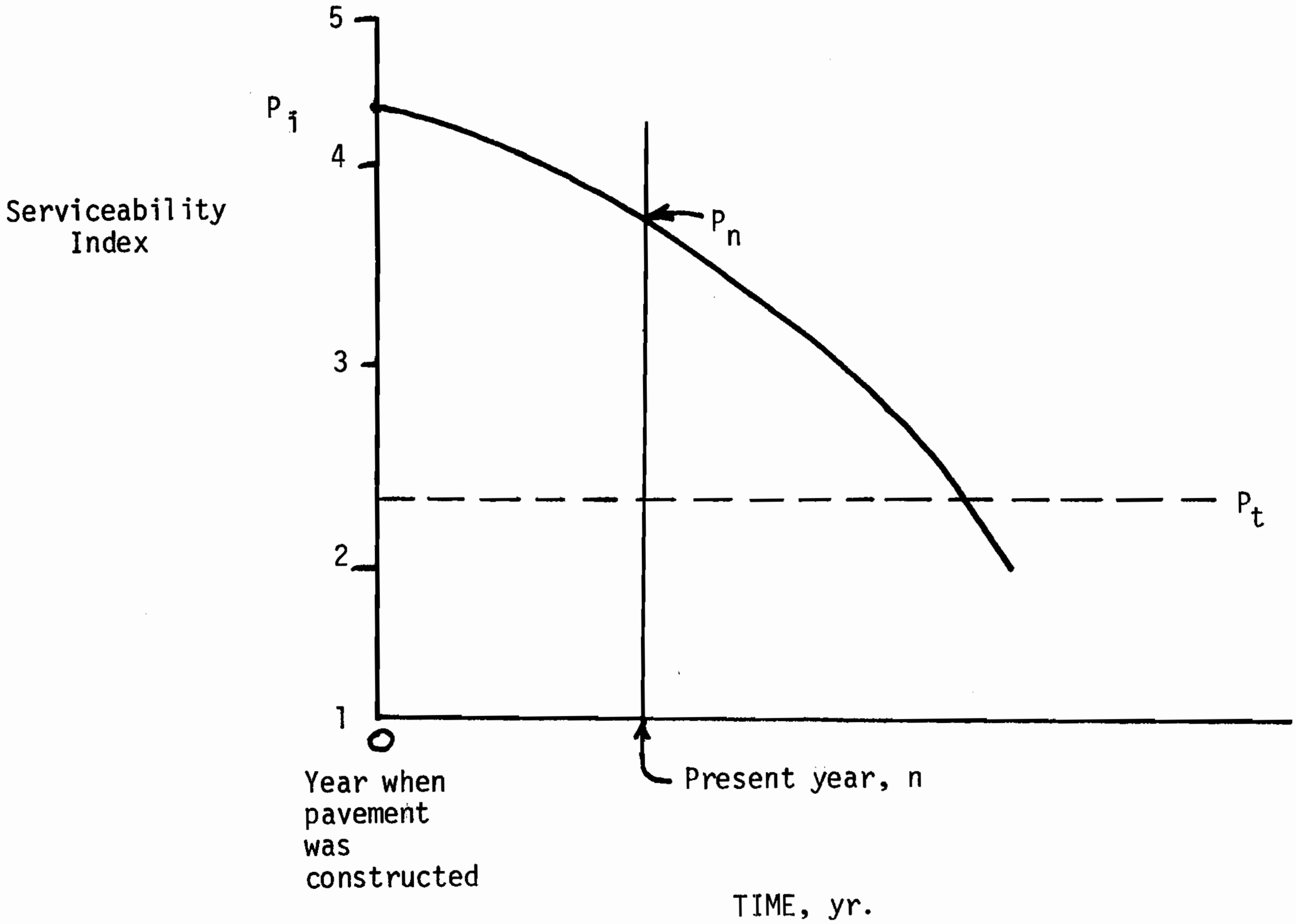


Figure 4.1 Graph of Serviceability Index versus Time

Once the time remaining in the life of the pavement is known, the survivor curve for this type of pavement can be generated.

4.2.1.2. Modifications Using Texas Flexible Pavement Performance Equations.

The AASHTO performance equation for flexible pavements has been found to be inadequate for describing the performance of these pavements in Texas. It has been found necessary to determine separate equations for the following types of pavements:

1. Hot mix asphaltic concrete on flexible base in its first performance period.
2. Thick hot mix asphaltic concrete pavements.
3. Hot mix asphlatic concrete pavements on bituminous base.
4. Overlaid flexible pavements.
5. Surface treated pavements.

The material properties used in these equations need to be measurable in the laboratory or inferred from non-destructive tests in the field. The elastic moduli of the materials in each layer are more convenient material properties to use than the AASHTO layer coefficients currently used in NULOAD. The recently developed Russian equations (in TTI Research Report 207-7F) make it possible to calculate Dynaflect deflections which are used in the Texas flexible pavement performance equations.

The form of each of these equations is different from that of the AASHTO Interim guide.

$$g = e^{-K/W_{18}^{\,n}}$$

where g = a damage function similar to the one discussed previously.

W_{18} = the number of 18-kip ESAL's that has caused the damage.

K = a deterioration rate constant which depends upon climatic variables, Dynaflect measurements (either calculated or measured in the field), age, daily traffic, and subgrade properties.

n = a power of the 18-kip ESAL.

Equations have been found for the K-values for each of the types of pavements mentioned above using actual data from Texas pavements. The climatic variables are actually measureable quantities, such as annual rainfall, freeze-thaw cycles, minimum annual temperature, and so on, rather than the ill-defined regional factor in the AASHTO equation.

The form of the equation given above produces an S-shaped curve which has been found to be more characteristic of actual pavement performance than the convex curve produced by the AASHTO equation.

The damage function as defined here is

$$g = \frac{P_i - P}{P_i - P_f}$$

where P_i = the initial serviceability index.

P = the present serviceability index.

P_f = the asymptote value of serviceability index which is discussed below.

The value of g changes from 0.0 when the pavement is new to some value less than one. The terminal value of g is defined by

$$g_t = \frac{P_i - P_t}{P_i - P_f}$$

where P_t = the terminal value of serviceability index

These four values of serviceability index are illustrated in the following figure (Figure 4.2). The value of p_f, the asymptote value of serviceability index is calculated using an equation that was derived from field data. In general, p_f was found to vary with climate, traffic, Dynaflect, and subgrade variables.

The equation for the number of 18-k ESAL's that have passed over the pavement to the present is

$$W_n = \left[-K/\log_e (g_n)\right]^{1/n}$$

The number of 18-kip ESAL's to terminal serviceability index is

$$W_t = \left[-K/\log_e (g_t)\right]^{1/n}$$

The number of 18-kip ESAL's that remain to be carried by the pavement is

$$W_r = W_t - W_n$$

Once these values have been calculated, the computation of the annual 18-kip ESAL applications, w_n, and the remaining years of life left in the pavement are as done before.

This approach explained thus far bases the calculation of remaining pavement life upon serviceability index alone. However, it is well known that pavements may be seriously distressed and in need of major rehabilitation before the serviceability index drops to its terminal value. This is particularly true of pavements with severe alligator and transverse cracks. In cases when p_f is higher than p_t or when the remaining life calculated from the serviceability index equation is very long (say 30 to 40 years), the pavement will probably need major rehabilitation due to distress, and

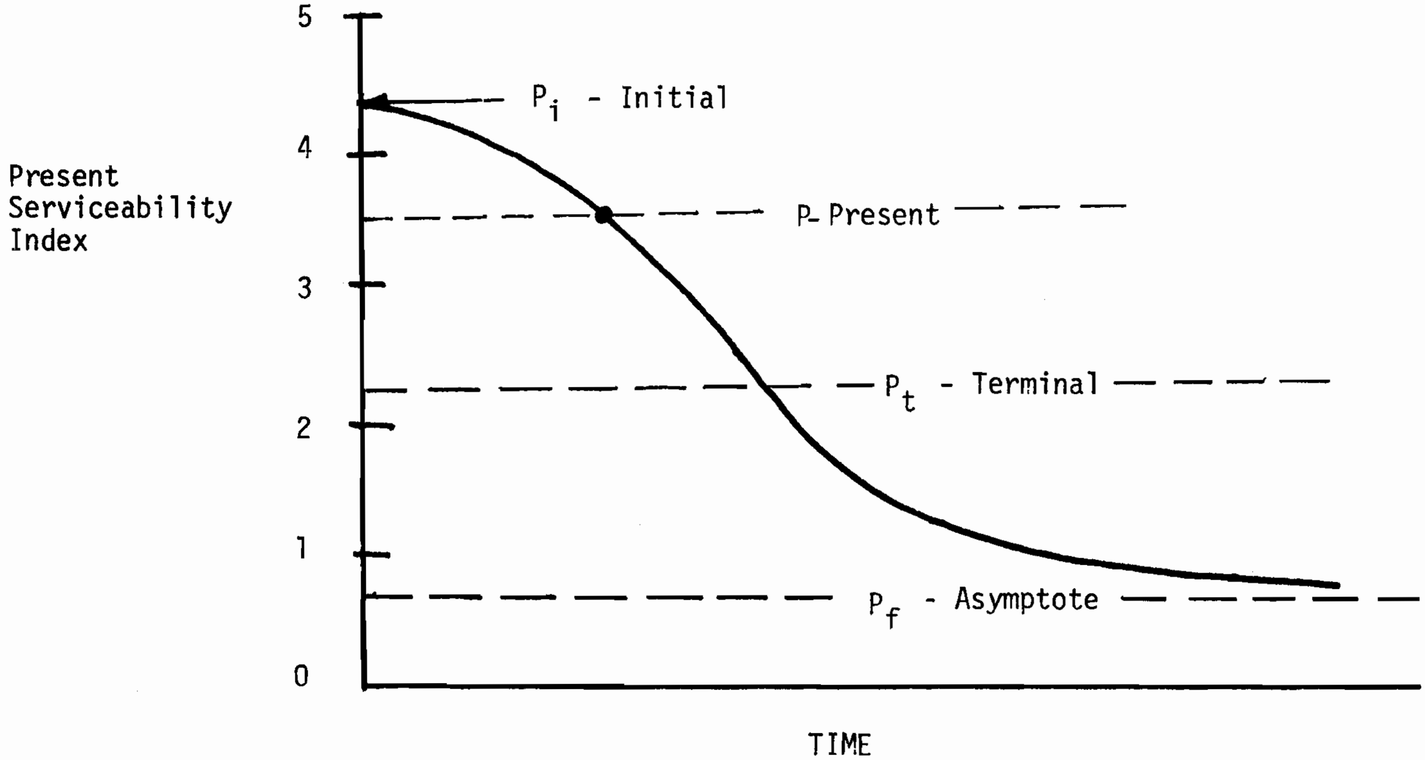


Figure 4.2 Graph of Serviceability Index versus Time Using The Texas Flexible Pavement Performance Equation

an auxiliary distress equation must be used to determine the values of W_n, W_t, and W_r.

The distress equations developed from Texas flexible pavement data are of the same form as the damage equations.

$$a = e^{-K_1/W_{18}^{n}}$$

$$s = e^{K_2 - K_3/W_{18}^{n}}$$

where

a = the percent of the pavement surface area covered by the distress expressed as decimals from 0 to 1.

s = the severity of distress expressed in numerical form: slight, 0 - 0.16; moderate, 0.17 - 0.33; and severe, 0.34 - 0.50.

K_1, K_2, K_3 = deterioration rate constants

These equations can be used as alternatives to determine W_n, W_t, W_r, w_n, and r.

These modifications will allow the revised NULOAD to reflect actual pavement distress, performance, and likely rehabilitation histories and are based upon data collected in Texas. The resulting estimates of pavement costs under current and revised size and weight limits should be more accurate and reasonable.

4.2.1.3. Modifications Using Texas Rigid Pavement Performance Equations

In the current version of REHAB, for each pavement category the program user can define the pavement performance by inputting a survivor curve based on the age of the pavement. This curve indicates what percentage of the total lane miles in a particular pavement category will probably have to be rehabilitated at a given time, depending on the pavement age. Normally, if the pavement has recently been constructed there is a zero probability that it will need immediate rehabilitation, and therefore relatively new pavements have an approximately 100% survivor probability. As the pavement age increases, it becomes more likely that rehabilitation will be required, and the survivor probability decreases. At some point in time the pavement age is high enough to make it almost certain that a rehabilitation would have been required before that time, and the survivor probability goes to zero.

Survivor curves presently used by the DHT are illustrated in Figures 4.3 through 4.12. These curves represent the predicted time to rehabilitation for each pavement category, as indicated below:

Figure 4.3 - Interstate, Pavement Type 2

Figure 4.4 - Interstate, Urban, Pavement Type 3

Figure 4.5 - Interstate, Rural, Pavement Type 3

Figure 4.6 - Farm-to-Market, Pavement Type 1

Figure 4.7 - Farm-to-Market, Pavement Type 1

Figure 4.8 - Farm-to-Market, Pavement Type 2

Figure 4.9 - Farm-to-Market, Pavement Type 3

Figure 4.10 - Other, Pavement Type 1

Figure 4.11 - Other, Pavement Type 2

Figure 4.12 - Other, Pavement Type 3

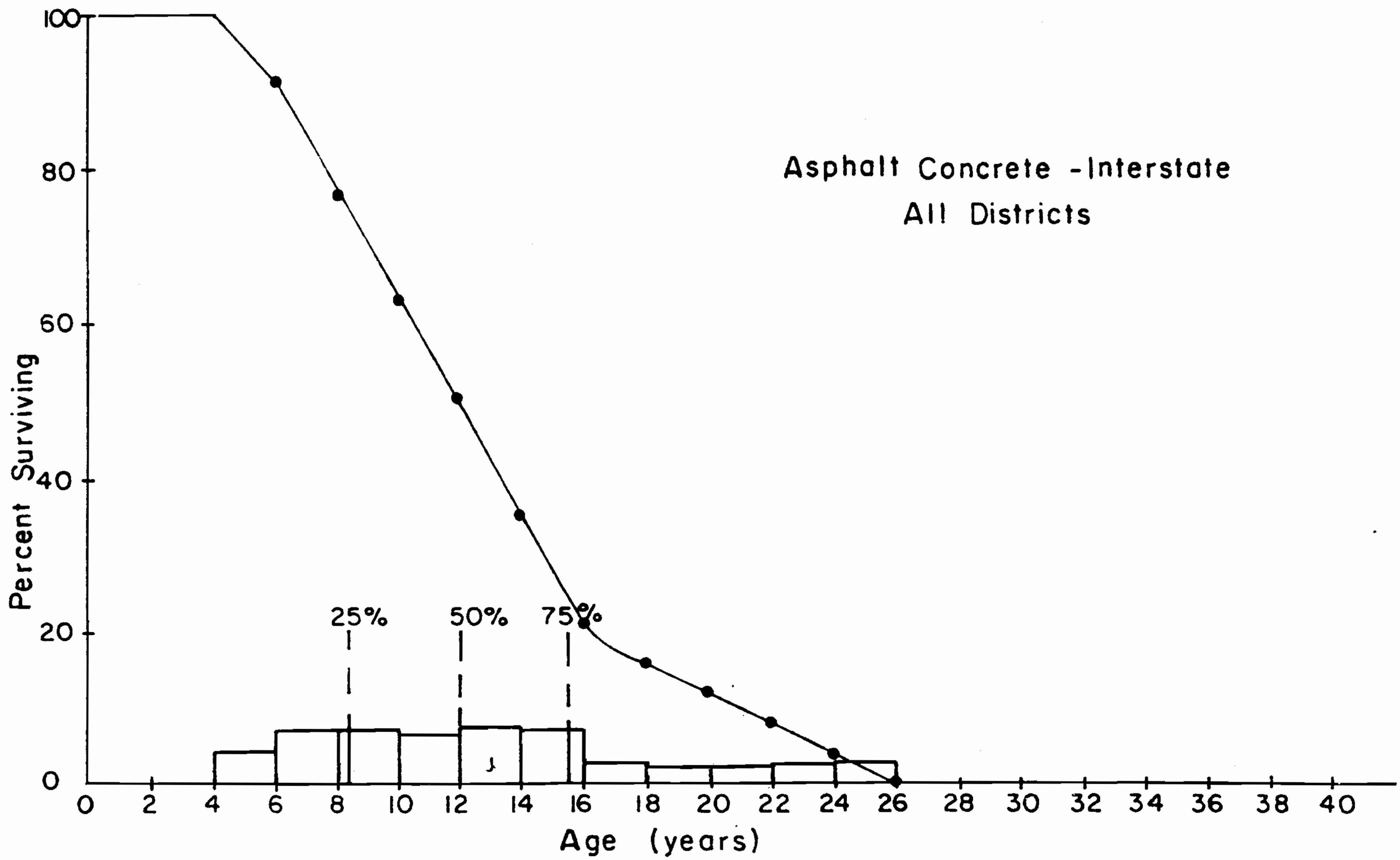

Asphalt Concrete - Interstate
All Districts
Percent Surviving
100
80
60
40
20
0
25%
50%
75%
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Age (years)

