A PAVEMENT DESIGN AND MANAGEMENT SYSTEM FOR FOREST SERVICE ROADS
A CONCEPTUAL STUDY

Thomas G. McGarragh
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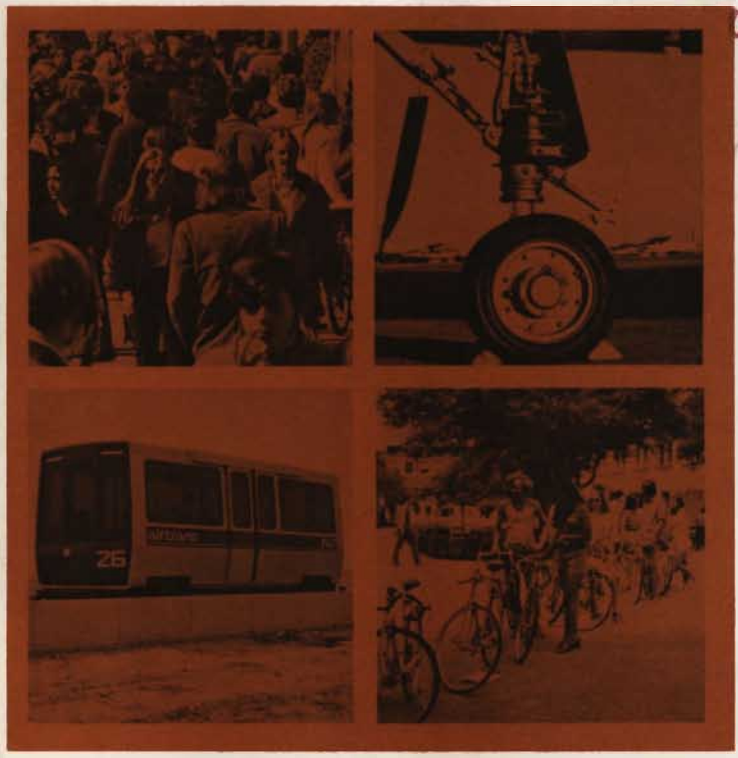

Report No. FS-1
Final Report
Phase I

JULY 1974

COUNCIL FOR ADVANCED TRANSPORTATION STUDIES

THE UNIVERSITY OF TEXAS AT AUSTIN

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U. S. Forest Service Agreement No. 13-686

conducted for

Forest Service
U. S. Department of Agriculture

by the

DIVISION OF RESEARCH IN TRANSPORTATION
COUNCIL FOR ADVANCED TRANSPORTATION STUDIES
THE UNIVERSITY OF TEXAS AT AUSTIN

July 1974

PREFACE

This is the final report for Phase I of a projected three-phase study being conducted for the Forest Service by the Council for Advanced Transportation Studies, The University of Texas at Austin. The purpose of the total project, FS-1, is to develop and implement a pavement design and management system for low-volume roads, in particular, Forest Service Roads. This report of Phase I is meant to summarize the problem analysis efforts of the project research team in addition to presenting a conceptual pavement management system and a discussion of its potential benefits when applied to a low-volume road network.

In an effort to obtain feedback for use in this final report, a draft version of the report was sent to the Forest Service for their review and editorial comments. The ideas and comments received as a result of this review are sincerely appreciated and have been incorporated, as far as relevant, into this final report. The support and advice of Mr. Adrian Pelzner and others in the Forest Service is appreciated.

Thomas G. McCarragh
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August 1974

ABSTRACT

The design of pavements for low-cost, low-volume roads is a complex procedure involving numerous variables. Because of the development of new information in the pavement field during the past decade, the complexity of the interaction of these design variables has become better understood and the need for a systematic approach to the problem of pavement design and management has become evident. This report is an attempt to apply this systematic approach to the design and management of low-volume Forest Service roads.

The report summarizes the problem analysis efforts of the project staff, beginning with the identification of the problem through its recognition and definition. Using the FPS type of working Pavement Design System developed in Texas as a conceptual base, an extensive examination of the major subsystems that make up the majority of existing pavement management systems for "higher type" roads was conducted. In attempting to define these basic components for the proposed low-volume road system, it was found that interaction between the project research staff and Forest Service personnel was of great importance. This interaction was achieved in the form of an interagency "brainstorming session" and later an "importance rating" of the ideas presented at this meeting. The results of this interaction along with the research efforts of the project staff allowed for an initial definition of the major components in the proposed system. Where complete definition of these subsystems was not possible, relevant questions and ideas were formulated for consideration in their further development. Finally, an example conceptual pavement management system for low-volume roads that incorporates all the ideas and concepts developed during the past year's research is presented.

It is concluded that the development of pavement management systems for low-volume Forest Service roads is indeed feasible and should be pursued in Phase II of the project. Recommendations for major areas of further research are also given.

KEY WORDS: Pavement system, low-volume roads, Forest roads, unsurfaced roads, low-cost roads, U. S. Forest Service

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CHAPTER 1. INTRODUCTION AND BACKGROUND

This report presents the results of a conceptual study of pavement design and management systems for low-volume roads. Such systems include the processes of (1) planning, (2) design, (3) construction, (4) maintenance, and (5) evaluation of low-volume roads. In this report an attempt is made to summarize the problem analysis efforts of the project research team in addition to presenting a conceptual pavement management system and a discussion of its potential benefits when applied to a low-volume road network.

Sponsored by the USDA Forest Service the study is primarily concerned with low-cost, low-volume forest roads under the jurisdiction of the Forest Service, although an attempt is made to develop a conceptual pavement design and management system flexible enough to be applicable to any road network consisting of low-volume facilities up to secondary highways.

Systems Approach

Pavements are complex structural systems influenced by many variables, including loads, environment, materials, construction, maintenance, performance, and various economic parameters. To facilitate the design of such a complex structure, existing procedures concentrate on certain important aspects of the design, such as structural capacity or thickness determination, but neglect other factors and their effects on the total pavement design. However, because of the tremendous increase in new information and developments of modern technology in the pavement field during the past decade, the complexity of the interaction of design variables has become better understood and the need for a systematic approach to the problem of pavement design and management is more evident.

A system has been described as a procedure or scheme which behaves according to some prescribed manner in performing an operational process (Ref 2). Accordingly, systems engineering provides a means of organizing the various segments of the total problem into an understandable framework. When using a systematic approach to solve a problem, the entire system is seen as a whole and not as a collection of individual parts functioning by themselves.

The advantages of using this coordinated approach towards the solution of pavement design and management problems are as follows (Ref 3):

(1) The development of a complete problem description provides new insight and perspective into the complexity of the problem, including the feedbacks and interactions involved.

(2) This insight, in turn, provides a structure for coordinating and utilizing research from many sources.

(3) A system description rapidly points out the areas of weakness and, consequently, areas of urgently needed research.

(4) A coordinated approach to the problem helps in understanding and developing the function and theories which can be used to determine optimal choices of design in the face of various judgment criteria and weighting functions.

(5) In the process of developing an overall optimal solution, immediate benefits can be gained by use of current state-of-the art information in the system framework until better techniques of analysis are developed.

The Problem

The Forest Service presently manages over 200,000 miles of roads throughout the United States representing an approximate investment of $2.5 billion. These roads are of primary importance for the protection and multiple use management of the lands and resources administered by the Forest Service. Ranging from narrow, low-volume, rudimentary tracks to multilane asphalt concrete highways, these roads combined with County and State systems form a network serving public, commercial, and administrative needs by providing access to recreational and timber land areas in the National Forests.

Population growth coupled with needs for sustenance, shelter, services, and recreational opportunities has rapidly increased the demands on forest lands. Consequently, to help meet the demand for accessible forest land the Forest Service has plans for the construction of another 136,000 miles of roads in the future. In addition to construction of these new roads, future work will also include the reconstruction of a great majority of existing roads.

Because of the complexities involved in efficiently designing, maintaining and managing pavements in such an extensive system, the National Forest Service initiated this study to explore the development of a comprehensive pavement design and management system for this network. Such a system, if developed, would permit consideration of many different pavement types, performance levels, stage construction, and other alternatives.

The specific objectives of this conceptual study as stated in the project's Detailed Study Plan (Ref 8) are

(1) to define the parameters involved in the problem,

(2) to assimilate the constraints with respect to (a) resource management objectives, (b) environmental concerns, (c) engineering skills, (d) engineering testing facilities, (e) on-site construction materials, and (f) available funds, and

(3) to formulate a concept of pavement design and management which will

    (a) permit optimization of the pavement investment, and

(b) provide pavement performance prediction methods which can be used in planning budgets and maintenance activities.