Figure 4.3

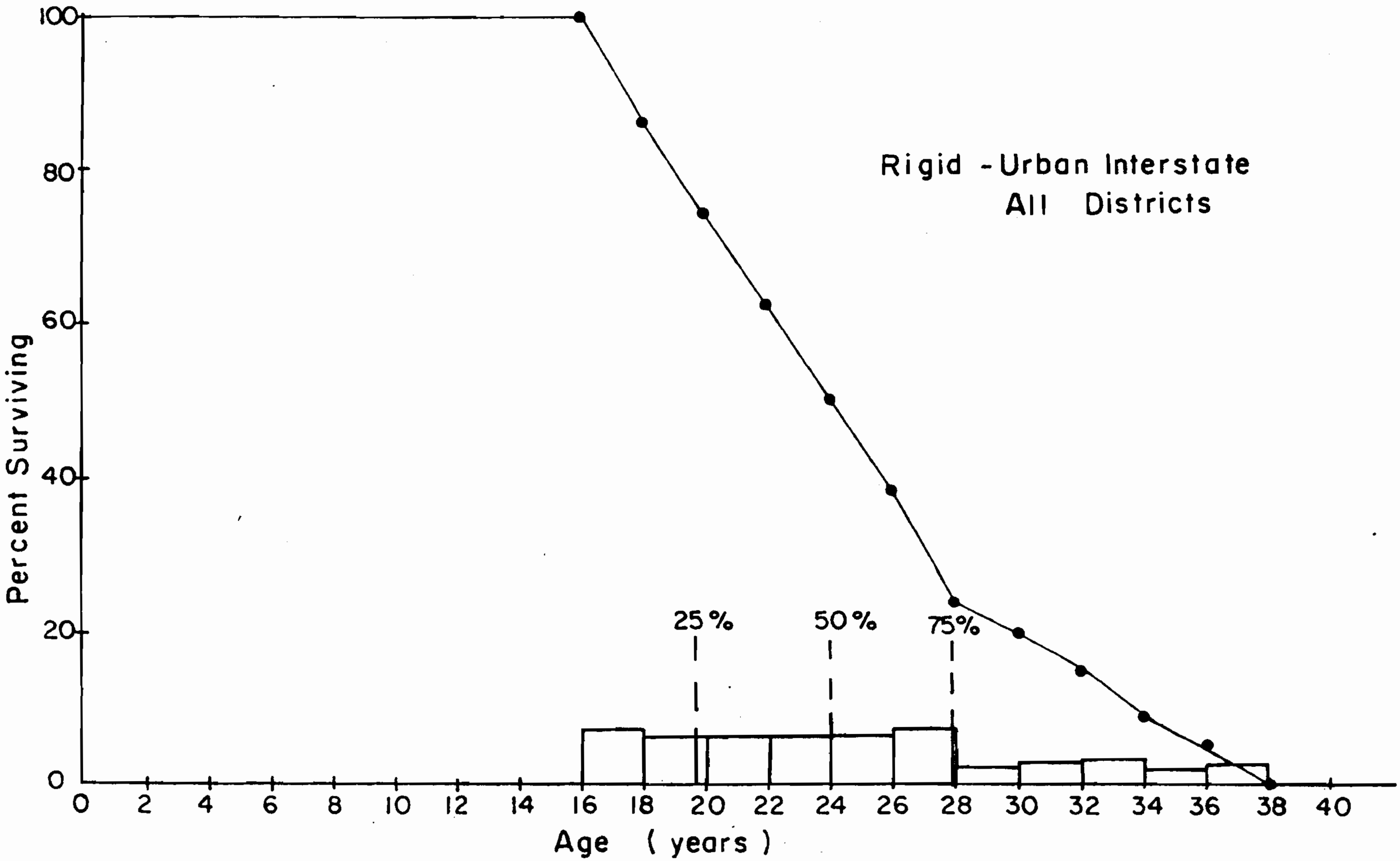
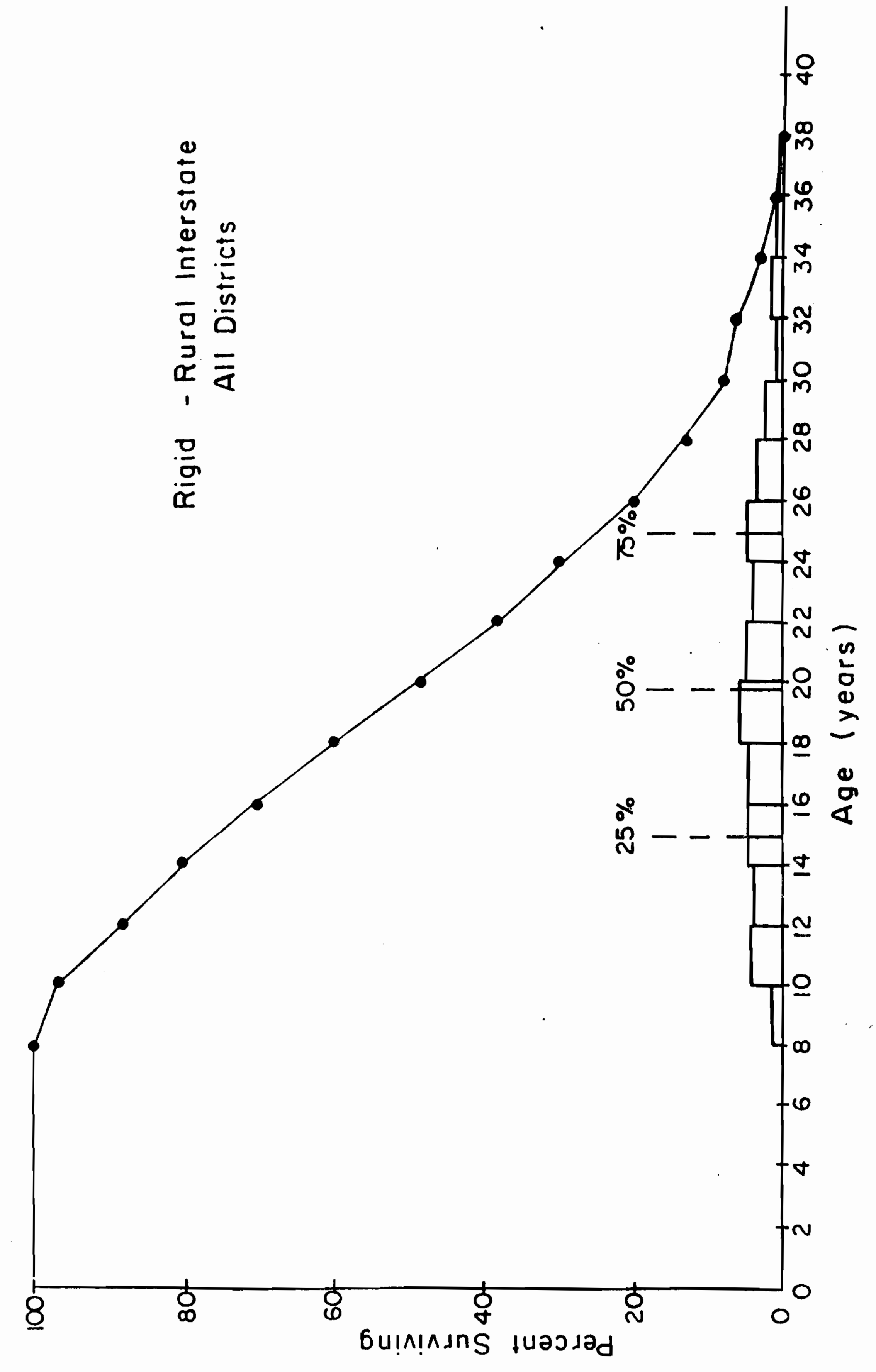

Rigid - Urban Interstate
All Districts
Percent Surviving
100
80
60
40
20
0
25 %
50 %
75%
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Age (years)

Figure 4.4



Rigid - Rural Interstate
All Districts
Percent Surviving
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
25%
50%
75%
Age (years)

Figure 4.5

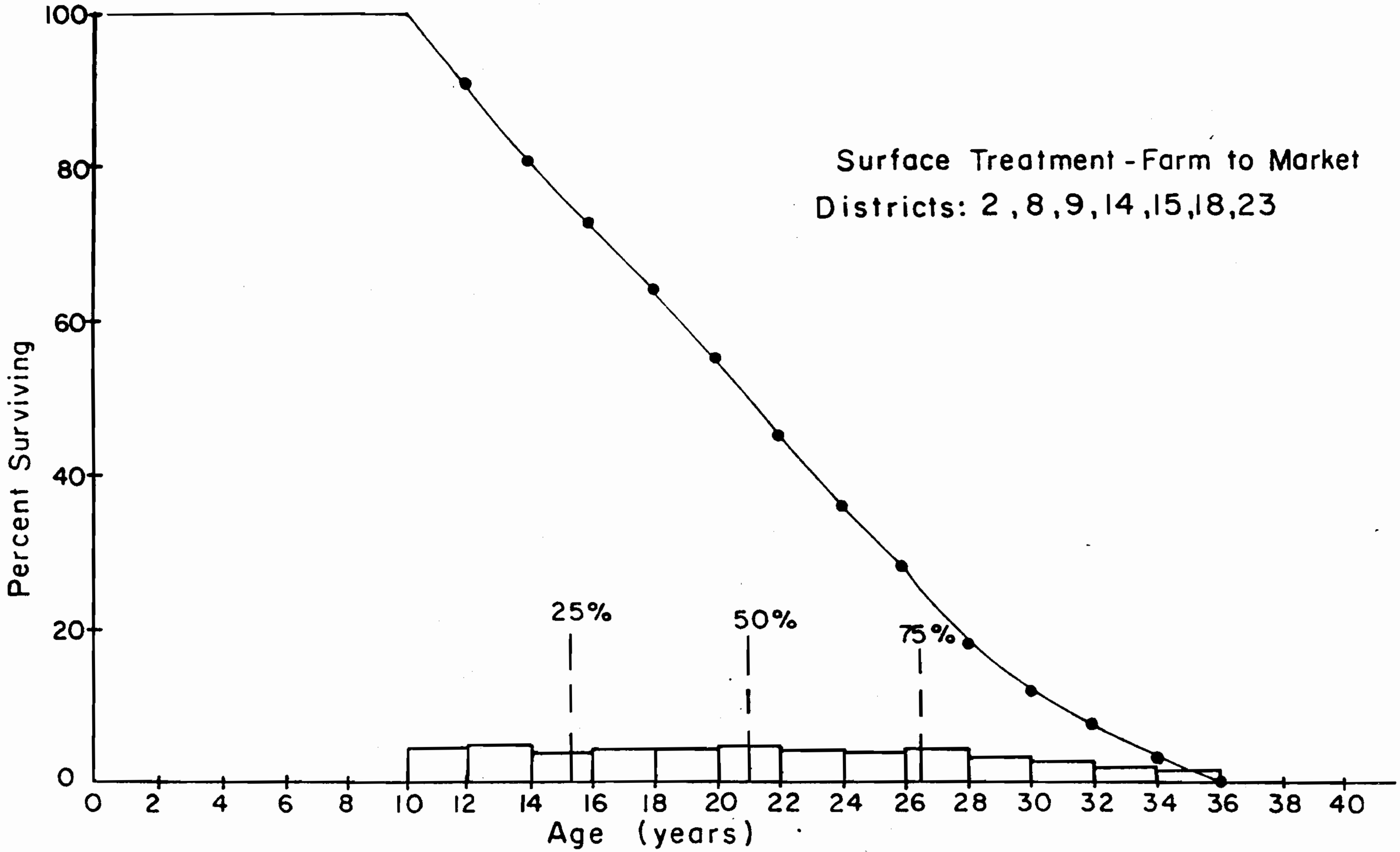
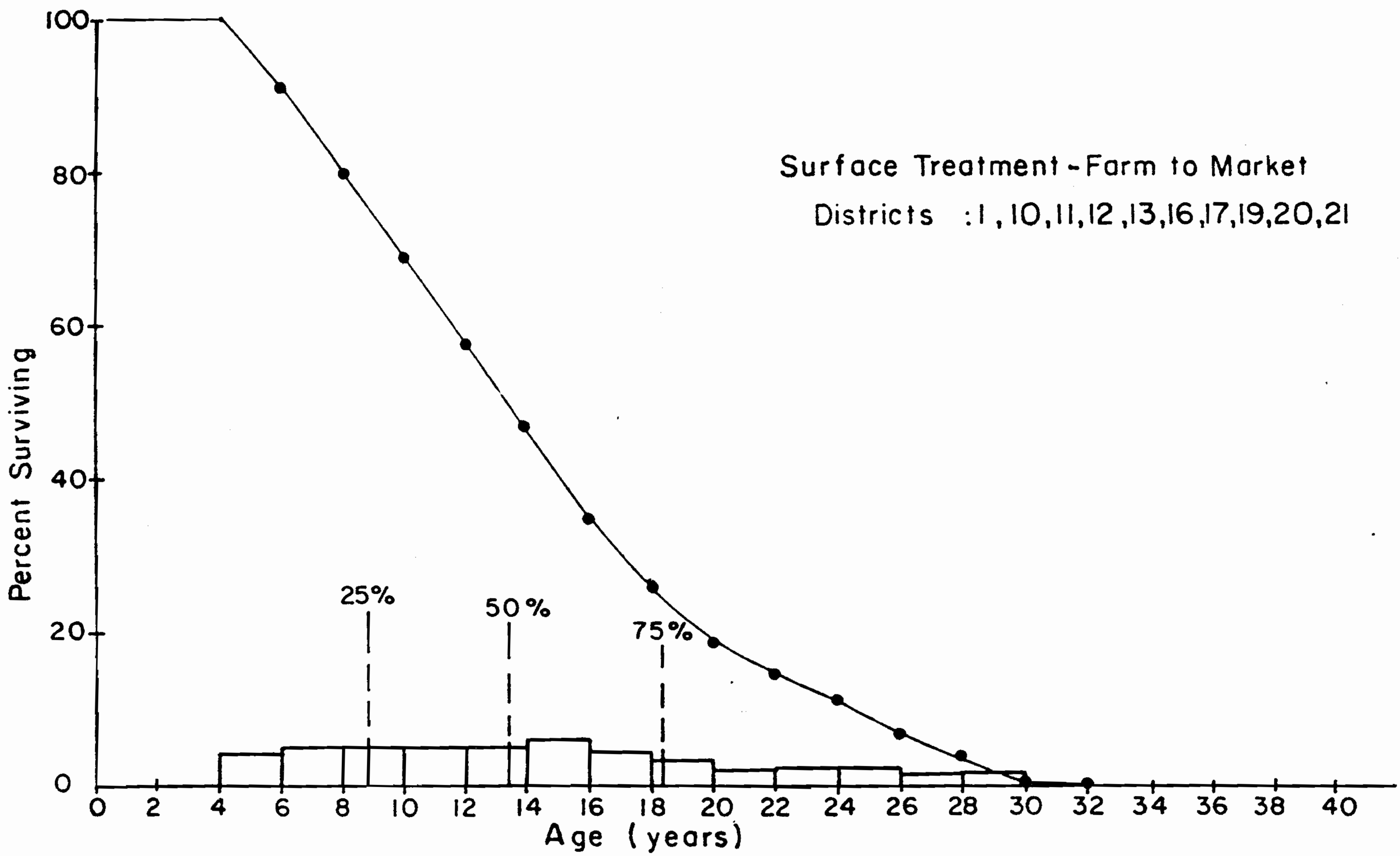