For the purpose of this report, the term "pavement" is being used to denote the total structural component of a road used to support traffic. A pavement, therefore, will consist of subbase, base, and surface courses placed singularly or in combination on a subgrade. Using this definition, it can then be said that on Forest Service roads a pavement may range anywhere from a compacted natural soil to a multilayered structure with an asphalt-concrete surface course.

In order to insure positive communication in developing the conceptual system, it will be necessary to define other terms as they are to be used in this report. Therefore, Appendix A of this report contains appropriate definitions of terms used herein. It is recognized that different usages of some terms does exist between various members of the Forest Service and among research groups and it is not likely that these differences will be resolved at this time. The list is offered to promote a common understanding of the concepts being introduced and to suggest a starting place for future consideration.

CHAPTER 2. ANALYSIS OF RESEARCH PROBLEM

As stated in Chapter 1, the principal objective of this project is to examine and define a conceptual pavement design and management system for low-volume roads, in particular, Forest Service roads. In order to accomplish this objective, recognition of the problem as it presently exists was an essential first step. This problem recognition was facilitated by acquiring background information and investigating the present state-of-the-art of Forest Service and other low-volume pavement design concepts. Following this problem recognition, it was essential that a definition of the problem be developed. This definition was to be in such terms as to facilitate an in-depth understanding of the problem.

Problem Recognition

Initial work in recognizing the research problem involved a broad study of pavement requirements and pavement strategies for low-cost, low-volume roads. This was accomplished through a literature review of such topics as soil stabilization, road maintenance, and pavement distress. Numerous references (Refs 10-23) on low-volume roads reviewed by the project staff indicate that most pavement design practices for such roads built in the United States follow the same pattern as for pavements carrying larger volumes of traffic in that economic measures are not applied in setting design standards. Therefore, it was felt to be more advantageous to review reports on low-volume road research being carried out in the developing countries of the world, where pavement design practices are developed specifically for low-cost, low-volume roads, and the economic aspects of design are of great importance. Also, the roads built in these countries more closely approximate those built by the Forest Service than do most other low-volume roads built in the United States.

In addition to the literature review, problem recognition was aided by extensive communication and interaction between the project staff and Forest Service personnel. Interagency meetings provided vital information on the operational standards of the Forest Service along with the expression of various views on the need for a pavement design and management system within the Forest Service. Field visits to National Forests allowed the project staff to observe the construction and performance of numerous forest roads under a variety of traffic and environmental conditions.

In addition to the gathering of background material and a review of the existing situation, a preliminary assessment of the Forest Service needs for a pavement management system was made. The synthesis of information collected during the problem recognition process assisted the project research staff in obtaining a better understanding of the problem.

It was evident from discussions with Forest Service personnel that the basic Forest Service needs for a pavement management system were agreed upon, but the emphasis on these needs was different for the various interests involved in the project's development. Forest Service management emphasizes the need for a system that will optimize the total pavement investment in addition to providing pavement performance prediction methods that can be used for such purposes as planning budgets and scheduling maintenance activities. Emphasis is also placed by Forest Service management on the need for a standardized pavement management system that will organize and unify design efforts within the Forest Service.

Forest Service personnel involved directly with the design of roads, such as the Forest Engineers and the Materials Engineers, emphasize the need for a system that will optimize resource management efforts, involving such factors as locally available construction materials, engineering skills, engineering testing facilities, and environmental impact. Also stressed is the need for a common "measuring tool" to evaluate the effectiveness of design methods and techniques for roads with different types of surfacings.

The proposed system, in addition to serving the above mentioned Forest Service needs, is viewed by the project staff as a means of collecting and organizing pertinent data for use as input in future pavement designs. The feedback data also can be of great value in evaluating the validity of the existing design models and aiding in their update.

Problem Definition

Once the problem of developing a pavement design and management system for low-volume Forest Service roads is well recognized, its deeper understanding and explicit definition become necessary before an effective solution can be generated. Because of the basic similarities between low-volume forest roads and higher type facilities, i. e., major highways, (the latter for which pavement design and management systems have already been developed as in Refs 1, 3, 4), we decided that problem definition could best be achieved by detailing the special constraints and considerations characteristic to the design of low-volume forest roads as compared with that of major highways. In this way, the problem of developing a pavement management system for low-volume Forest Service roads can be defined in such a way as to take advantage of the pavement management systems previously developed for "higher type" roads as guides in developing the proposed Forest Service system.

In detailing the special constraints and considerations involved in this problem, it was necessary to consider two basic questions: (1) what design factors are different for low-volume roads as compared to other roads, and (2) what special constraints are characteristic only of low-volume Forest Service roads?

In answering the first question many factors were considered. Listed below are those factors which differ between low-volume and standard roads and which seem to have the greatest influence on the development of a pavement design and management system for low-volume roads.

(1) Lower Volume of Traffic. Low-volume roads will be lightly travelled as compared to public highways. By this it is meant that most low-cost roads will have lower traffic volumes, generally less than 400 vehicles/day (Ref 10), and lower loading frequencies than major highways.

(2) Use of Local Construction Material. Because the transporting of quality paving material over large distances involves considerable costs, most low-volume roads are constructed with on-site or locally available material. The quality of these materials are, in many cases, inferior to that required for the construction of most "higher class" roads.

(3) Restricted Earthwork. On many low-cost, low-volume roads funds, and environmental factors permit only restricted earthwork. This not only affects the horizontal and vertical alignment of the road, but limits the removal and replacement of large quantities of poor subgrade material such as swelling clay or a frost susceptible silt.

(4) Surface Types. The types of running surfaces for low-volume roads differ considerably with those of "higher class" roads. While most public highways are constructed with a minimum of 4 or 5 inches of either asphaltic concrete or portland cement concrete for surface layers, few low-volume roads will have more than two inches of asphaltic concrete surfacing. A large percentage of low-volume roads have nothing more than a gravel or a natural soil surface.

(5) Environment. Due to the nature of the pavement surfacings, environmental conditions, namely moisture and temperature, incluence the performance of low-volume road pavements to a greater extent than the pavements of "higher class" roads.

(6) Types of Distress. The type and magnitude of pavement distress encountered on low-volume roads may be different than that found on public highways. This is also related to the differences in pavement surfacings, for example surface abrasion leading to dust problems and loss of surface material would be more acute on a low-volume gravel surfaced material than on a "higher class" asphaltic concrete pavement.

(7) Minimum Level of Acceptability. The minimum acceptable level of serviceability on most low-volume roads is lower than that on public highways. This is because the purpose of a low-cost, low-volume road is not so much to provide a smooth riding surface on which travellers will have a comfortable ride, but rather to provide an economical means of travelling from one point to another.

(8) Channelized Traffic. Because low-volume roads are usually narrower than public highways, the traffic on them tend to be more channelized. This is especially true on narrow gravel or earth surfaced roads where extensive rutting often occurs in the wheel paths.

To define the problem of developing a pavement design and management system for low-volume Forest Service roads, it was not only necessary to know what design factors were different for low-cost roads as compared to "higher class" roads, as listed above, but also to become thoroughly familiar with the special constraints and considerations characteristic to Forest Service roads and road management. Listed below are those that would have the greatest influence on the conceptual pavement management system.

(1) Road Users. The original purpose of a majority of Forest Service roads is to facilitate loghauling operations. Therefore, although the volume of traffic on these roads is light, the number of equivalent wheel loads are sometimes quite high as a result of the heavy loads carried by logging trucks. A Forest Service road will generally carry three classes of traffic during its lifetime:

  (a) Forest Commercial Traffic - during production years (cyclic).

  (b) Forest Visitor Traffic - during and after production years.

  (c) Forest Administrative Traffic - during and after production years.

(2) Distribution of Traffic. The distribution of traffic on a Forest Service road varies considerably depending on the time of year, for instance, during the winter months some of the lower grade roads are impassable due to mud or snow, but during the drier summer months these same roads may carry as many as 200 vehicles or more per day.

(3) Forecast of Traffic. Because the Forest Service controls the size of its timber sales, it is in a position to predict the number and size of loads travelling across its timber roads. This allows reasonable estimates to be made of the total load carried over a road for a particular period of time.

(4) Environmental Impact. A fundamental concept held by the Forest Service is that the environment must not be deteriorated as they build and operate their transportation system. Policies on dust control, surfacing rock depletion, stream pollution, mass soil movement, and maintenance of scenic values are all important issues that must be considered in the design of forest roads.

(5) Engineering Manpower. Because of the lack of sufficient engineering manpower in some of the Forest Service Regions, it is not always possible to do a quality job on all Forest Service road projects (Ref 9). Collection of design input data is also hampered by this lack of manpower.

(6) Prudent Operator Concept. Because a majority of Forest Service roads are built under Timber Purchaser Contracts by the timber purchaser himself, a "prudent operator" concept must be adhered to by Forest Service personnel when designing the roads. This concept requires that a road be constructed only to the standard and quality needed to remove the timber in the sale, therefore, the design life of the road is only for the length of the timber sale. However, if the road is needed beyond the timber sale period, the Forest Service may use either stage construction or supplemental funding to provide for higher standards and quality than needed for the timber sale.

(7) Maintenance Levels. The Forest Service's maintenance management program designates five different levels at which maintenance is performed, starting with a "basic custodial care" for roads not in use, and continuing with each level requiring greater maintenance effort. This program also designates that forest roads are to be maintained by their users, i.e., logger, commercial haulers, and the Forest Service.

(8) Diverse Design Conditions. Because the Forest Service manages forests throughout the United States, the design for their low-volume roads must incorporate considerations for a great variety of climatic and topographic conditions, in addition to consideration of the many different types of subgrade conditions and paving materials found within these areas.

As indicated above, the problem for which a solution will be attempted in this research project is that of developing a pavement design and management system for the National Forest Service that will satisfy their needs in terms of (1) optimizing the total pavement investment, (2) providing pavement performance prediction methods for planning purposes, (3) optimizing resource management efforts, (4) providing a tool for evaluating the effectiveness of specific pavement designs, and (5) unifying pavement design efforts within the Forest Service.

If, because of the basic similarities between low-volume forest roads and public highways, the pavement management systems already developed for "higher type" roads are used to advantage in developing this proposed system, then the problem can best be defined by concentrating on enumeration of major differences between Forest Service roads and higher type facilities. With the identification of these differences, an attempt can be made to formulate the proposed conceptual system by modifying an existing pavement management system to account for them.

CHAPTER 3. FORMULATING A CONCEPTUAL SYSTEM

In the previous chapter a statement of the problem of developing a pavement design and management system for low-volume Forest Service roads was presented. On that basis it is possible to begin the definition and formulation of the conceptual system. In doing this, it will first be desirable to examine the requirements of a general pavement management system. Once the basic components have been established an attempt can be made to apply with them, the special constraints and parameters involved in this particular problem to arrive at a conceptual pavement management system applicable to low-volume Forest Service roads.

General System Requirements

A pavement management system, as termed by Haas and Hutchinson (Ref 5) consists of a coordinated set of activities used in the planning, design, construction, maintenance, and evaluation of pavements. Figure 1 illustrates this in a logical simulation of the progression of activities that could be used by any agency in providing pavements. In practice it is not possible to isolate the various components involved in pavement management, therefore, a pavement design and management system synthesizes these major components to form an integrated framework.

In 1967 work on such a concept was begun by Hudson, Finn, et al. on NCHRP Project 1-10. The interim report (Ref 2) from that project provides a basic framework for considering pavement design and management problems (Fig 2) which, while only conceptual, shows the integration of the many

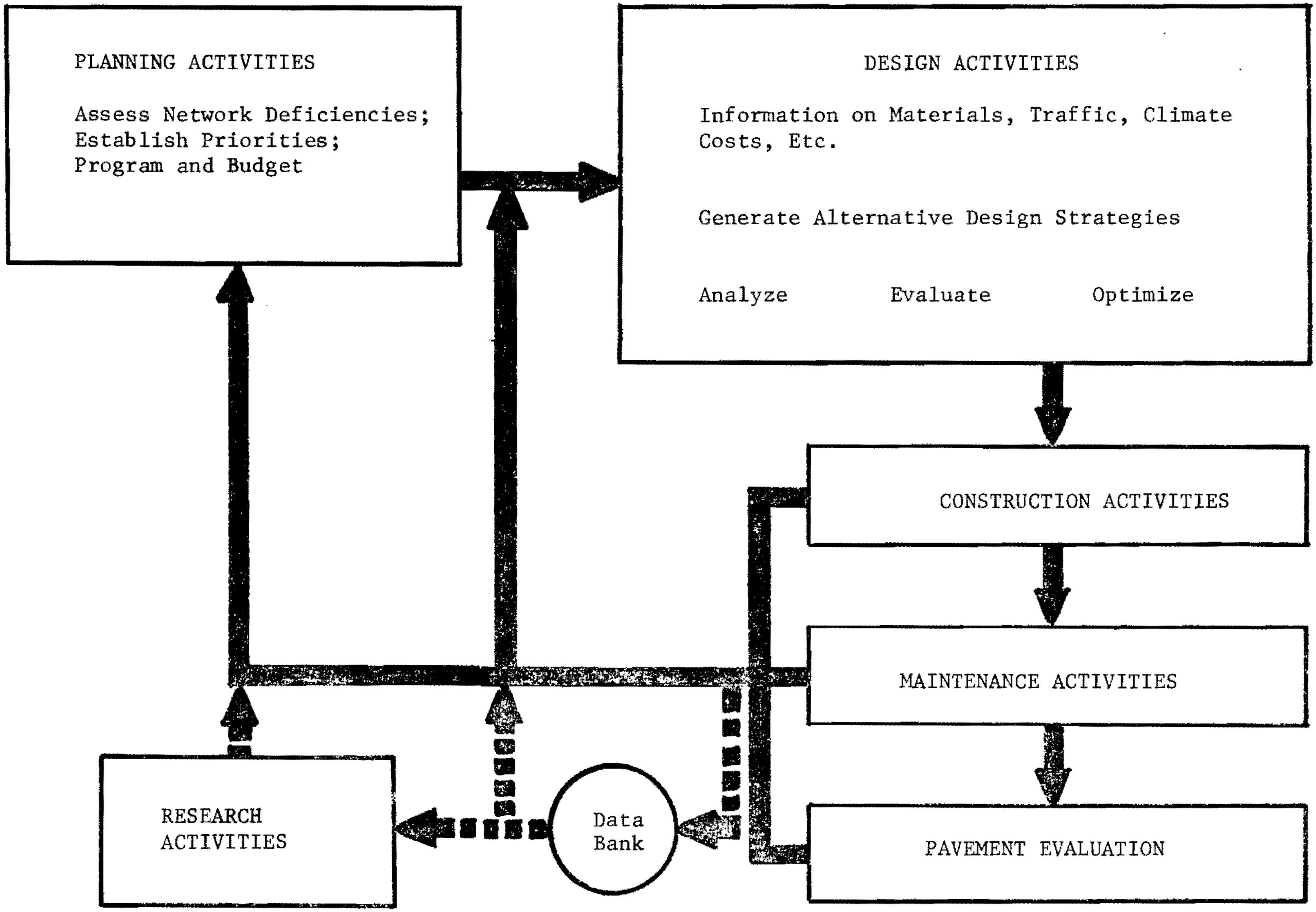


Fig 1. Major classes of activities in a pavement management system (Ref 26).