Surface Treatment - Farm to Market
Districts: 2, 8, 9, 14, 15, 18, 23
Percent Surviving
Age (years)
25%
50%
75%
0
20
40
60
80
100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

Figure 4.6


Surface Treatment - Farm to Market
Districts :1, 10, 11, 12, 13, 16, 17, 19, 20, 21
Percent Surviving
Age (years)
25%
50%
75%
0
20
40
60
80
100
0
2
4
6
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14
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22
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32
34
36
38
40

Figure 4.7

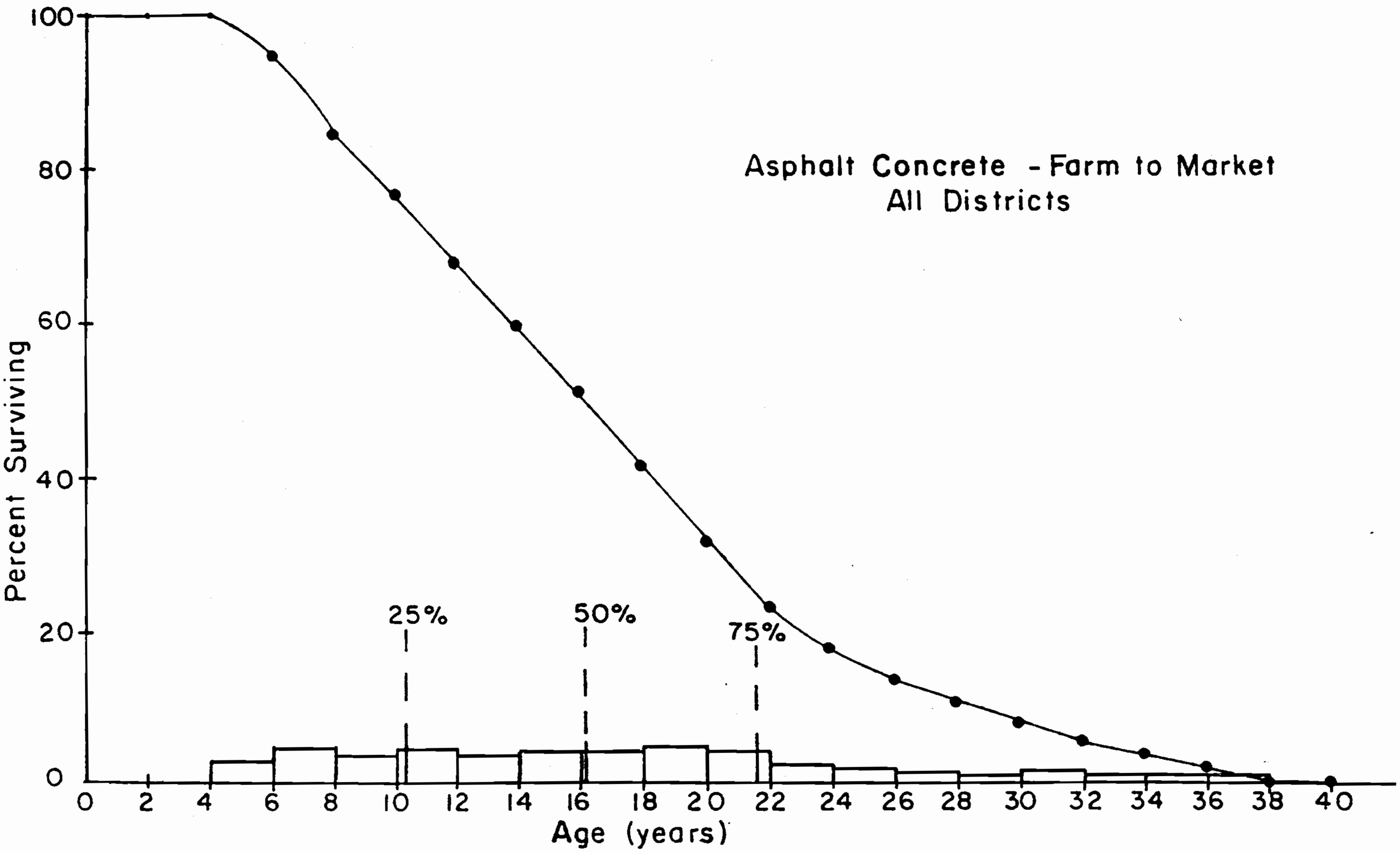
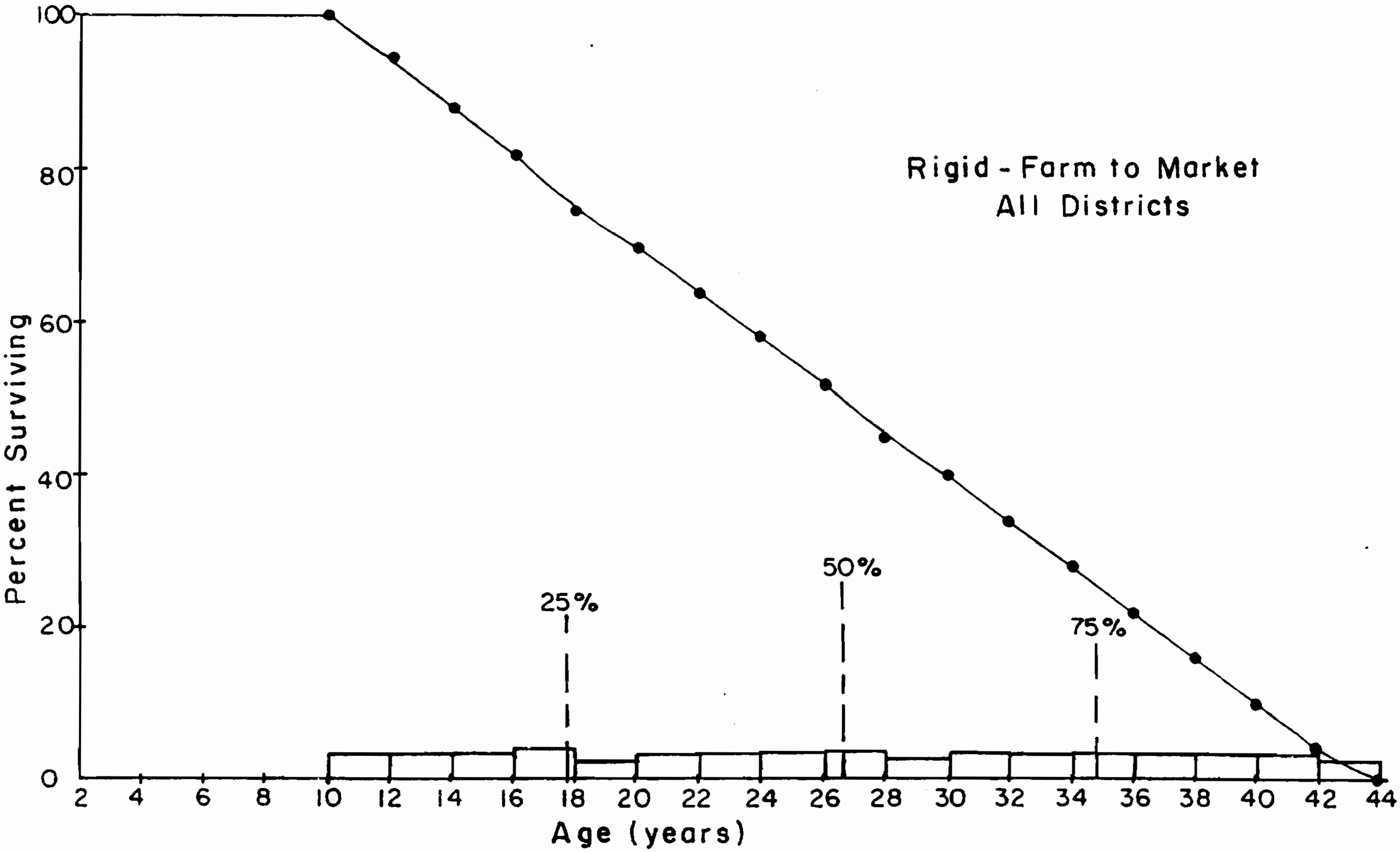

Asphalt Concrete - Farm to Market
All Districts
Percent Surviving
100
80
60
40
20
0
25%
50%
75%
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Age (years)

Figure 4.8


Rigid - Farm to Market
All Districts
Percent Surviving
Age (years)
25%
50%
75%
0
20
40
60
80
100
2
4
6
8
10
12
14
16
18
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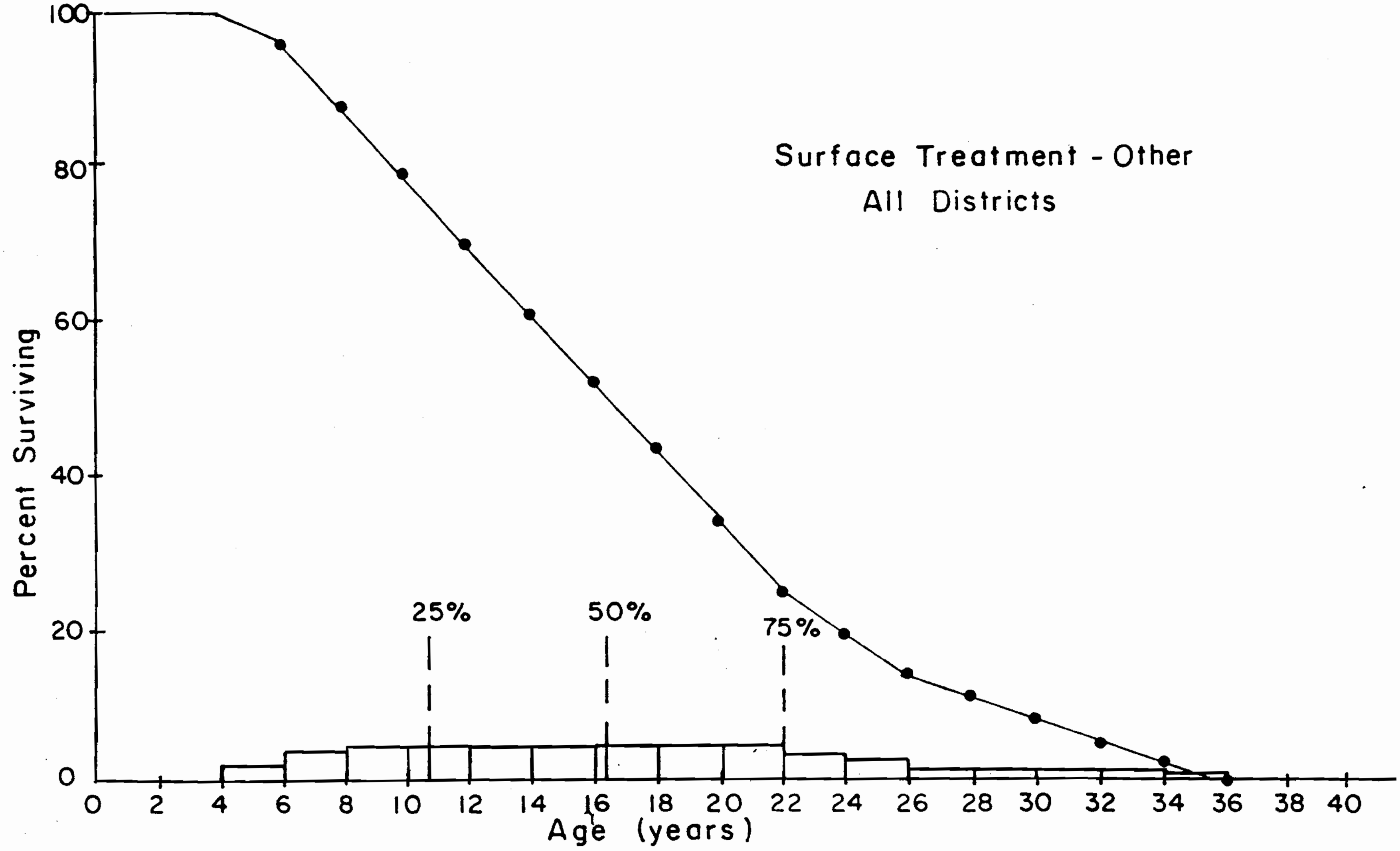
22
24
26
28
30
32
34
36
38
40
42
44

Figure 4.9



Surface Treatment - Other
All Districts
Percent Surviving
100
80
60
40
20
0
25%
50%
75%
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Age (years)

Figure 4.10

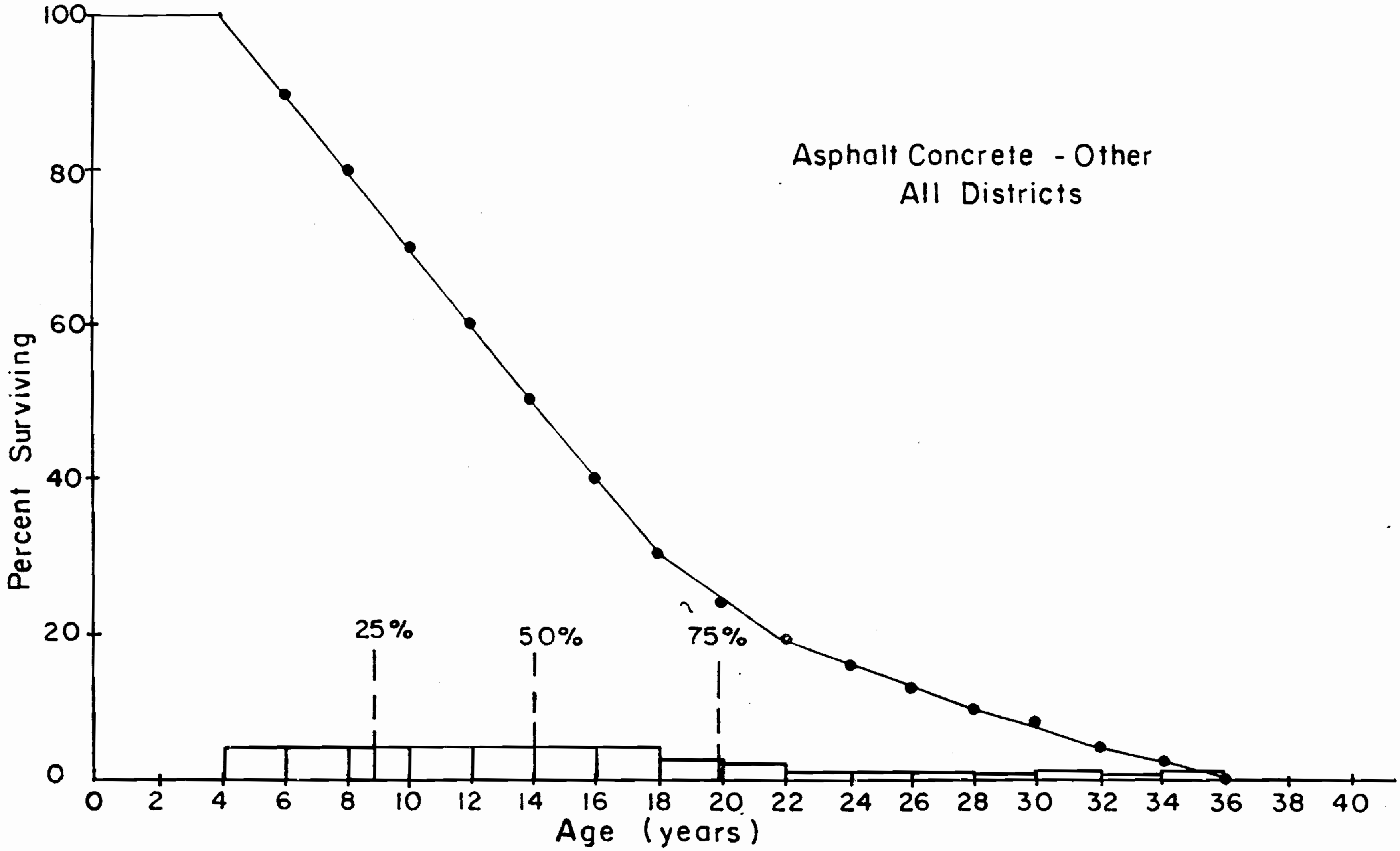

Asphalt Concrete - Other
All Districts
Percent Surviving
100
80
60
40
20
0
25%
50%
75%
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Age (years)