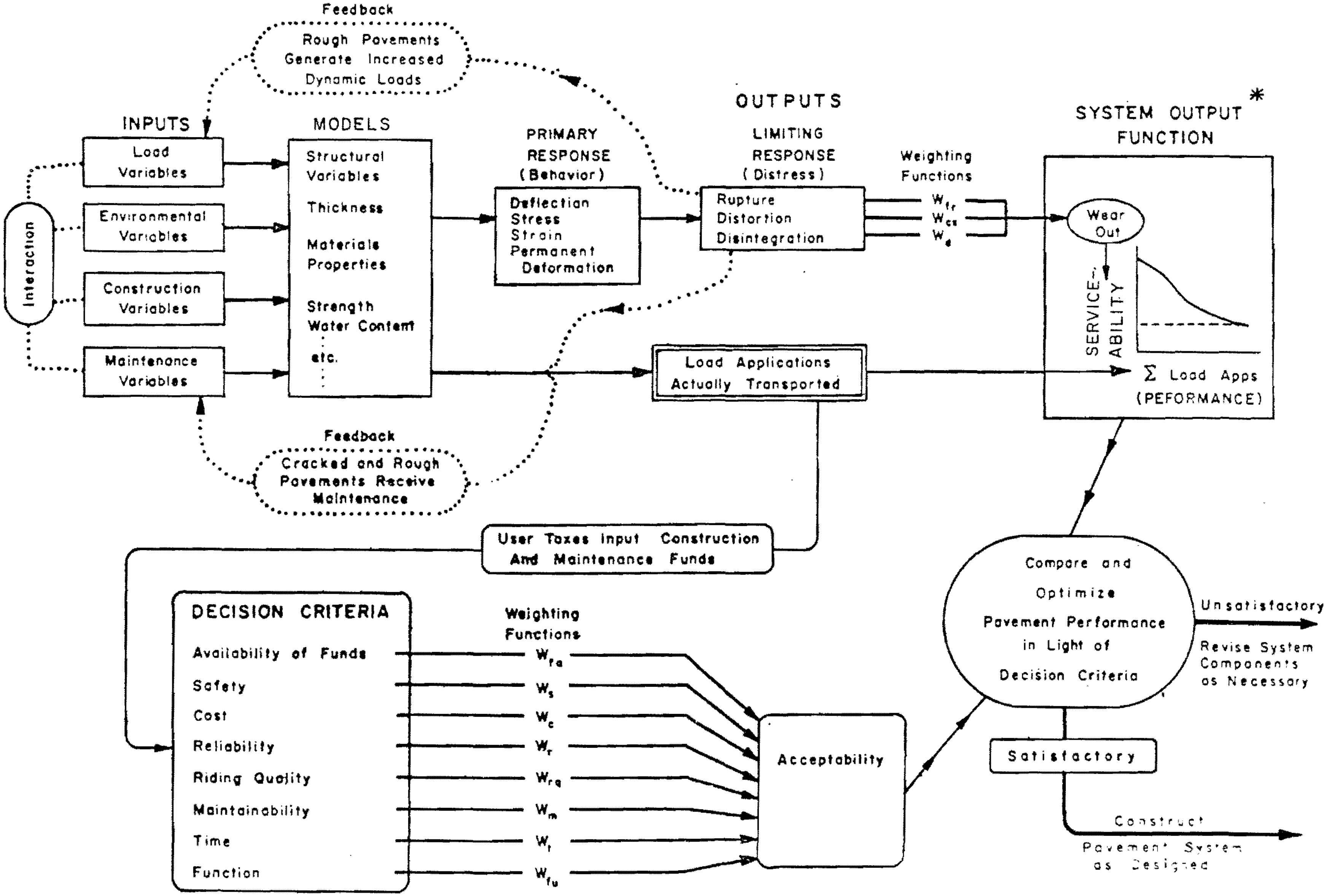


Fig 2. Conceptual pavement system (Ref 2).

factors involved in the problem. This is a broad, encompassing framework that allows for considerable variation of models and details within each major subsystem. As can be seen in Figure 2, the main elements of the system are (1) inputs, (2) a structural design subsystem, (3) system outputs and responses combining to form the system output function, (4) decision criteria, and (5) an optimization technique for use in comparing the performance of alternative designs. Other important concepts included in the pavement design system are stochastic variation of variables, feedback within the system, and interaction between variables.

In an attempt to apply this system concept to real world situations, Texas Highway Department Research Project 123, "A Systems Analysis of Pavement Design and Research Implementation" (Ref 1), was initiated at The University of Texas and Texas A & M University by the Texas Highway Department. As a result a computerized working pavement design system was developed for flexible highway pavements (Fig 3) which is now being implemented in the design and management of Texas highways.

Conceptual Basis

After extensive examination of these and other works (Refs 1 to 6), we decided that the Flexible Pavement System type of working pavement design system developed in Texas offered an excellent conceptual base from which a pavement design and management system could be formulated for low-volume Forest Service roads because its flexible framework allows for considerable variation of models and its success is proven in real world situations. This Pavement Design Framework was broken down into a series of basic components for purposes of examination (inputs, structural design, output, decision criteria, optimization process). Each of these subsystems were then defined and evaluated in terms of their function in the design and management of low-volume roads.

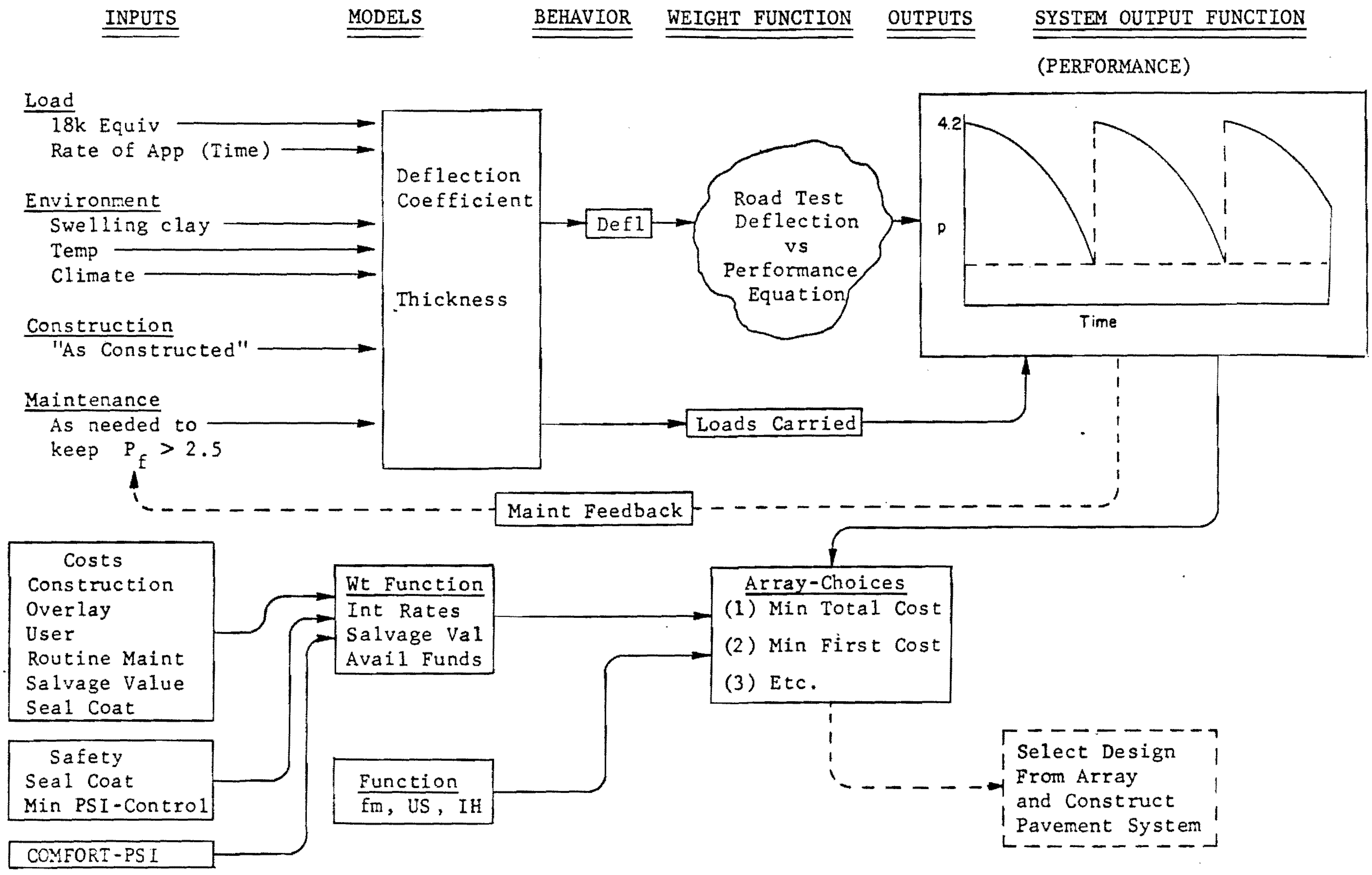


Fig 3. Working pavement system, FPS (Ref 1).

Evaluation of Subsystems

In evaluating the major components of the Flexible Pavement System in terms of their function in the design of low-volume roads, the project staff first looked at the system as a whole, studying the part each individual subsystem played in the design and management of a pavement. Using information and data obtained through the review of numerous references on low-volume roads and pavement design and management systems development, an attempt was made to rate each major subsystem as to (1) the current knowledge available on the subject and (2) the estimated difficulty expected in defining the subsystem for use in a pavement management system for low-volume forest roads. This approach gave a better idea as to which areas would require the most effort in developing the proposed conceptual system. Although each major subsystem received considerable study and evaluation, it was felt that inputs, decision criteria, and system outputs should receive the major portion of the research effort since they represent the areas of greatest uncertainty in defining this conceptual system.

In evaluating the individual subsystems, the project research staff divided each into a series of its basic components, then each of these component parts was thoroughly examined and, where necessary, further broken down to facilitate a more complete evaluation. An attempt was then made to define these subsystems as they would be used in a low-volume road pavement management system. For example, extensive lists of input variables and decision criteria were developed that took into consideration the many special constraints and design parameters typical for low-volume roads.

Where definition of a subsystem was not possible, because the need for research was beyond the scope of this conceptual study, relevant questions and ideas were formulated for consideration in the eventual development of the subsystem definition. For example, when evaluating the structural design subsystem, the adequacy of a single pavement design method for all types of Forest Service roads was seriously questioned, and as a result, an idea was developed that divided this subsystem into two parts, allowing different structural design methods to be considered for paved and unpaved roads.

"Brainstorming Session"

In addition to the extensive literature review previously mentioned, an essential part of this initial evaluation of subsystems was the interaction and exchange of information between the research staff and Forest Service personnel. In an attempt to further this interaction, a "brainstorming session" was held at The University of Texas in Austin on March 20-22, 1974. At this meeting the results of the project research staff's initial evaluation was presented and discussed in order to obtain "field input" from the Forest Service. A summary of the ideas and discussions presented at this conference including those on (1) system input variables, (2) decision criteria, (3) terminology, (4) pavement performance, (5) the decision making process within the Forest Service, (6) pavement failure, and (7) special constraints and considerations for Forest Service roads, was prepared by the project staff and is presented in Appendix B along with revised lists of input variables and decision criteria developed at the brainstorming session.

This brainstorming session not only presented an opportunity for the research staff to draw on the valuable experience of Forest Service field personnel in obtaining information in many areas of low-volume road design and management, but also helped familiarize Forst Service personnel with the project and encouraged their direct participation in its development.

"Importance Rating"

Because such a large amount of subject matter was discussed at the brainstorming session, a comprehensive evaluation of the relative significance of each variable as compared with other variables was not possible in most cases. Therefore, the session attendees agreed that it would be advantageous in the further development of the project to follow up the conference with a rating analysis of the importance of the various items in the proposed pavement management system. It was felt that the information obtained from this "importance rating" could be used to great extent in setting priorities for developing the major subsystems of a pavement management system for low-volume Forest Service roads.

Instructions for the Rating Analysis

The following "Instructions for the Rating Analysis," which was sent to all conference attendees by the project staff, explains what was included in the "importance rating" and the procedures used to rate the material.

INSTRUCTIONS FOR RATING ANALYSIS

I. Please read the enclosed "Summary of FS-1 'Brainstorming Session'" written by the project staff.

II. On sheets labeled "Comments on Summary" please comment on:

(1) Any area of discussion in the summary that might be a misinterpretation of the ideas actually discussed at the "brainstorming session."

(2) Any relevant ideas mentioned during the session that do not appear in the summary.

(3) Any new ideas that have come to you since the session that might be helpful in developing the PMS for the Forest Service.

III. On the appropriate sheets, please rate each of the input variables and decision criteria listed as to their importance to the proposed PMS, your expertise on the subject, and its relative "state of the art" within the Forest Service. The importance of each item to the proposed PMS should be rated on a 0.0 to 5.0 scale. A rating of 0.0 would indicate that you believe the item to be of absolutely no importance. A rating of 5.0 would be used to express your opinion that the item is extremely important to the proposed PMS. Other degrees of perceived importance can be expressed by selecting an appropriate number between these extreme values using a standard format of two significant figures with one figure to the right of the decimal. In rating your expertise on the subject, a 0.0 to 5.0 scale is also used with a 0.0 rating indicating that you strongly feel you know nothing whatsoever about the item in question and a 5.0 rating indicating that you consider yourself an expert on the subject. When rating the "state-of-the-art" within the Forest Service of a particular item, please use the following two scales to indicate your approximate feelings.

Scale 1 - Available Information on Item

A - Very little or no information is available to Forest Service on this item.

B - Limited information is available on this item

C - Information on this subject is complete

Scale 2 - Collection of Information

1 - Major difficulty would be encountered in collecting data on this subject.

2 - Minor difficulty would be encountered in collecting data on this subject.

3 - No difficulty would be encountered in collecting data on this subject.

Please comment if there is any question on interpreting the meaning of any particular item. If there is, indicate your interpretation of the item.

IV. On the sheets labeled "Rating of Special Constraints and Considerations," please rate on a 0.0 to 5.0 scale, as explained previously, your Opinion of how important to the proposed pavement management system are each of the seventeen items listed in this category on pages 5-7 of the summary. Comments would also be appreciated on any of the items themselves or the ratings assigned to them.

V. On the sheet labeled "Definitions," please indicate how you would define each of the terms listed.

Analysis of Importance Rating

In analyzing the returns of the importance rating, the project research staff first reviewed the comments on the "summary of the brainstorming session" written by the participants of the conference. These comments clarified a number of misinterpreted ideas on Forest Service operations held by the project staff, in addition to expressing field views on such relevant topics as pavement failure, serviceability measurements, and decision criteria.

We next evaluated the ratings received for the input variables and the decision criteria. This was done by first finding the "weighted" mean importance rating for each variable. By "weighted" is meant that the rating given each variable by a rater is adjusted by his expertise level on the subject in calculating the average importance rating. In other words, the importance rating of a variable by an individual who considers himself an authority on the subject will weigh more heavily in the computation of the "weighted" mean importance rating than will that by an individual who knows little on the subject of which the variable is a part.

The "weighted" mean importance rating was calculated using Equation (1).

$$\frac{\Sigma\ (I \times E)}{\Sigma\ E} \tag{1}$$

In this equation the product of the importance ratings (I) and the expertise rating (E) is summed over the number of ratings for a particular variable. This value is then divided by the sum of the expertise rating for that variable to arrive at the "weighted" mean importance rating. Figure 4 illustrates this procedure of calculating a "weighted" mean importance rating. Hypothetical data is used for the different importance and expertise ratings for this example.

	Ratings for Variable X		I × E	$\frac{\Sigma(I \times E)}{\Sigma E}$
	Importance (I)	Expertise (E)		
	4.5	4.0	18.00	$\frac{69.1}{17.0} \cong 4.1$
	3.0	2.0	6.00	
	4.0	4.5	18.00	
	4.2	3.5	15.70	
	3.8	3.0	11.40	
Σ	19.5	17.0	69.10	
Raw Mean =	3.9			

Median Rating = 4.0

Fig 4. Example calculation of a "weighted" mean importance rating.

As shown in the Rating Analysis Summary for input variables and decision criteria, Figure 5, these "weighted" importance ratings ranged from a high of 4.95, for the "use of initial construction cost as a decision criteria," to a low of 1.73, for the "use of static loads in the characterization of loads on pavement structure."

While recognizing the potential significance of the "weighted" mean importance ratings in the evaluation of the system variable, we felt that it was also important to look at the raw mean importance rating and also at the median importance rating for each variable. These can be used in comparisons with the "weighted" mean ratings to examine hidden discrepancies in the use of this "weighted" rating as a representation of the potential relative importance of variables to a pavement management system for low-volume Forest Service roads. All data averages are given in Figure 5.

In comparing the raw mean and median values with the "weighted" mean importance rating for all the variables, few substantial variations were found. Those that were discovered received careful study by the project staff with the eventual observation that, in all cases, large variations were the result of inconsistent ratings by individuals that rated themselves low in expertise on the subject being rated. It was, therefore, agreed that the "weighted" mean importance rating would be a sufficient representation of the relative importance of each variable to the low-volume road pavement management system, as seen by the conference attendees, and as such, were used to define the potential input and decision criteria subsystems of the proposed system.