Figure 4.11

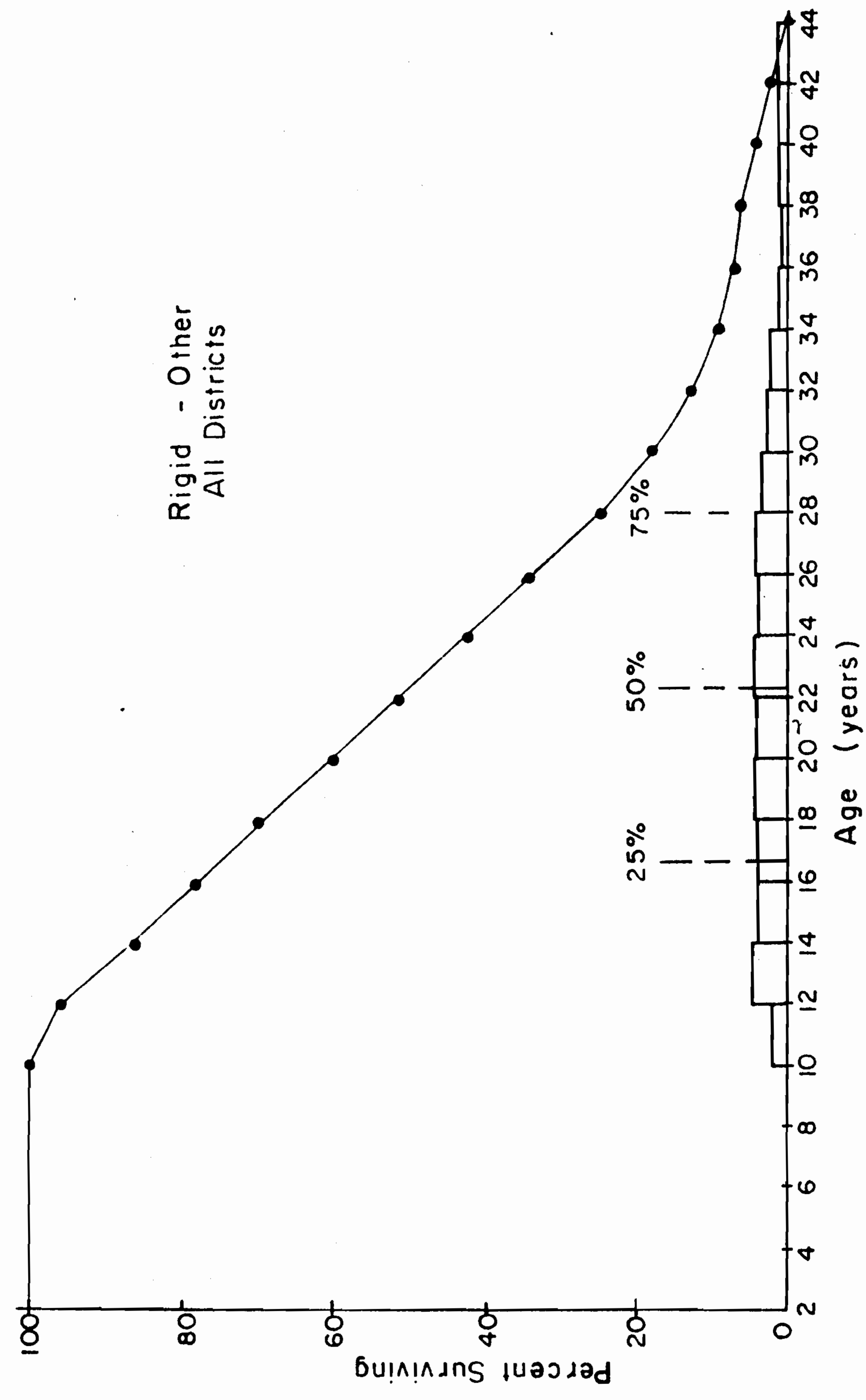
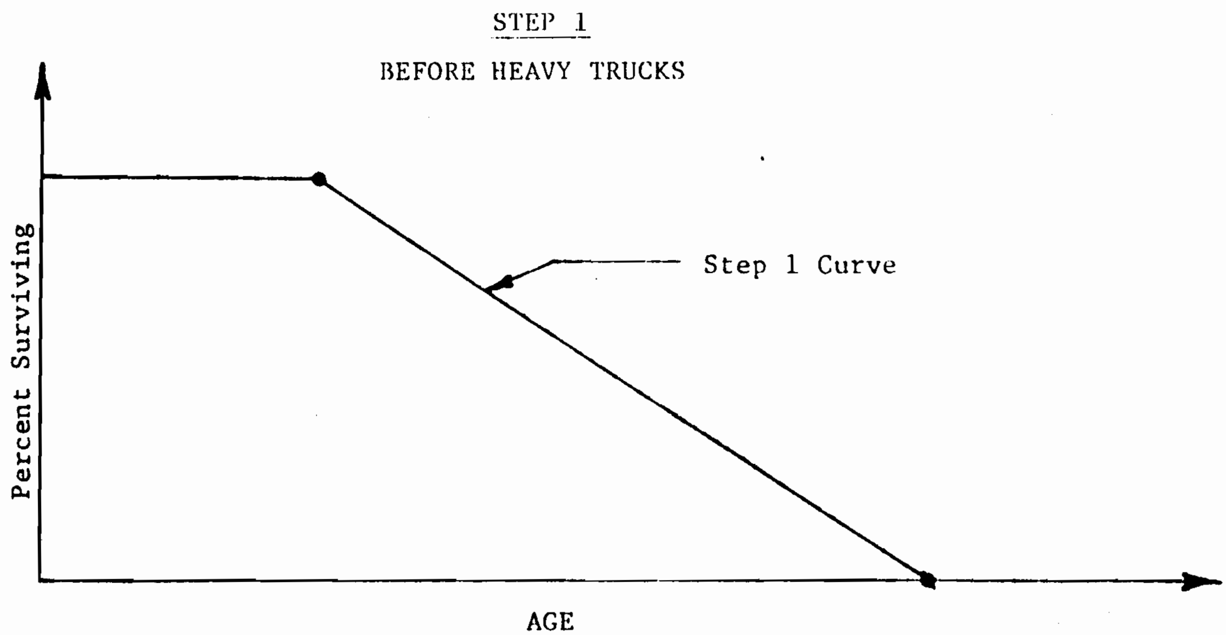

Rigid - Other
All Districts
Percent Surviving
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
25%
50%
75%
Age (years)

Figure 4.12

Essentially, the survivor curve is a cumulative probability distribution, which is formed by adding cumulatively over the length of the analysis period the probabilities of requiring rehabilitation in each year. In each of the figures listed above, both the cumulative distribution (survivor curve) and yearly probability distributions are illustrated. An examination of the survivor curves used by the Texas SDHPT reveals that for most of the pavement categories, the probability distribution for time to rehabilitation is nearly a uniform distribution. This means that at any point in time there is approximately an equal probability that a pavement will require rehabilitation, regardless of age.

The reason for this characteristic of the survivor curves comes mainly from the assumptions and simplifications made when using the REHAB program. Firstly, it is necessary to assume that all pavements in the same category will have identical behavior. With the broad pavement categories shown in Fig 2.2 there is no chance to differentiate different pavement thicknesses, soil types, climate conditions, and most importantly traffic volume and growth rates. There are, therefore, many different kinds of pavement situations within each category, thereby reducing the accuracy of the performance prediction and "spreading out" the probability distributions. Secondly, the procedure for inputting the survivor curve recommends that the curve be assumed to be linear (See Figure 4.13) When this assumption is made the yearly probability distributions automatically become uniform. Thirdly, the survivor curves used by the Texas SDHPT were developed primarily from subjective reasoning and experience, without the benefit of a significant amount of data.

The capability for analyzing the effects of heavier load limits with program REHAB depends entirely upon the user. There is no way to


STEP 1
BEFORE HEAVY TRUCKS
Percent Surviving
Step 1 Curve
AGE

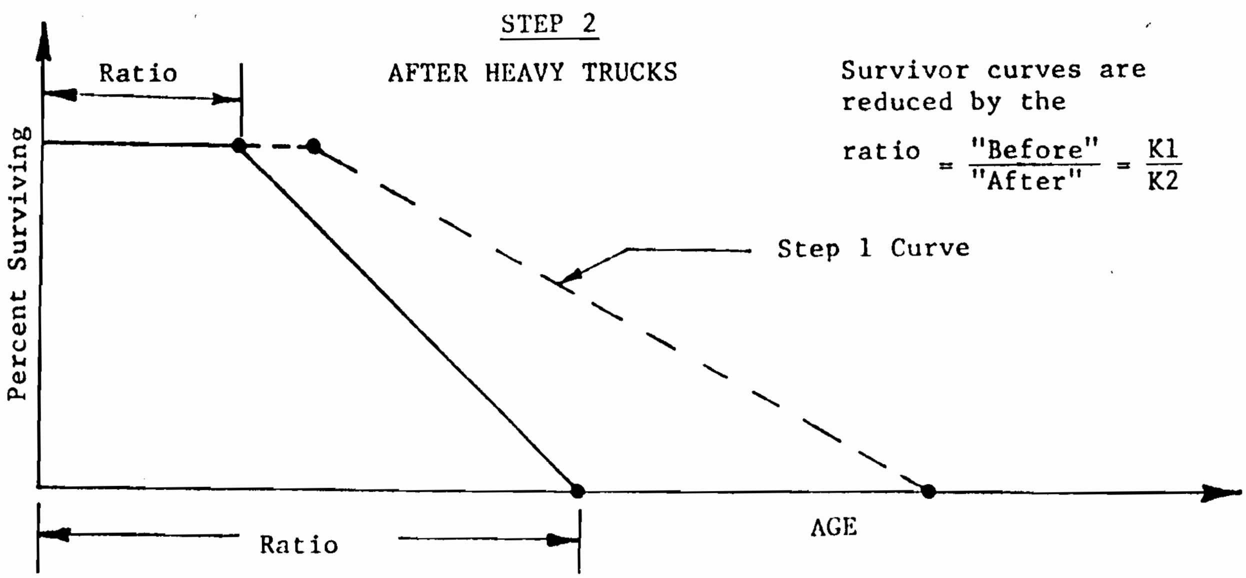

STEP 2
AFTER HEAVY TRUCKS
Ratio
Survivor curves are reduced by the ratio = "Before" / "After" = K1 / K2
Percent Surviving
Step 1 Curve
Ratio
AGE

Figure 4.13

simply input the new load limits and have the program calculate the effects. Instead, the user must calculate the number of 18-kip equivalent axle loads with the old load limit (K_1), and for the proposed load limit (K_2), and input the ratio of K_1/K_2. The program will then shift the survivor curve according to this ratio (See Figure 4.14). This requirement for user input is typical of the REHAB program, which generates a great deal of work for the user. The fact that the user must input survivor curves for each pavement category, and also determine the 18-kip equivalent axle load applications for different load limits, is a serious drawback of program REHAB. As stated earlier, there are no pavement deterioration "models" in the program. The user must define the performance of the pavements under all conditions.

In summary, the following features are noted concerning the pavement deterioration characteristics of program REHAB:

1) because of the broad pavement categories, pavements with different soil types, thicknesses, traffic volumes, etc., are grouped together and assumed to have the same performance,
2) assumptions made in the program and program input have resulted in survivor curves that are nearly a uniform probability distribution, and
3) the user must define all pavement deterioration for the different conditions being considered, thereby requiring a great deal of work for the user.

The modifications recommended for the rigid pavement portion of REHAB are the following:

1. After trial verification using the AASHTO rigid pavement equation as is currently programmed in NULOAD, either use it as modified

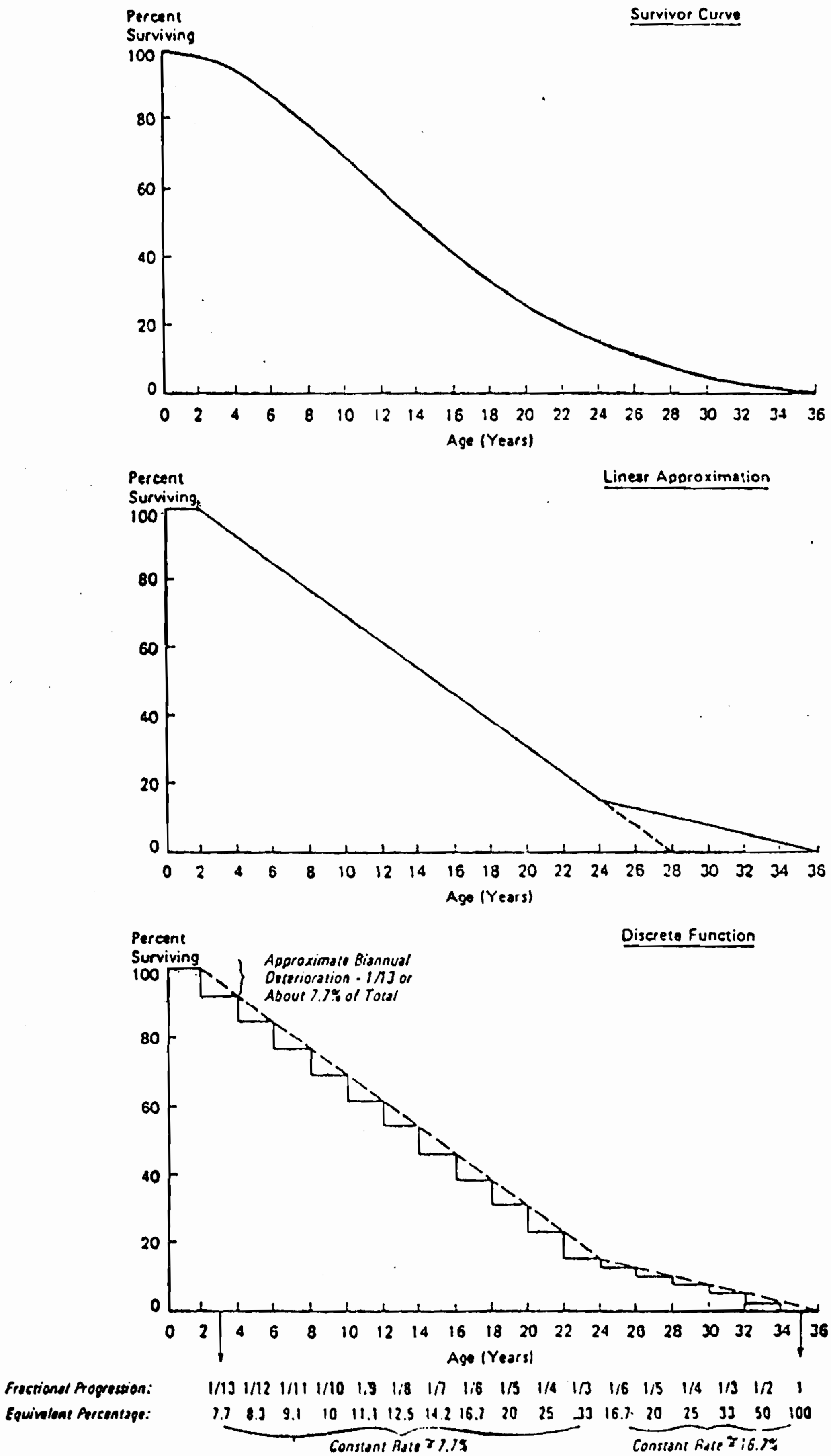

Survivor Curve
Percent Surviving
100
80
60
40
20
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Age (Years)
Linear Approximation
Percent Surviving
100
80
60
40
20
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Age (Years)
Discrete Function
Percent Surviving
100
80
60
40
20
0
Approximate Biannual Deterioration - 1/13 or About 7.7% of Total
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Age (Years)
Fractional Progression: 1/13 1/12 1/11 1/10 1/9 1/8 1/7 1/6 1/5 1/4 1/3 1/6 1/5 1/4 1/3 1/2 1
Equivalent Percentage: 7.7 8.3 9.1 10 11.1 12.5 14.2 16.7 20 25 33 16.7 20 25 33 50 100
Constant Rate ≅ 7.7%
Constant Rate ≅ 16.7%

Figure 4.14

for Texas conditions or use another equation developed from Texas data. In any case, the equation needs to be sensitive to differences in pavement structure, soil type, traffic, and climate.

2. Determine from Texas data whether the normal distribution of pavement life that is assumed in NULOAD to apply to rigid pavement survivor curves actually does apply. Also, determine from Texas rigid pavement data some typical values for the coefficient of variation of pavement life. From these determinations, modify the method of generating survivor curves that is currently used in NULOAD as is necessary.

4.2.2 Highway Cost Index

Use of the Highway Cost Index (HCI) would provide up-to-day cost information related to the maintenance and rehabilitation requirements forecast by NULOAD and REHAB.

House Bill 3 specifies the Highway Cost Index to be based on the weighted combined costs of Highway Construction, Operations and Maintenance. The Department has elected to determine a separate cost index for each of these functional areas and to compute the HCI as the weighted average of the three indices. The weight of each functional area is defined as its respective cost during the base period expressed as a percentage of the total expenditures of the Department during the same base period, excluding the expenditures that are nontypical of any functional area, [16].

Throughout the HCI procedures manual many references are made to current weights. During the base year, all weights---functional area, category, element, control item--will reflect current values. However, the weights shown on the Twelve Month Moving Report for the period ending August 31 will become the official base period weights. At that time necessary changes will be made in the HCI Procedures Manual to correct all inappropriate references to current weights.

In determining HCI expenditures in each of the three functional areas during the base year, the Department considers an expenditure to be made when an obligation is consummated; that is, when a purchase order is issued for a specific quantity of materials, equipment or commodities; when payment is made for personal or commercial services or when a contract is executed for a specific quantity of work.

Each of these functional areas has been carefully examined and the major expenditure activities selected to serve as a basis for calculating the functional area indices and the HCI. The major expenditure activities of each functional area were analyzed and placed in categories. These categories were subdivided into one or more classes of expenditure, each called elements, composed of one or more sets of one or more items. Some sets have only one item of expenditure, and one of these serves as the control item representing that set.

To determine the index for each functional area it is necessary to calculate the index for each control item element and category. A control item cost index is obtained by dividing its current unit price by its respective base period unit price. An element cost index is the summation of the product of each control item cost index in that element and its control item base period weight. For elements that are represented by only one control item, the weight assigned to that control item will be 100,00. If any control item in an element has no current unit price during the reporting period, the last unit price recorded for that control item will be substituted. If it becomes apparent after a period of monitoring that a selected control item is no longer being used or no longer represents its respective set of items, the Department will request HCI Committee approval to replace the control item by another item of expenditure from the set of items that will be representative of that set. The base period unit price for any new control item will be determined so that the calculated control item cost index for the new item will be related to the same base period as the other items in the HCI.

The element cost indices are determined by calculating the weighted average of control item cost indices within the element. The category cost indices are determined by calculating the weighted average of the element cost indices within a category. The functional area cost indices are determined by calculating the weighted average of the category cost indices within the functional area. The Highway Cost Index is determined by calculating the weighted average of the functional area indices. Each of these four weighted averages is calculated using the weights determined from the base year. The control item data is updated monthly to introduce current quantities and current unit prices and to introduce the current expenditure in the segment of the element represented by the control item [16].

If HCI forecasts are prepared by the DHT for relatively short periods (3-5 years), the effects of inflation can be estimated and used in both REHAB and NULOAD to more accurately predict maintenance and rehabilitation costs. This proposed methodology is more effective than considering a constant inflation annual rate (REHAB) or estimating inflation-dependent budgets (NULOAD) for road rehabilitation.

4.2.3 Load Redistribution Procedures

The proposed methodology is the same as that developed in the Texas Truck Study [17]. Conceptually the load shifting procedure when new load legal limits are considered can be summarized as in Figure 4.15.

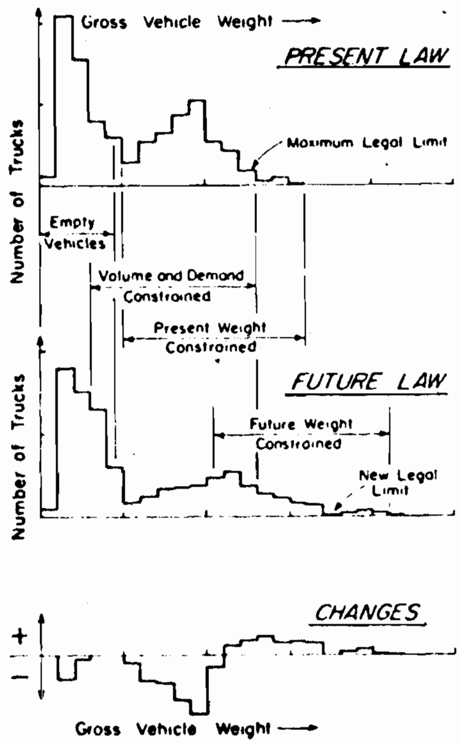


Figure 4.15 Truck Population and Changes Resulting From An Increase in Maximum Legal GVW

The NULOAD study currently incorporates the NCHRP laod shifting methodology developed and documented in Reference [11]. The present discussion of the proposed load shifting procedure applies to two scenarios A and B, defined as follows:

<u>Scenario A</u>:

Single axle = 88.9 KN

Tandem axle = 151.24 KN

GVW = 355.87 KN

Scenario B:

Single axle = 115.66 KN

Tandem axle = 195.73 KN

GVW = 533.8 KN

The NCHRP researchers examined historical GVW distributions before and after changes in size and weight laws. There is a pattern in these data that shows a shift to heavier trucks and a small shift on the empty weight portion of the distribution. A shift that is approximately proportional to the ratio of the practical maximum gross weight under the new law to the practical maximum gross weight under the old law exists on the loaded weight protion of the distribution.

The results of applying this type of shift to scenario A for one hundred 3-S2 trucks on a representative 1.6 km (1 mile) of Interstate highway are shown in Figure 4.16. Figure 4.16 (a) shows a large decrease in 80-kN SALS for trucks that are operating near the current legal limit. This decrease is negated by the increase caused by the new heavy trucks. Figure 4.16 (b) is similar expect that a large savings in truck operating costs is indicated for empty and lightly loaded vehicles. Such data caused us to rexamine the shifting procedure.

If weight laws (only) were changed, certain consequences might be expected. Those trucks that operate near the legal axle or GVW limit would increase their loads, and this would result in fewer loaded and empty trips. Vehicle that carry low-density cargo and are constrained by vehicle volume (size) woud be unaffected. A significant number of partially loaded vehicle trips are made. Some of these are delivery trips in which vehicle weight decreases or increases along the route. Segments

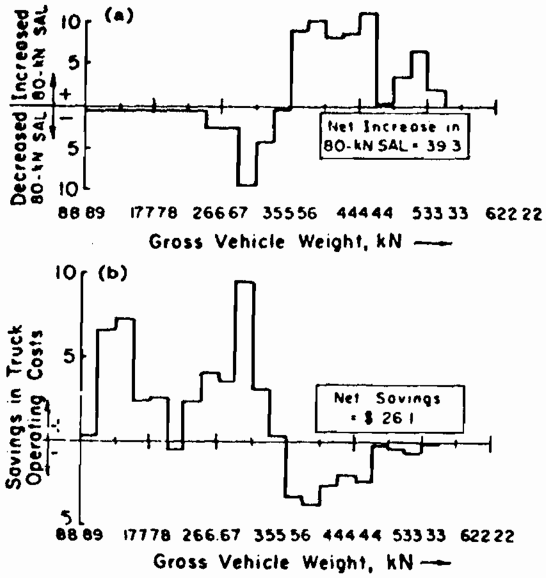


Figure 4.16 Results of Use of NCHRP Shift: (a) Decrease in 80-kN SAL and (b) Savings in Truck Operating Costs

of these trips could be affected by the change in the weight laws, whereas the less-loaded trips, which are made because the demand is only for a partial load, would be unaffected.

It was concluded that a shifting procedure would be used that would have the following characteristics: (a) heavily loaded vehicle trips would shift to a larger GVW in proportion to the previously mentioned ratio of practical maximum gross weights, (b) lightly loaded vehicles would be unaffected by the change in the law, and (c) empty-vehicle trips would be reduced in proportion to the reduction of loaded-vehicle trips.

It is postulated that the historical changes in GVW distributions that were used as a basis for the NCHRP shift were the result of factors other than changes in weight laws. To explore this phenomenon, a sensitivity study was conducted to examine the effects of several possible shifts on the computed savings in truck operating costs and increased 80-kN SALs. In general, truck operating cost savings are more sensitive than 80-kN SAL to shifts that increase the weight of lightly loaded trucks. Furthermore, for shifts that primarily affect heavily loaded vehicles, neither output is extremely sensitive to the shifting procedure.

The results obtained by using the shifts are shown in Figures 4.17 through 4.20. Results for the NCHRP procedure are based on one hundred 3-S2 trucks in scenario A and 61.7 trucks with the same payload in scenario B on a representative 1.6 km (1 mile) of Interstate highway. Results for the Texas procedure are based on one hundred 3-S2 trucks in scenario A and 85.7 trucks with the same payload in scenario B.

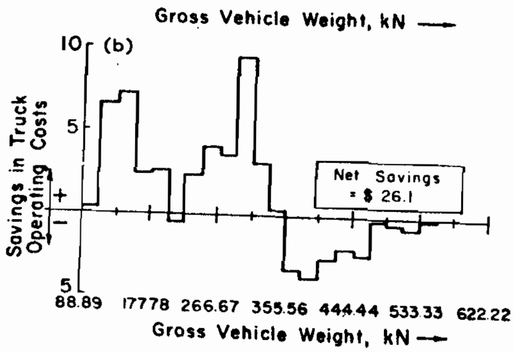


Figure 4.17 Change in 80-kN SAL versus GVW: NCHRP shift

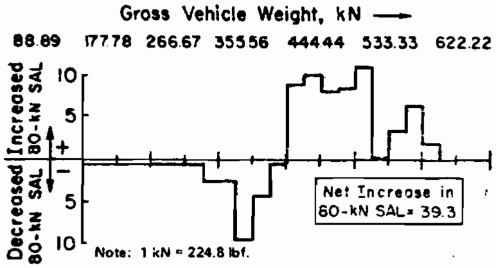


Figure 4.18 Change in 80-kN SAL versus GVW: TSDHPT shift

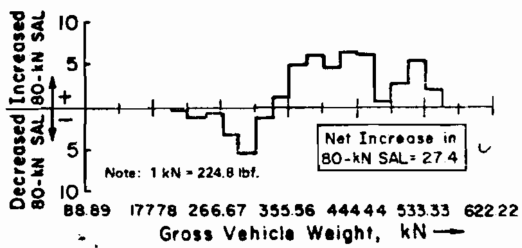


Figure 4.19 Change in Truck Operating Costs versus GVW: NCHRP shift

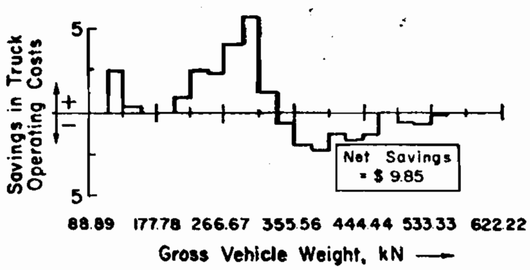


Figure 4.20. Change in Truck Operating cost versus GVW: TSDHPT shift

Note that for the adopted (TSDHPT) shift the following results were obtained:

1. Fewer empty trips resulted in savings.
2. Some partially loaded or lightly loaded trucks were unaffected.
3. The number of trucks possibly constrained by axle or GVW laws was reduced.
4. The number of trucks that exceed the present law (but are constrained by future law) was increased, This resulted in increased savings.
5. Net savings in truck operating costs were affected much more than was the net increase in 80-kN SALs by the adopted shift versus the NCHRP shift.

Figure 4.21 shows the NCHRP and TSDHPT shifting factors. The TSDHPT shift is considered a "most likely" outcome; it must be pointed out, however, that the basis for its selection lacks precision. For much cargo, the point of diminishing returns as far as gross or axle-weight limitations are concerned may already have been reached.

4.2.4 Road Maintenance Cost Methodology for Pavements Other Than A.C.P.

The purpose of this section is to describe a general method for estimating maintenance costs of low-volume rural roads. This discussion was developed and documented in Reference [4], and is based on the work by C. H. Oglesby [12]. The types of roads under consideration, their description, and the corresponding materials are given in Table 4.1.

The general approach to evaluate maintenance costs consists of estimating the kind and frequency of maintenance operations, and then developing estimates of the costs of equipment, manpower, and materials required to perform these operations.

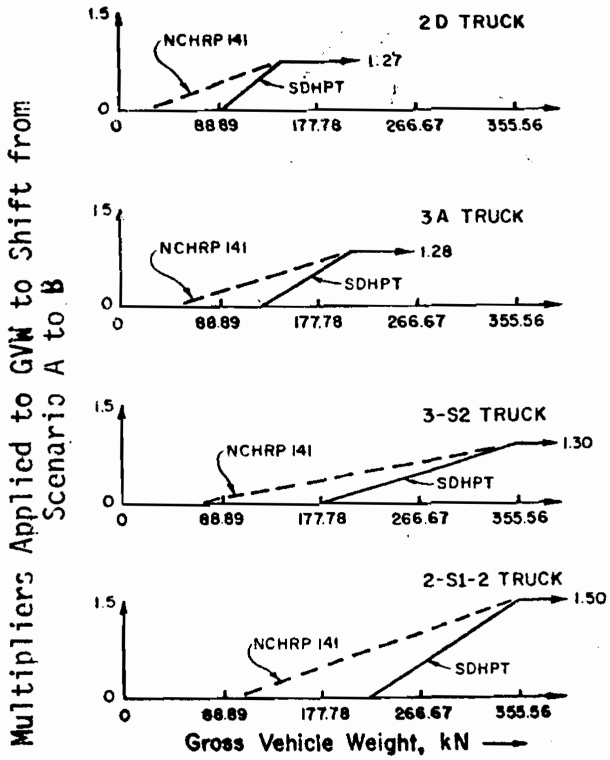


Figure 4.21. Multipliers adopted for shifting GVW distributions from scenario A to scenario B

Table 4.1 Road Surface Type Description

TYPE OF ROAD	DESCRIPTION	MATERIAL
1. Bituminous surface-treated	A thin layer of asphalt aggregate covered with chips or screenings is added to type 2	Asphalt,screenings Gravel Embankment
2. Surfaced with road mix	A layer of pavement mixed in place is placed on top of a gravel base	Seal coat Road mix Gravel
3. Surfaced with plant mix	Same as previous one, but plant mix is used instead of road mix	Seal coat Plant mix Gravel

Only surface maintenance costs are considered. Overhead costs of the maintenance organization are not included since they are a fixed charge under any alternative to be considered.