The state-of-the-art ratings (defined in the "Instructions for the Rating Analysis") that are included in the Analysis Summary, Figure 5, are the approximate average values of those ratings fiven by the conference

INPUT VARIABLES

Item	"Weighted" Mean Importance Rating (0.0 to 5.0)	Raw Mean Importance Rating (0.0 to 5.0)	Median Importance Rating (0.0 to 5.0)	State-of-Art (A-C)	State-of-Art (1-3)
LOAD AND TRAFFIC VARIABLES					
Total Load	4.37	4.35	5.0	B	2
Number of Applications	4.72	4.68	5.0	B	2
Frequency of Loads	3.17	2.85	3.0	B	2
Speed	2.75	2.81	3.0	B	2
Tire Pressure	3.68	3.29	4.0	C	2
Characterization-Distribution of Load	4.54	4.17	4.5	A	2
Axle Spacing	3.86	3.62	3.0	B	3
Type of Load					
(a) static	1.73	1.85	2.0	B	2
(b) dynamic	4.32	4.18	4.5	A	2
Distribution of Traffic					
(a) seasonal	4.58	4.60	5.0	B	2
(b) annual	3.58	3.46	4.0	B	2
Surface Wear Effect-Gravel Loss	4.23	4.14	4.5	B	1
Lateral Distribution of Roadway Channelization	3.04	3.00	3.0	A	1
ENVIRONMENTAL VARIABLES					
Rainfall					
(a) amount	3.81	3.80	3.5	B	3
(b) intensity	3.56	3.70	3.0	B	2
(c) seasonal distribution	3.79	3.80	4.0	B	2
Snowfall					
(a) amount	2.73	2.83	3.0	B	2
(b) characterization	2.90	2.92	3.0	B	2

(Continued)

Fig. 5. Rating analysis summary for input variables and decision criteria.

INPUT VARIABLES

Item	"Weighted" Mean Importance Rating (0.0 to 5.0)	Raw Mean Importance Rating (0.0 to 5.0)	Median Importance Rating (0.0 to 5.0)	State-of-Art (A-C)	State-of-Art (1-3)
Temperature					
(a) average	2.65	2.65	3.0	B	3
(b) range	3.36	3.35	3.0	B	3
Soil Type	4.11	4.04	4.0	B	2
Freeze-Thaw Cycle	4.21	4.23	4.0	B	2
Vegetation	2.41	2.31	2.0	B	2
Area Sensitivity	3.10	3.31	3.0	B	2
Exposure-North Side	3.15	3.12	3.0	C	3
Topography-Drainage					
(a) surface	4.38	4.30	4.0	B	2
(b) subsurface	4.60	4.50	5.0	B	1
Snow Removal	3.77	3.12	4.0	B	3
CONSTRUCTION VARIABLES					
Quality Control					
(a) thickness	4.58	4.57	5.0	B	2
(b) smoothness	3.14	3.19	3.0	B	2
(c) compaction	4.60	4.57	5.0	B	3
(d) material	4.62	4.70	5.0	B	3
(e) moisture and temperature	3.97	3.92	4.0	B	2
Work Technique					
(a) Forest Service appropriated funds	3.18	3.15	3.0	C	3
(b) timber sales	3.55	3.54	4.0	C	3
(c) regional specs	2.45	2.50	3.0	C	3
Equipment Availability	3.66	3.54	4.0	B	3
Exposure	2.97	2.73	3.0	B	2
Personnel-Skill Level	4.16	4.11	4.0	B	2

Fig 5. Continued.

INPUT VARIABLES

Item	"Weighted" Mean Importance Rating (0.0 to 5.0)	Raw Mean Importance Rating (0.0 to 5.0)	Median Importance Rating (0.0 to 5.0)	State-of-Art	
				(A-C)	(1-3)
Construction Length	3.11	3 00	3.0	C	3
Topography-Geometrics	3.93	3.85	4.0	B	3
Equipment					
(a) environmental impact	3.39	3.33	3.0	B	2
(b) adaptability	3.49	3.54	3.0	B	2
Subgrade Properties					
(a) k value	4.87	4.77	5.0	B	2
(b) permeability	4.27	4.37	4.0	B	2
(c) gradation	4.12	4.15	4.0	B	2
Type and Quality of Paving Material Available	4.58	4.30	5.0	B	2
Testing Equipment Available	3.55	3.42	3.0	C	3
Cross-Section	3.95	3.65	4.0	C	3
Stabilization Program	4.28	4.36	4.5	B	2
Frost Design	3.82	3.92	4.0	B	2
Layers					
(a) number	3.74	3.75	4.0	B	3
(b) thickness	4.58	4.58	5.0	B	3
(c) arrangement	4.34	4.25	4.5	C	3
MAINTENANCE VARIABLES					
Level of Maintenance	4.45	4.50	4.5	C	2
Road Users	3.79	3.80	4.0	B	2
Available Funds	3.96	3.88	4.0	B	2
Personnel					
(a) force account	3.33	3.33	3.5	B	2
(b) timber purchaser	3.40	3.41	4.0	B	2
(c) contract	3.20	3.08	3.0	B	2

Fig 5. Continued.

INPUT VARIABLES

Item	"Weighted" Mean Importance Rating (0.0 to 5.0)	Raw Mean Importance Rating (0.0 to 5.0)	Median Importance Rating (0.0 to 5.0)	State-of-Art (A-C)	State-of-Art (1-3)
Turn Over to Other Agency	3.39	3.23	3.0	C	3
Rehabilitation					
(a) patching	3.49	3.36	3.5	B	2
(b) sealing	3.90	3.66	4.0	B	2
(c) overlaying	4.11	3.91	4.0	B	2
(d) gravelling	4.14	4.08	4.0	B	2
Type of Equipment Required	3.36	3.38	3.0	C	3
OPERATIONAL VARIABLES					
Controlled Use	4.40	4.38	4.0	B	2
Control on					
(a) loading	4.74	4.69	5.0	B	2
(b) speeding	2.98	3.00	3.0	B	2
Time Lag in Funds	4.00	4.00	4.0	B	1
Operational Planning-Enforcement					
(a) snowplowing?	2.30	2.16	2.0	B	2
(b) major hauling all allowed?	4.20	3.70	4.0	B	3
CONSTRAINTS					
Maximum Allowable Cost					
(a) initial construction	4.60	4.54	5.0	B	2
(b) total maintenance	4.17	4.23	5.0	B	2
Minimum Layer Thickness	4.49	4.46	5.0	C	3
Minimum Time Until First Major Maintenance	4.28	4.15	5.0	A	2
Minimum Time Between Major Maintenance	4.23	3.92	4.0	B	2

Fig 5. Continued.

INPUT VARIABLES

Item	"Weighted" Mean Importance Rating (0.0 to 5.0)	Raw Mean Importance Rating (0.0 to 5.0)	Median Importance Rating (0.0 to 5.0)	State-of-Art (A-C)	State-of-Art (1-3)
Environmental Constraints	4.35	4.23	4.0	A	2
Political	4.16	4.00	4.0	B	2
Management	4.23	4.30	4.0	C	2
Prudent Operator Concept	3.56	3.62	3.0	C	3
Design Life	4.50	4.54	5.0	C	2
Fiscal Year	2.69	2.64	3.0	C	3

DECISION CRITERIA

Item	"Weighted" Mean Importance Rating (0.0 to 5.0)	Raw Mean Importance Rating (0.0 to 5.0)	Median Importance Rating (0.0 to 5.0)	State-of-Art (A-C)	State-of-Art (1-3)
(1) Cost					
(a) initial	4.95	4.92	5.0	C	3
(b) maintenance	4.18	4.23	5.0	B	2
(c) user	3.74	3.85	4.0	B	2
(d) operational	3.83	3.69	4.0	B	2
(2) Funds					
(a) available	4.73	4.69	5.0	B	2
(b) probability of additional	4.24	4.15	4.0	A	2
(c) type	3.61	3.08	3.0	C	3
(3) Riding Quality	3.18	3.15	3.0	A	2
(4) Safety					
(a) skid resistance	3.11	3.08	3.0	A	2
(b) dist	4.42	4.08	4.0	B	2
(c) geometric-shoulders	3.21	3.00	3.0	A	2

Fig 5. Continued.

DECISION CRITERIA

Item	"Weighted" Mean Importance Rating (0.0 to 5.0)	Raw Mean Importance Rating (0.0 to 5.0)	Median Importance Rating (0.0 to 5.0)	State-of-Art (A-C)	State-of-Art (1-3)
(d) guard rail-cross section	2.97	2.85	3.0	B	2
(5) Administrative Requirements	4.00	3.92	4.0	C	3
(6) Function of the Road	4.35	4.23	5.0	C	3
(7) Service Requirements	3.87	3.72	4.0	B	2
(8) Environmental Impact-Optimize	4.42	4.38	4.5	A	2
(9) Confidence Level	3.90	4.00	4.0	A	1
(10) Stage Construction	4.19	4.08	4.0	B	2

Fig 5. Continued.

participants for each variable. These ratings, representing the present and the anticipated future availability of data for inputs to the system, have been used in the definition of the input and decision criteria subsystems to evaluate the feasibility of collecting information for the various inputs to the operational low-volume road management system.