Figure 4.22 summarizes the maintenance cost methodology.

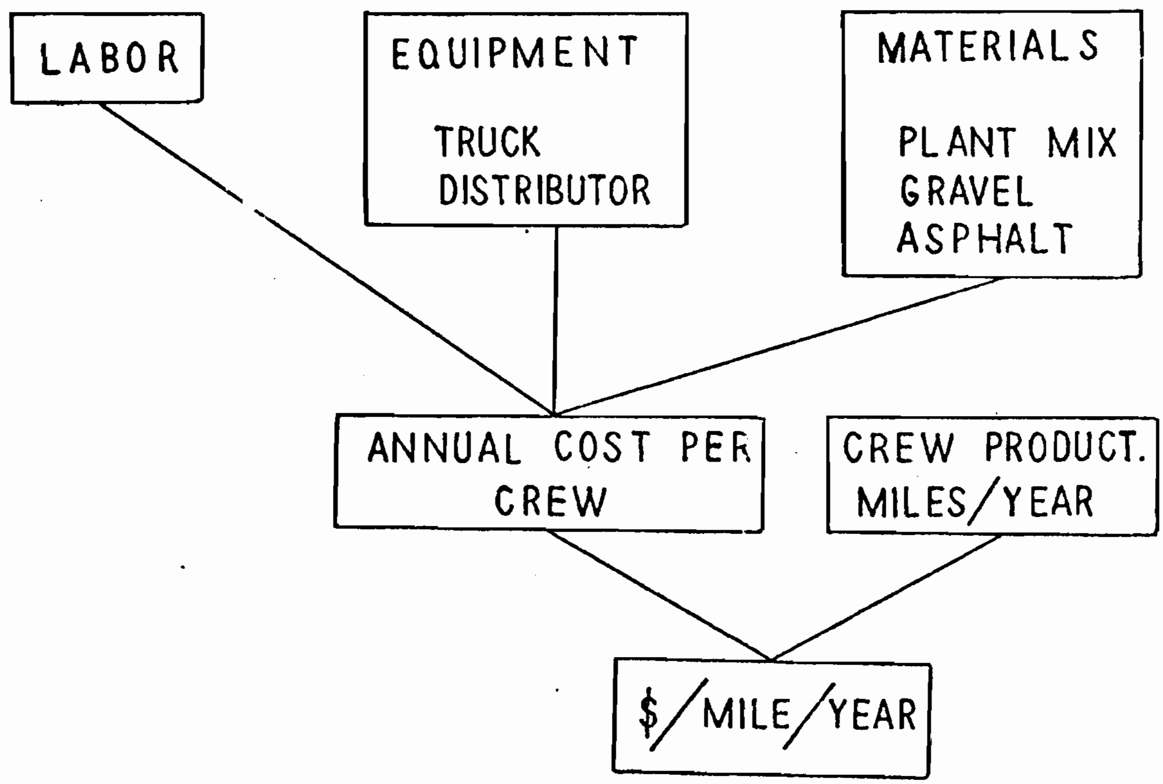


Figure 4.22 Maintenance Cost Methodology for Bituminous Roads

A summary of the specific actions indicated by Oglesby is given in Table 4.2.

Table 4.2 Maintenance Operations for Rural Paved Roads

	SURFACE TREATMENT	BITUMINOUS MAT
SURFACE PATCHING	1. Where potholes have formed: clean potholes, coat surfaces with asphalt form distributor, fill holes with plant mix material, roll with truck 2. Where surface treatment has broken or frayed, but no potholes have formed: spray affected areas with asphalt from distributor, cover asphalt with pea gravel	Clean potholes, coat surfaces with asphalt from distributor, fill holes with plant-mix material, and roll with truck
EDGE PATCHING	Coat affected areas with asphalt and then fill them with plant-mix materials	Same as for surface treatments

In each case (surface patching or edge patching), the corresponding maintenance cost can be broken down into the following components: (1) labor costs, (2) equipment costs, and (3) materials costs. The following notation will be used here:

P_j First cost of equipment j

N_j Service life (in years) of equipment j

D_j Average number of days per year equipment j is in use

M_j Daily maintenance charge (fuel, oil, grease, repairs, storage, etc) for equipment j

a_j Average daily need of material j

C_j Per-unit cost of material j

S_j Sum of monthly wages and benefits for worker j

N_m Number of materials

N_e Number of pieces of equipment

N_c Number of workers in the maintenance crew

r_c Estimated crew productivity rate (miles per year)

$\hat{C}_l$ Labor cost (\$/year)

$\hat{C}_e$ Equipment cost (\$/year)

$\hat{C}_m$ Material cost (\$/year)

A. Annual Labor Cost

Assuming 22 working days in a month, and 5 working days in a week, we can write:

$$\text{Daily labor cost} = \sum_{j=1}^{Nc} S_j / 22$$

$$\hat{C}_l = (52)\ (5)\ (\text{Daily labor cost})$$

$$= 11.82 \sum_{j=1}^{N_c} S_j$$

B. Annual Equipment Cost

$$\text{Daily equipment cost} = \sum_{j=1}^{N_e} \frac{P_j \ CRF(N_j, i)}{D_j} + M_j$$

$$\hat{C}_e = (52)\ (5)\ (\text{Daily equipment cost})$$

$$= 260 \sum_{j=1}^{N_e} \frac{P_j \ CRF(N_j, i)}{D_j} + M_j$$

C. Annual Material Cost

$$\hat{C}_m = 260 \sum_{j=1}^{N_m} a_j C_j$$

D. Annual Maintenance Cost

The annual maintenance cost per mile (for either surface patching or edge patching) can be obtained by adding up the labor cost, the equipment cost, and the material cost, and dividing this total by the estimated crew production rate (miles per year)

$$\text{Annual Maintenance Cost} = \frac{260}{r_c}\left[\frac{1}{22}\sum_{j=1}^{N_c} S_j + \sum_{j=1}^{N_e} \frac{P_j\ CRF(N_j,1)}{D_j} + \sum_{j=1}^{N_e} M_j + \sum_{j=1}^{N_m} a_j C_j\right] \qquad (4\text{-}3)$$

Using Eq. (4-3) for surface patching we obtain $\hat{C}_s$, and using Eq. (4-3) again for edge patching, we obtain $\hat{C}_e$. The total annual cost will be given by $\hat{C}_s + \hat{C}_e$.

4.3 Recommended Modifications for REHAB

At present the REHAB program requires a significant amount of computational work in order to generate the program's input data. The purpose of the recommended changes is to reduce or eliminate this phase and to provide REHAB with better predictive capabilities. A list of the recommended changes is given below:

A. Generation of survivor curves.

B. Consideration of several rehabilitation alternatives

C. Incorporation of load redistribution methods.

D. Use of a Cost/benefit methodology.

4.3.1. Generation of Survivor Curves

It is easier to generate survivor curves within a computer program than to read them in point by point as input data. The data that are needed to generate a survivor curve are the following:

1. The mean remaining life of the pavement.
2. The standard deviation of the remaining life.
3. The type of probability distribution of remaining life time.

Currently, NULOAD assumes that the probability distribution for the remaining life time is symmetric about the mean, and normal. The survivor curve thus produced is S-shaped with its steepest slope at the predicted value of the remaining life time of the pavement. This curve, its probability distribution, and the predicted serviceability index curve are shown in Figure 4.23.

The survivor curves currently used in REHAB are based upon historical data on some pavement types and on the remainder were simply assumed. They are more linear and are like the curve in Figure 4.24 which is generated by a uniform probability distribution.

The survivor curves that have been determined from historical data in TTI's flexible pavement data base have been S-shaped but unsymmetrical, such as shown in Figure 4.25. The equation for the survivor curve has been found to be dependent upon the 18-kip ESAL's that have been applied to the pavement, and is of the following form

$$\text{time} < t_o; \quad \text{Percent Surviving } (p) = 1.0$$

$$\text{time} > t_o; \quad p = 1 - e^{-K/(W_{18})^n}$$

where $n > 2$

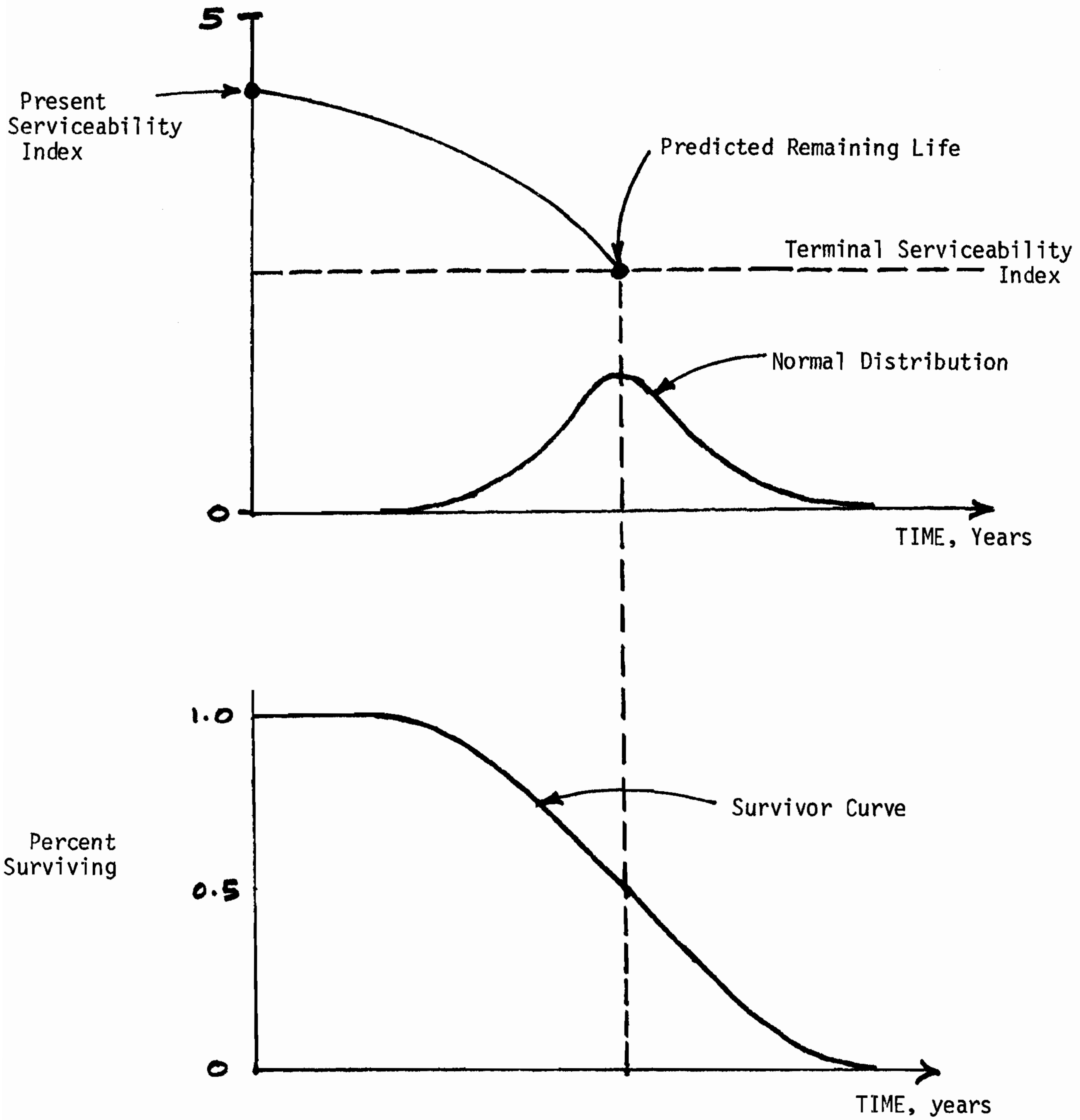


Figure 4.28 Serviceability Index and Survivor Curve as Assumed in NULØAD

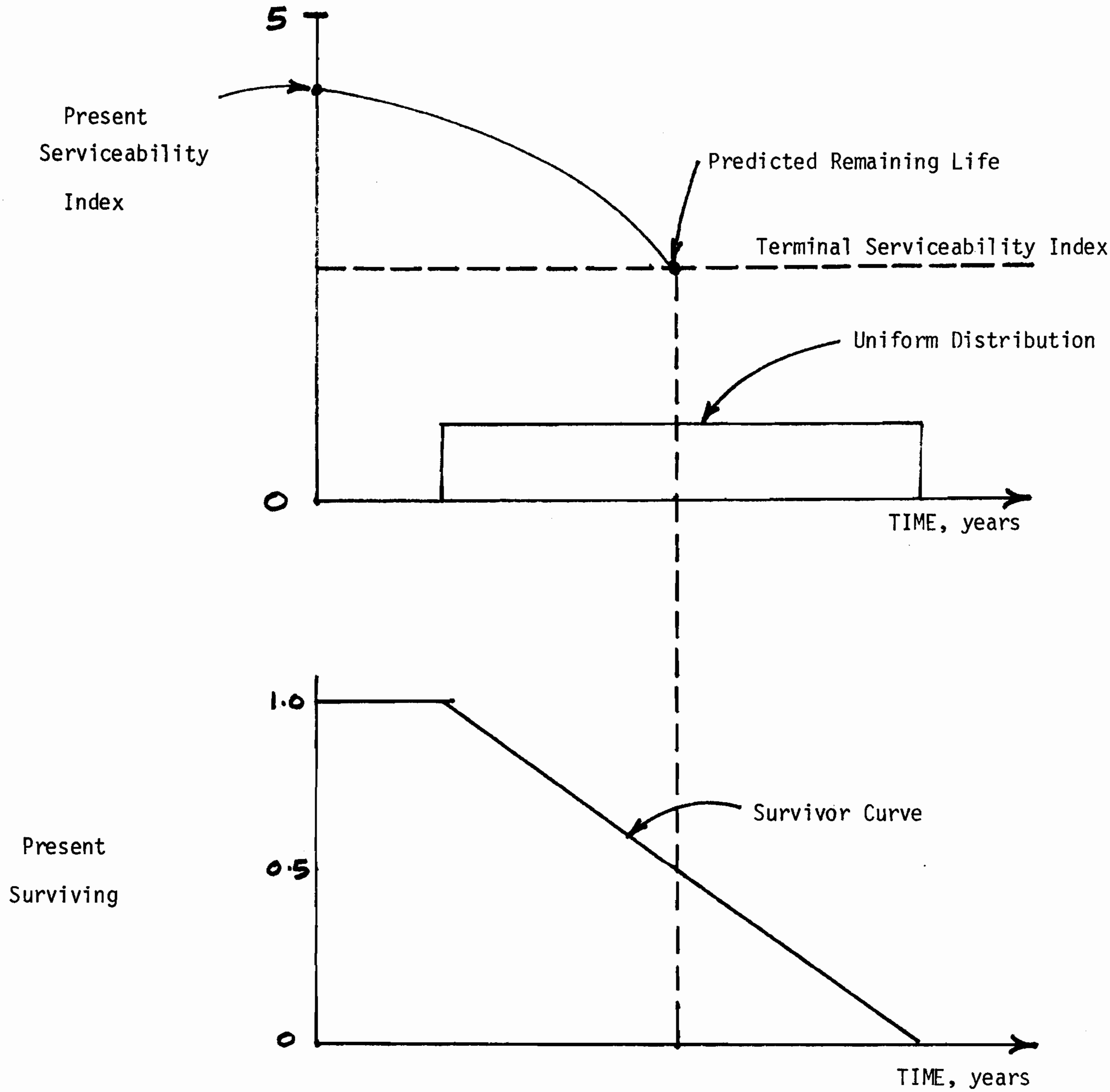


Figure 4.24 Serviceability Index and Survivor Curve as Assumed in REHAB

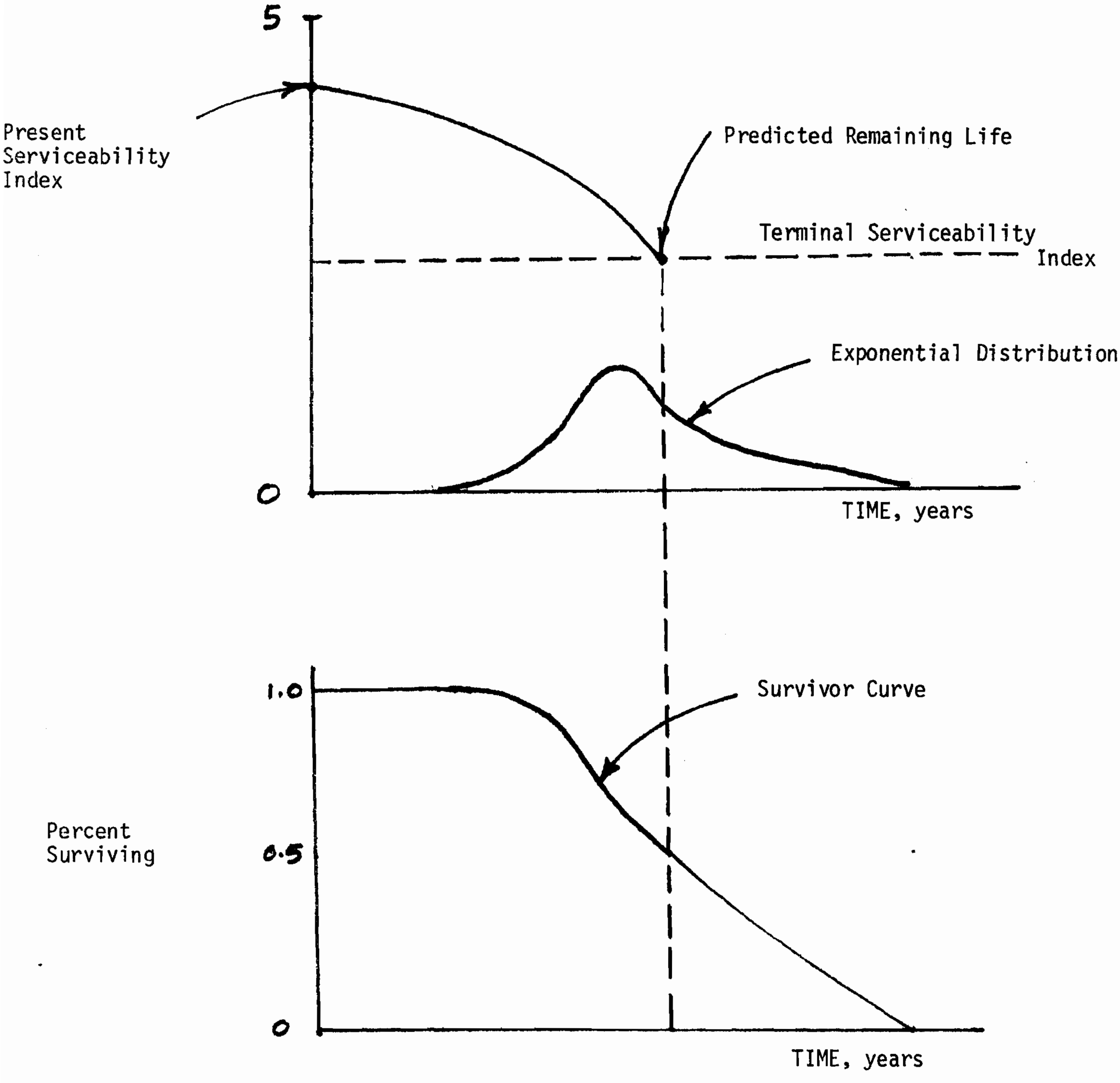


Figure 4.25 Serviceability Index and Survivor Curve Using Exponential Probability Density Function

The mean value and standard deviation of these curves depend upon K and n and are found by using the method of maximum likelihood estimators. The latter type of survivor curves may be preferable to the other two because they make the survival rate of pavements dependent upon:

1. Historical data.
2. The level of 18-k ESAL applied to the pavement

instead of the assumed values used in NULOAD and the rough approximations used in REHAB.

4.3.2. Consideration of Rehabilitation Alternatives

Currently, the only rehabilitation alternative considered by NULOAD is an overlay whereas the input data for REHAB simply considers a single unit cost for rehabilitation after having worked out by hand an average unit cost considering the use of several alternatives over the analysis period before inputting it to the program. The desirable arrangement would automatically generate the cost of using several rehabilitation alternatives internal to the computer program.

The way this can be done simply is the following:

1. For each type of pavement, <u>input</u> the percent of those pavements that usually (historically) receive rehabilitation alternatives 1, 2, 3, ..., n. Also input the unit costs of all n alternatives.
2. For each type of pavement, <u>compute</u> internally the average unit cost with the following formula:

$$\overline{C}_j = \sum_{i=1}^{n} P_{ij} \, C_{ij}$$

where $\overline{C}_j$ = the average unit cost rehabilitation of pavement type j.

P_{ij} = the percentage of pavement type j that receives rehabilitation alternative i.

C_{ij} = the unit cost of rehabilitation alternative i when applied to pavement type j.

This is a simple alteration to either NULOAD or REHAB and will probably result in more realistic estimates of rehabilitation costs. The percentages and unit costs may be tables that can be generated as a report from the State data base.

4.3.3 Incorporation of Load Redistribution Methods

The load redistribution procedure presented in Section 4.2.3 can also be implemented in REHAB. Currently this procedure is generated before the program is run.

In summary, the necessary revisions will change the REHAB program so that when heavier trucks are applied the life curves are shortened, which causes the pavements to wear out faster. The "worn-out" pavements are then rehabilitated. Those that receive minor rehabilitation (thin overlays) continue to wear out at the accelerated rate. However, those that receive major rehabilitation are redesigned at an increased cost to handle the heavier trucks. These redesigned pavement structures now begin to wear out at a slower rate. The slower rate is the same rate as the original life curves for these pavements.

4.3.4 Cost and Benefit Methodology

The overall purpose of the cost and benefit analysis is to identify acceptable public projects. The output from REHAB should be modified as to incorporate information useful to the state administrators responsible for requesting and evaluating road work projects. This information essentially would allow an estimation and evaluation of net benefits associated with proposed rehabilitation alternatives to achieve specified levels of road serviceability.

In addition to road rehabilitation costs, the following elements are fundamentally important to the development of the cost and benefit analysis:

A. Maintenance Costs.

B. User Costs.

C. Salvage Value.

D. Highway Cost Index.

4.3.4.1 Maintenance Costs

The EAROMAR Equations [1] currently used in NULOAD to estimate maintenance costs for A.C.P. roads can be incorporated in REHAB. For roads other than A.C.P., the proposed methodology is exactly the same as that already explained in Section 4.2.4.

4.3.4.2 User Costs

The two types of variable user costs that are generally associated with the operation of a transit system are the mileage-dependent cost (V_1) and the time-dependent cost (V_2). Mileage-dependent costs include the cost of power and the cost of keeping vehicles in operative conditions. Time-dependent costs arise from the value of passanger travel time and the wages paid operating personnel traveling with the vehicle. The two costs under discussion can be combined in a single user cost parameter, C^u, given the speed, S, in miles per hour:

$$C^u = V_1 + V_2/S \qquad (\$/\text{mile})$$

The running cost is affected by the following factors: (1) the highway, (2) the vehicle, (3) the operator, and (4) the weather and topografy. Here it is assumed that only the type of vehicle, the type of road surface, and the running speed of the vehicles are relevant factors.

For a given road and a given vehicle, the operating cost V_1 can be written as

$$V_1 = \sum_{i=1}^{I} \hat{C}_i \quad ,$$

where $\hat{C}_i$ is the cost of the i^{th} input in \$/mile. The following inputs must be considered in order to derive an estimate of current operating costs:

(a) Fuel (i=1)

(b) Engine oil (i=2)

(c) Tire wear (i=3)

(d) Depreciation (i=4)

(e) Interest (i=5)

(f) Maintenance (i=6)

The notation to be used here is given as follows:

r_f rate of consumption of fuel in gallons per mile

C_f cost of one gallon of fuel

r_o rate of consumption of oil in quarts per mile

C_o cost of one quart of oil

r_t percent wear of one tire per mile

N_t number of tires

C_t cost of one tire

C_v vehicle cost

r_v estimated service life of the vehicle in miles

C_d depreciable value of the vehicle (vehicle cost minus tires cost)

p percentage of vehicle cost depreciated by constant speed operation

r_i interest rate

f_1 present average value factor (average value of vehicle as a percent of C_v)

f_2 percentage of fleet in commercial utilization

m mileage per year

M_1 cost of parts per mile, expressed as a percentage of the depreciable value of the vehicle

M_2 average number of hours of labor required per mile traveled

h cost of an average maintenance labor hour, including overhead,

The per-mile costs of the inputs under study can be expressed in terms of the previously explained notation. A short explanation is given in each case.

(a) Fuel cost

Fuel consumption of vehicles is the most obvious item of vehicle operating cost. Major factors affecting the rate of fuel consumption (r_f) are the type of the vehicle, the speed of the vehicle, the rate of rise and fall of the road, the curvature of the road, and the type of surface of the road. The fuel cost per mile is given by

$$\hat{C}_1 = r_f C_f$$

In Figure 4.26 we can see the procedure required to estimate the rate of fuel

consumption for the following types of vehicles and road surfaces:
The methodology given in Figure 4.26 must be combined with the use of tables which give a variety of parameters needed for specific calculations related to a particular situation. Such tables can be obtained from [3], [14], and [18].

(b) Engine oil cost

This item is by far the least important in the total makeup of vehicle operating costs. Because of its low rate of consumption and the technical difficulty involved in relating oil consumption to differences in speed, little research has been done on this subject. Oil consumption is more a factor of engine speed (piston travel) than it is of road speed, but oil consumption increases with vehicle road speed. The cost of engine oil is given by

$$\hat{C}_2 = r_o C_o$$

In Figure 4.27 we show the methodology which must be followed to estimate $\hat{C}_2$. Again, use of tables is required.

(c) Tire wear cost

This is a much more important item than engine oil. For each individual type of vehicle, tire wear can be measured as a percentage of wear of one tire. This percentage is given per mile, and combined with the cost of a tire can be converted into dollars per mile. The number of tires is already taken care of. Figure 4.28 gives the basic procedure to estimate tire wear costs. The corresponding tables are given in [3].

The following expression can be used to determine the tire wear cost after extimating the percentage of tire wear per tire and per mile.

$$\hat{C}_3 = r_t \, C_t$$

(d) Depreciation cost

The depreciation expense of a vehicle is a real cost related to time and use of the vehicle. There is not a proved just base on which to divide total depreciation cost among mileage, time, and nonhighway factors, so it must be done by judgement. As in [14], the following assumptions can be made in order to estimate depreciation:

(1) The full value of the vehicle (not including tires) should be depreciated over its useful life

(2) Only the portion of depreciation due to constant speed operation must be considered

(3) Operation at higher speed reduces useful life of vehicles. As indicated by L. G. Shippy, J. De Weille [3] does not develop depreciation costs under this assumption, conflicting with the opinion of some people in the field of transportation [14].

In Figure 4.29, the reader can find the methodology to estimate depreciation costs, once proper parameters are obtained from the tables. The depreciation cost per mile can be written as

$$\hat{C}_4 = p \, C_v / r_v$$

(e) Interest cost

The calculation of depreciation costs does not include any charge for the capital invested in the vehicle. However, since vehicles last in average from 7 to 14 years [3], interest costs are rather significant. The method to estimate these costs is given in Figure 4.30. Once corresponding parameters are obtained from the tables, the following formula may be used.

$$\hat{C}_5 = C_v \; r_i \; f_1 \; f_2/m$$

(f) Maintenance cost

In [3], two components of the maintenance cost are considered. One is the cost of repair materials, and the other is the cost of hours of labor. Maintenance expense is defined as the monetary cost of cleaning, adjusting, repairing, replacing worn and damaged parts, lubricating (except oil), and antifreeze. The methodology for estimating maintenance costs related to vehicle operation in the road is shown in Figure 4.31. Here this formula may be used.

$$\hat{C}_6 = m_1 \;\; (C_v - N_t \; C_t) + m_2 h$$

Now that each $\hat{C}_i$ has been considered, it is possible to express V_1 as follows,

$$V_1 = r_f \; C_f + r_o \; C_o + r_t \; C_t + p \; C_v \; / \; r_v + C_d \; r_i \; f_1 \; f_2 \; / \; m + m_1 \;\; C_d \;\; + m_2 \; h,$$

where $C_d = C_v - N_t \; C_t$ is the depreciable value of the vehicle. When sufficient past data can be obtained, a regression analysis approach can be used to identify proper relationships between each component of V_1 and the corresponding factors affecting it. An example of such a study is given in [13].

The time-dependent user costs will be now considered. The value of travel time of commercial vehicles has two fundamental components: drivers' wages and drivers' nonwage compensation. Also, it is possible to include such factors as return on investment, depreciation, and property tax [18], since they are affected by a reduction in travel time due to road improvements. In [14], a list of 1974 travel time costs is given. There the travel time cost is considered as a function of speed and type of vehicle.