For the evaluation of the special constraints and considerations ratings, mean and median importance ratings were calculated for each individual item, the results of which are presented in Figure 6. In comparing these values, only one item was found to have a substantial variation. This item was No. 10, "Keep the system simple." The mean rating for this item was 4.07, while its median rating was 5.0. It was found in an examination of the returns for this rating that, while a majority of the conference attendees felt that it was extremely important to "keep the system simple," a few of the raters felt that this was relatively unimportant and therefore rated it low, thus causing a large variation in the mean and median ratings for this item.

The results of the ratings evaluations for all the individual constraints and special considerations were used as an indication of the conference attendees feeling as to their inclusion in the conceptual pavement management system.

To begin the definition and formulation of the proposed conceptual pavement management system for low-volume Forest Service roads, it was first necessary to examine the requirements of a general pavement management system. Once the basic components had been established as consisting of five major subsystems, (1) inputs, (2) a structural design subsystem, (3) system outputs, (4) decision criteria, (5) an optimization process, an evaluation as to their application in the design and management of low-volume forest roads was possible. This evaluation involved an initial examination and attempted

Item Number Page 6 - Summary	Mean Importance rating (0.0 - 0.5)	Median Importance rating (0.0 - 0.5)
(1) Unpredictable traffic on Forest Service Rds.	3.15	3.0
(2) "Prudent Operator" Concept	2.85	3.0
(3) Who will use PMS?	3.15	4.0
(4) Control of Timber traffic on F.S. Rds.	3.80	4.0
(5) Fatigue Failure	2.85	3.0
(6) Classes of traffic on Forest Service Rds.	3.92	4.0
(7) Influence of surface type on F. S. Rds.	4.00	4.0
(8) Does black paving on F.S. Rd. increase safety?	3.00	3.0
(9) The PMS for F.S. Rds.	3.73	4.0
(10) Keep the system simple	4.10	5.0
(11) Poor regions and the PMS	2.95	3.0
(12) Frost heave on gravel roads	2.63	3.0
(13) Acceptance of PMS design models	4.15	4.0
(14) Collection of input data	4.62	5.0
(15) Separate systems for gravel and black paved roads	3.75	3.0
(16) Naming of PMS	2.80	2.0
(17) Administrative constraints	3.92	4.0

Fig 6. Mean and median importance ratings of special constraints and considerations.

definition of the subsystems by the project staff, followed by a "brainstorming session" during which valuable "field input" on subsystem definitions were conducted. The results of the analysis of this rating, summarized in Figures 5 and 6, will be used extensively in the further definition of the subsystem presented in the following chapter.

CHAPTER 4. MAJOR SUBSYSTEMS

Following the extensive evaluation, presented in Chapter 3, of the major subsystems that would be needed in a pavement management system for low-volume forest roads, it is now possible to attempt a final definition of the individual subsystems using the results of this evaluation as a guide to the requirements of the proposed system. Because of the many complex factors involved in the development of a low-volume road pavement management system, complete definition of some of the subsystems was not possible. In these areas revelant ideas and recommendations were formulated for consideration in the eventual development of the complete subsystem definition.

System Inputs

Inputs to a pavement system represent the information and tools that the designer should have to adequately design and manage a road pavement. These inputs which represent the conditions under which the pavement must function are transformed into outputs by the system, in light of the established goals and objectives. In representing a pavement design system for low-volume Forest Service roads, seven different categories of input variables were used, (1) load and traffic variables, (2) environmental variables, (3) construction varables, (4) structural design variables, (5) maintenance variables, (6) operational variables, and (7) constraints. Within these categories fall the variables that are considered essential to the development of a system that will satisfy Forest Service needs for pavement design and management.

For the definition of the system input variables, it was advantageous to use the results of the "importance rating" discussed in the previous Chapter, specifically the "weighted" mean importance ratings. In reviewing these "weighted" ratings, it was estimated, based on a total comparison of the ratings for all varibles, that a rating of less than 3.00 indicated that a variable was not considered essential to the proposed system, and that a variable with a rating between 3.00 and 3.50 was questionable as to its usefulness in the proposed system. Those variables with a rating greater than 3.50 were felt to be of the greatest significance and deserving of strict evaluation during the actual development of the system and its models.

Therefore, the input subsystem definition for the proposed Forest Service pavement management system consists of the variables categorically listed in Table 1 in the order of their estimated importance to the system. In the further development of the proposed system, this list of variables should not be used as a limit to the program inputs, but rather as a guide to satisfy the need of such a system.

An important aspect that must be considered in relation to input variables and their effect on the system is the variable interaction between and within the major categories. While some variables act independently to influence the system output, the effect of most variables on the output depends on the level of one or more other variables or parameters in the system. This can be illustrated by the fact that while "number of applications" is an important traffic input variable its relevance to the system depends mainly on the "total load" of the individual applications. For example, 50 applications of a 100-kip load would have a much greater influence on the system's output than would the same number of two-kip applications. Interactions are

TABLE 1. INPUT VARIABLES

Load and Traffic Variables

Number of Applications (4.72)*
Distribution of Traffic
  (a) seasonal changes (4.58)
  (b) annual changes (3.53)
Characterization-Distribution of Loads on Vehicles (4.54)
Total Load (4.37)
Type of Loading (4.32)
Axle Spacing (3.86)
Tire Pressure (3.68)

Construction Variables

Quality Control
  (a) material (4.62)
  (b) compaction (4.60)
  (c) thickness (4.58)
  (d) moisture and temperature (3.97)
Personnel-Skill Level (4.16)
Road Geometrics (3.93)
Equipment
  (a) availability (3.66)
  (b) environmental impact (3.49)

Maintenance Variables

Level of Maintenance (4.45)
Type of Rehabilitation
  (a) gravelling (4.14)
  (b) overlaying (4.11)
  (c) sealing (3.90)
Available Funds (3.96)
Road Users (3.79)

Constraints

Maximum Allowable Cost
  (a) initial construction (4.60)
  (b) total maintenance (4.17)
  (c) user's
Design Life of Road (4.50)
Minimum Layer Thickness (4.49)
Environmental Constraints (4.35)
Minimum Time Until First Major Maintenance (4.28)
Minimum Time Between Major Maintenance (4.23)
Constraints from Management (4.23)
Political Constraints (4.16)
Prudent Operator Constraints (3.56)

Environmental Variables

Drainage
  (a) surface drainage (4.38)
  (b) subsurface drainage (4.60)
Freeze-Thaw Cycle (4.21)
Soil Type (4.11)
Topography (3.93)
Rainfall
  (a) amount (3.81)
  (b) seasonal distribution (3.79)
  (c) intensity (3.56)
Area Sensitivity to Lanslides (3.50)
Temperature Range (3.36)

Structural Design Variables

Subgrade Properties
  (a) strength (4.87)
  (b) permeability (4.27)
  (c) gradation (4.12)
Type and Quality of Paving Material Available (4.58)
Layers
  (a) thickness (4.58)
  (b) arrangement (4.34)
  (c) number (3.74)
Stabilization Policy (4.28)
Cross-Section (3.95)
Frost Design (3.82)
Testing Equipment Available (3.55)

Operational Variables

Controls on Road Use (4.40)
Time Lag in Obtaining Funds (4.00)
Operational Planning and Enforcement
  (a) allowance for major hauling (4.20)
  (b) snow removal (3.77)

*(x.xx) = "weighted" mean importance rating

usually expressed in a mathematical model in the form of cross product terms. A typical example of this, using the above illustration, is the use of the cross product term, $W_{i_{18}} = N_i e_i$ (number of 18-kip single-axle load applications) in the AASHO pavement design procedure where e_i is a function of "total load" and N_i represents "number of applications" (Ref 7).

When developing the mathematical models for the system, it must be kept in mind that quantification of many of these variables will be difficult. For example, a problem may arise in attempting to define Personnel Skill Level or Area Sensitivity to Landslides in terms suitable for use in a mathematical model or equation.

In addition, recent studies (Ref 28) in statistical quality control of pavement properties have indicated that large variability exists in the as-constructed properties of pavement materials, along with a significant amount of uncertainty in traffic forecasting. Therefore, it will ultimately be desirable to investigate these and other possible uncertainties in predicting input variables and to develop methods of considering them in the system.