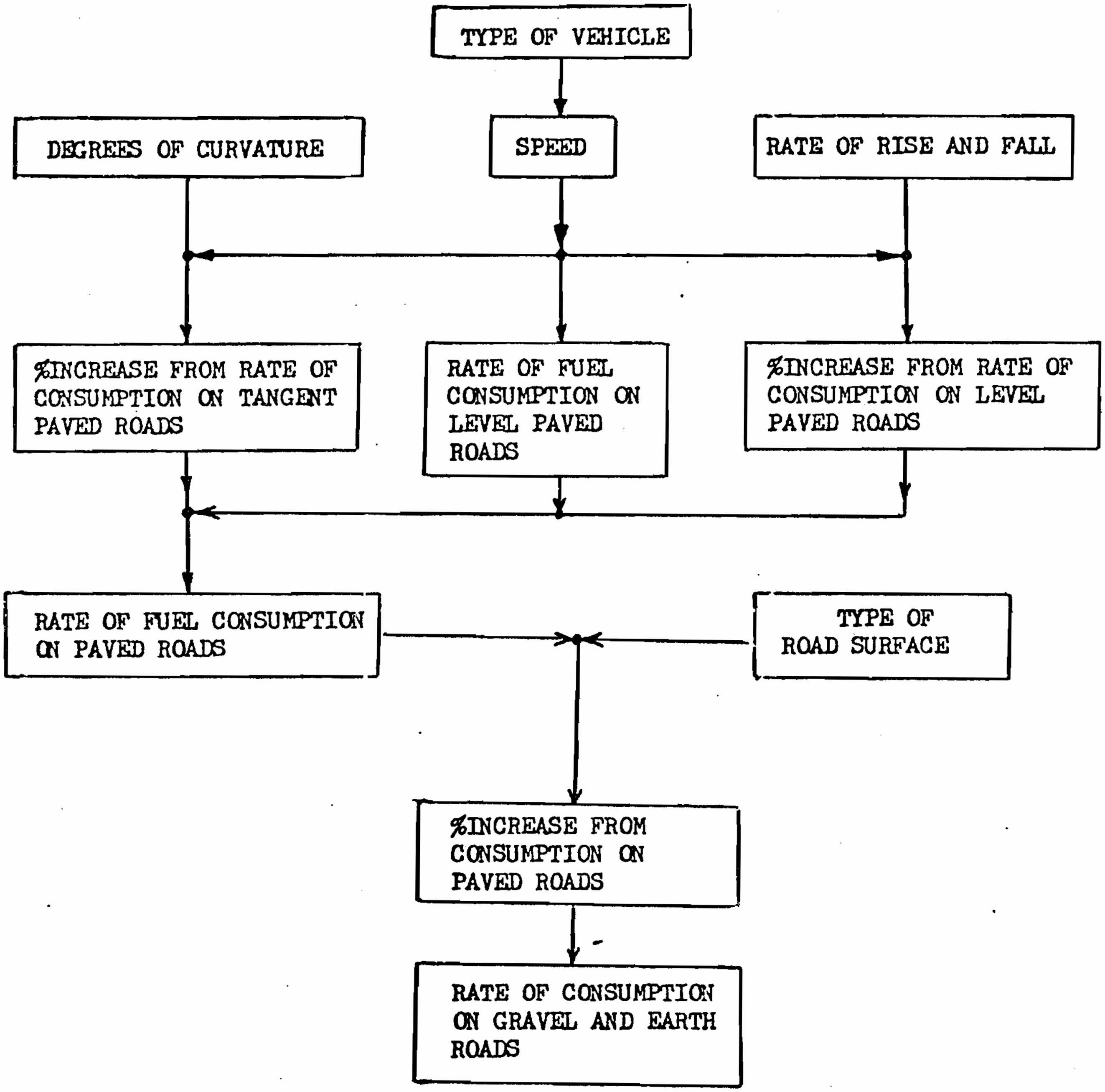


Figure 4.26 Procedure to estimate fuel costs

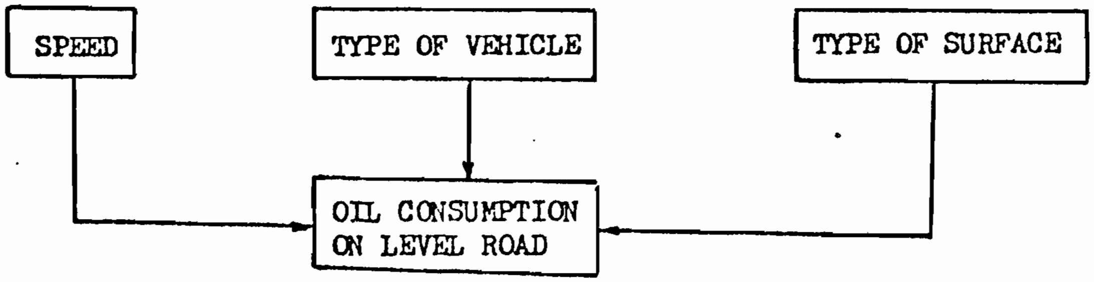


Figure 4.27 Method to estimate oil costs

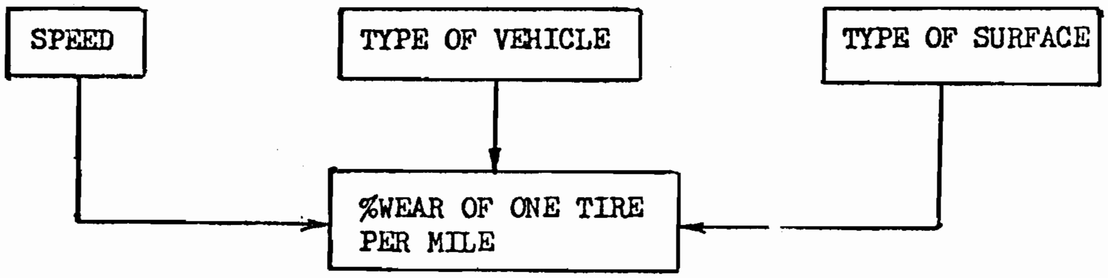


Figure 4.28 Method to estimate tire wear costs

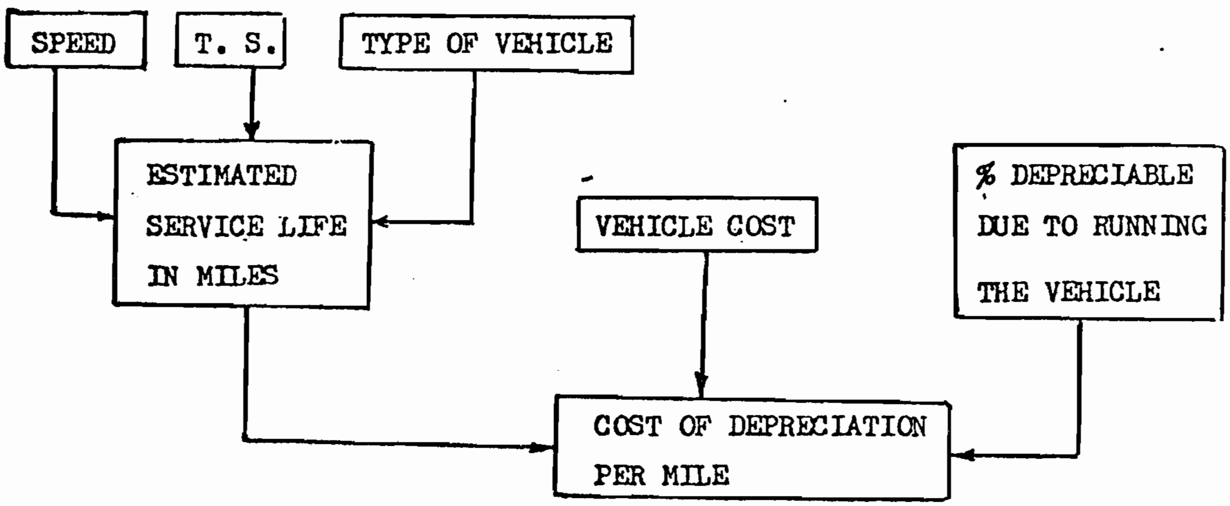


Figure 4.29 Methodology to estimate depreciation costs

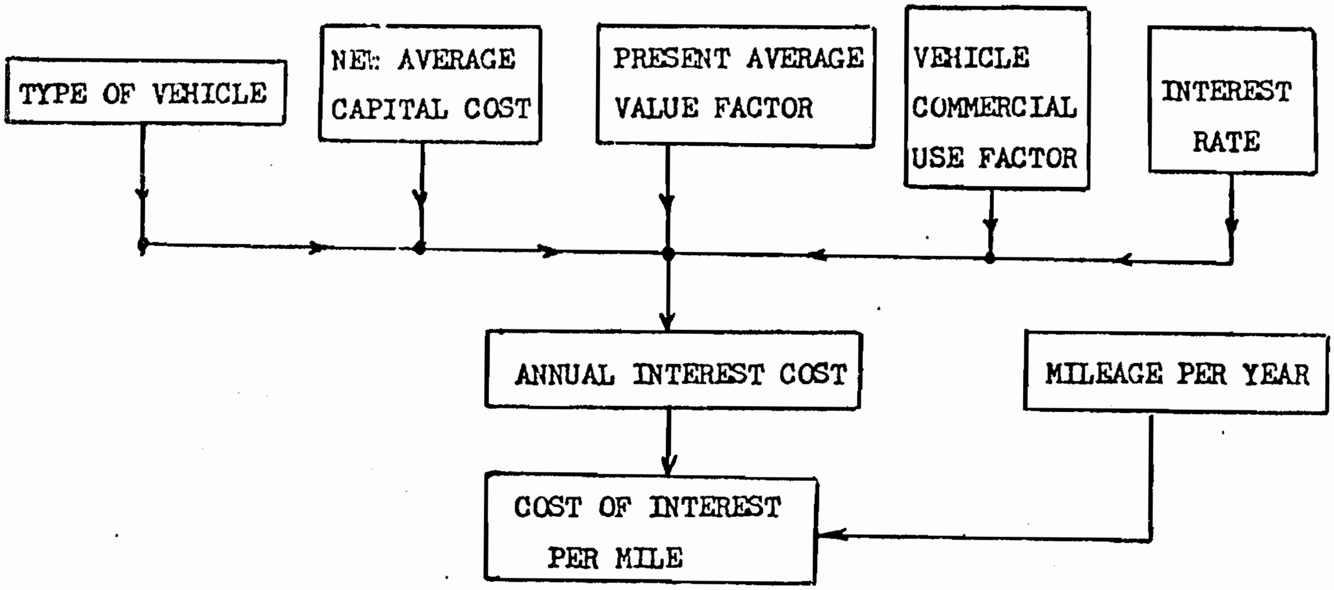


Figure 4.30 Procedure to estimate interest costs

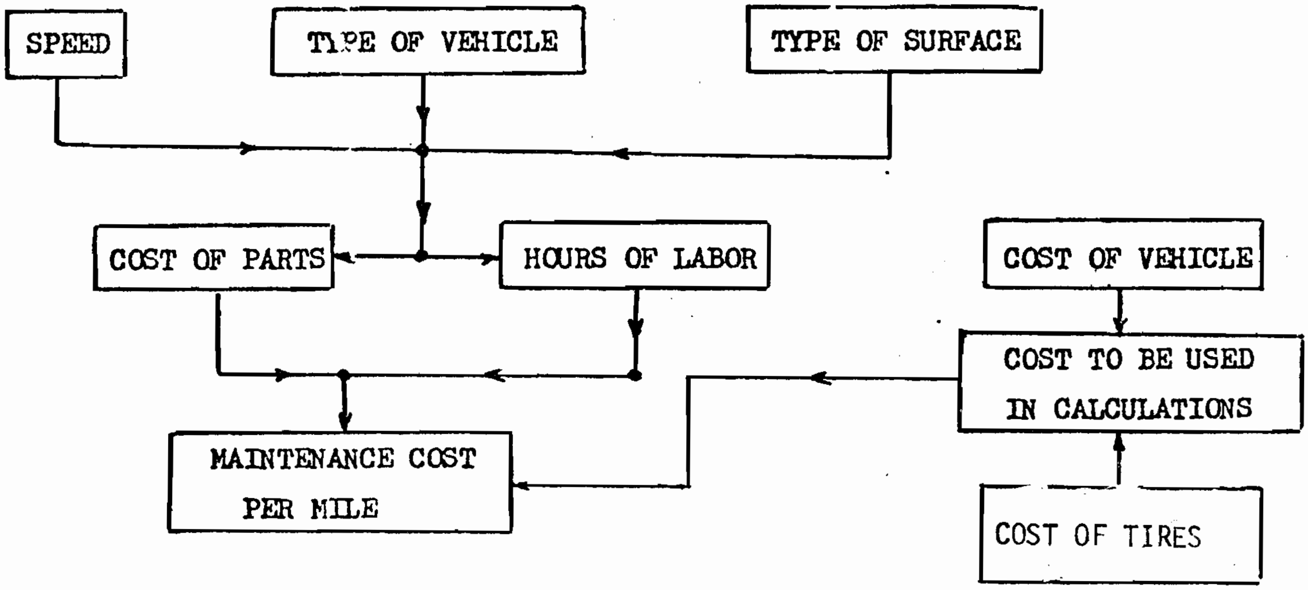


Figure 4.31 Procedure for estimating maintenance costs

4.3.4.3. Salvage Value

There is an inter-relationship between salvage value and the length of the analysis period. Ideally, the analysis period should end when it is expected that the road will be abandoned or have major reconstruction work done on it; and the salvage value of the pavements should be estimated at the end of this analysis period. Since very few roads are completely abandoned, the end of the ideal analysis period usually is expected to be the time at which the road will have major reconstruction work done on it. For purposes of designing pavements, which is the concern here, major reconstruction work on a road relates to major reconstruction that will affect the pavement that is being designed. This includes major pavement reconstruction with the same vertical and horizontal alignment or with new vertical and/or horizontal alignment. Major pavement reconstruction where vertical and horizontal alignment are not changed might be done where (1) it is decided that it is more economical to perform major reconstruction than to continue to repair the old (present) pavement, (2) lane widths are changed or extra lanes and/or shoulders are added with major reconstruction being performed simultaneously on the old pavement, (3) continued overlaying of the old pavement would be too costly because of curb and median heights and bridge clearances.

One of the problems encountered in estimating salvage value is related, then, to the fact that the analysis period that is used does not end at the time major pavement reconstruction is expected to take place; it is instead an analysis period that is less than the pavement's life, and is one that has been chosen primarily because it is the length of time over which it is thought that program inputs can be estimated with reasonable accuracy. Thus, at the end of this "practical" (as opposed to the "ideal") analysis period, it is in fact expected that the pavement presently being designed will be used for some additional time. During this additional pavement life, routine maintenance will be performed on the pavement and seal coats and overlays may also be applied to the pavement. In fact, for most analysis periods, this probably will be the case.

It seems reasonable, therefore, to make some allowance in the calculation of pavement costs for the fact that the last overlays for the different pavement designs last for different amounts of time beyond the end of the analysis period. Thus, with, say, and analysis period of twenty years, the last overlay of one design might decrease to the acceptable serviceability index precisely at the end of twenty years whereas that of another design might reach that index five years beyond the end of the analysis period.

There are two principal ways in which the currently-used procedure might be changed to adjust for overlays that last beyond the analysis period. One way would be to adjust the last overlay (down, say, even to hundredths of an inch) so that it lasted exactly to the end of the analysis period.

The other way would be to increase the salvage value of the pavement if the last overlay lasts beyond the end of the analysis period. There are several ways in which this might be done, either by adjusting the total pavement salvage value or by adjusting the salvage value of only the last overlay. However, it is believed that the adjustment should be made only to the salvage value of the last overlay, [8].

A procedure for calculating the salvage value for both the existing pavement structures and the future overlays has been developed and is included in NULOAD. The procedure requires that the user develop estimates of the present monetary value of the materials and remaining life of the existing pavement structure for each representative section. These present pavement structure values must be estimated for an average mile of pavement of each pavement age in the age, lane-mile distribution. In addition, the rate of loss of value of the pavement structure is also a required input. This rate of loss may be changed for each pavement age but should probably change only when a causative factor such as a new construction procedure or change of specification occurred. Using the present value of the pavement structure and the rate of loss in value, the salvage value of the pavement structure can be calculated at the end of the analysis period.

The salvage value of the overlay is based on estimates of the remaining life of the total overlaid structure at the end of the analysis period. The remaining life is calculated to be the difference between number of design 18 kip (80 kN) ESAL and the number experienced between the overlay and the end of the analysis period. The salvage value for a mile of pavement from one age slice is the product of the ratio of remaining 18 kip (80 kN) ESAL of the overlay to the design ESAL and the overlay cost. The total salvage value for all pavements is accumulated at the end of the analysis period and then output in terms of present worth. The salvage value represents the positive value of the investment in the pavement structure and, therefore, is of opposite sign from the construction, maintenance, and overlay costs, [1].

A better model for estimating salvage values and for taking into account the relationship between the salvage value, the pavement life, and the length of the analysis period is needed. An overall consideration should attempt to determine the major variables that influence salvage values. Development of better models probably would entail the consideration of the overall highway system and not just the pavement system.

In addition to considering better models for salvage values, there is a need to develop better data on how salvage values vary with different material types and road types.

If REHAB is to be modified, then a salvage value calculation needs to be included. If NULOAD is to be modified, the salvage value routine currently used should be modified to reflect a more comprehensive "value in use" concept of salvage value. Such a concept views the salvage value of a pavement as the dollar value of the pavement after it is improved minus the cost of the improvements.

4.3.4.4 Highway Cost Index

The proposed modification for REHAB is identical to that recommended for NULOAD, and discussed in Section 4.2.2.

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