Structural Design

The structural design subsystem is best described as a model which relates inputs to outputs as the pavement relates the inputs to the outputs, in other words, this model generates responses and outputs as a function of the inputs. The structural design model used in a system might be very simple in concept, such as an empirical index value, or it might be comparatively complex, for example, layer theory. Whatever model is used, though, must effectively predict the system outputs for the type of pavement being considered. For example, although Westergaard equations could be used in a structural design subsystem for rigid pavements, they would not be effective in designing a flexible layered pavement.

In terms of structural design, Forest Service roads can be classified into three categories, paved roads (includes hot-mix AC, built-up mats, and surface treatment), aggregate surfaced roads, and unsurfaced roads. From references on low-volume road design (Ref 17-21), it was found in the majority of cases that design variables for aggregate surfaced and unsurfaced roads were essentially similar, and that the pavement performance for roads in these two categories were usually characterized by the same parameters.

This was not the case for paved roads and unpaved roads (aggregate or unsurfaced). Design factors such as those for environmental variables are usually different for pavements on these two types of roads. For example, the amount of rainfall in the area would be a critical design factor for an unpaved road because of its effect on aggregate loss for gravel roads and shear strength or stability of natural soil roads, while for a well drained paved road rainfall quantity would only be a significant factor when expansive soils were also encountered in a pavement area. Type and magnitude of distress on unpaved roads is also quite different from those found on paved roads. On unpaved roads, surface abrasion (dusting) or aggregate loss is considered a critical distress, but for paved roads it is seldom used as a design criteria. Maintenance activities, as considered in the total pavement management system, also differ considerably for pavements on these two types of roads.

In evaluating the function and form of the structural design subsystem in the design and management of low-volume Forest Service roads pavements, it seemed that, because of the major differences in characteristics and behavior of the pavements on unpaved roads versus those on paved roads, it may be desirable to use separate structural design subsystems within the system for these two types of roads.

Ideas for the development of these separate subsystems will be treated in Chapter 5 of this report.

System Responses and Output

The outputs of a pavement management system are generated from measurements of the mechanical state of the pavement. As can be seen in Figure 2 the structural design model is used to predict the behavior of a pavement when it is subjected to an environment, as represented by the system inputs. Pavement behavior is described by primary responses which include measurable quantities of deflection, stress, strain, deformation, and deterioration. When these primary responses reach some limiting value, distress occurs in the form of rupture, distortion, or disintegration. Then, as a function of these predicted values of distress, the pavement's "serviceability," or its ability to serve traffic, is determined at any point in time in terms of riding quality, skid resistance, users cost, or other critical design criteria.

The major outputs of a pavement design system can be represented by serviceability-age histories of the pavement as illustrated in Figure 7 . The form of output to be used must be defined in accordance with what the various pavement management activities are trying to achieve as an end product. For example, because the objective of most higher type roads is to provide a smooth riding surface on which travelers will have a comfortable ride, many highway pavement designs incorporate the present serviceability concept developed by Carey and Irick (Ref 6) which uses riding quality as its major decision criterion.

In evaluating the form of output to be used in the Forest Service pavement design system, it seems that because the purpose of most low-volume roads is to provide a means of serving traffic at the least cost to both

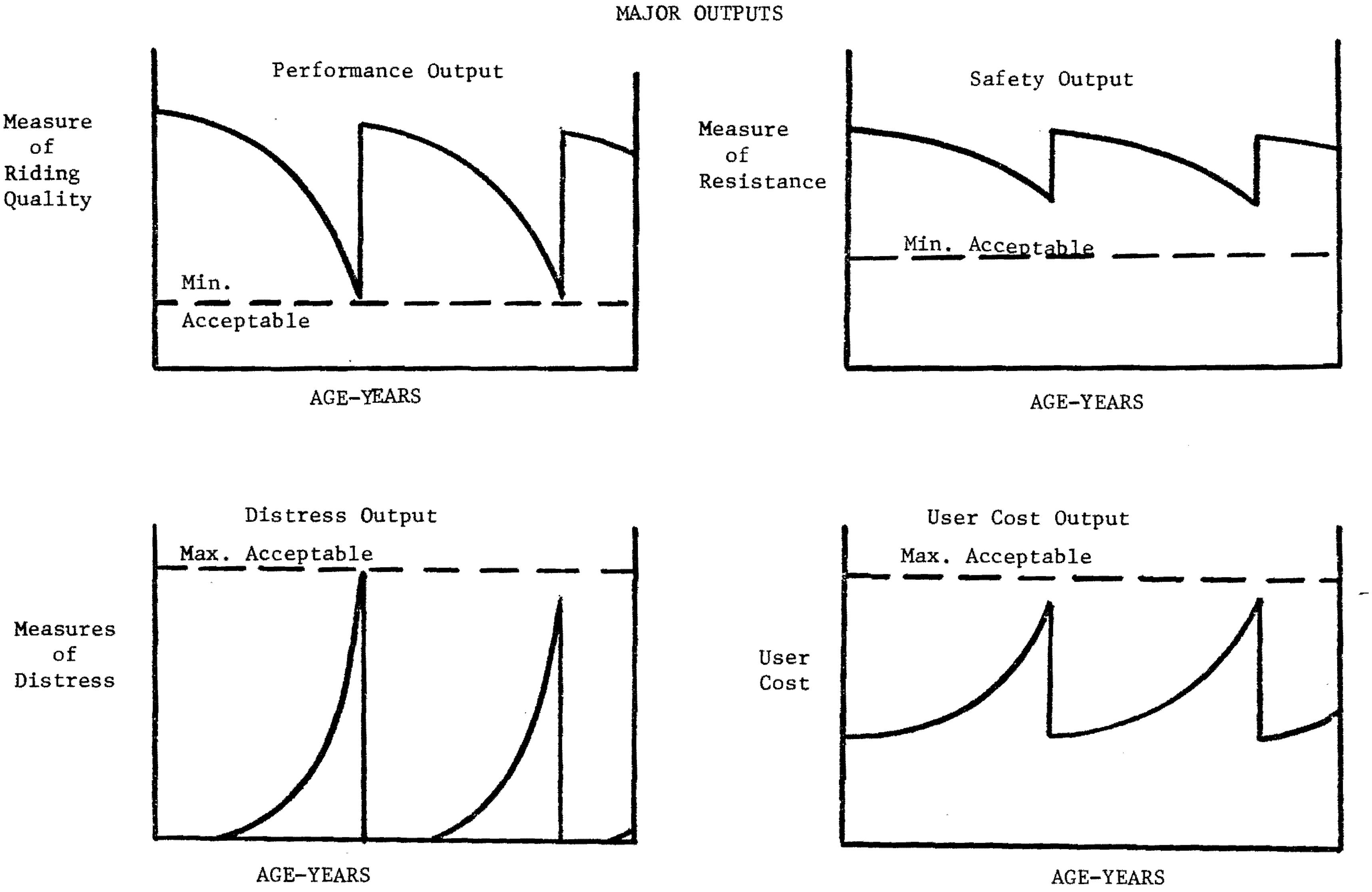


Fig 7. Typical major pavement design outputs.

the user and the road builder, a function of the total cost of providing this service should be used as the major decision criteria. In addition, it should be noted that becasue this proposed pavement management system will be applied to pavements on both paved and unpaved roads, its final form of output should be one that will be applicable to all the different types of pavement surfacing used by the Forest Service. This will allow for comparisons to be readily made between the performances of pavements with different surfacing types.

Because the project staff believes that the representation of system outputs will be one of the key problem areas in the development of the actual Forest Service pavement management system, a more detailed discussion of the ideas presented here is given in Chapter 5 of this report.

Decision Criteria

Decision criteria are rules defined for the purpose of choosing the best among alternative designs that have been proposed and analyzed in the system. They are used in two ways to accomplish this purpose. First, they are utilized in establishing a minimum acceptable level of serviceability below which the pavement does not satisfactorily serve its intended purpose and can be said to have "failed". This acceptable level of serviceability is shown as a horizontal dashed line in the system output functions of Figures 2 and 3. This level of acceptability then provides a basis for comparing and optimizing the system output, from which decision criteria again are used, this time to choose the best design among those that satisfy the constraints of the system.

According to Haas (Ref 27) there are four requirements that decision criteria should be capable of satisfying:

(1) It must unify competing objectives. This is pragmatically achieved through a functional relationship of benefits and costs.

(2) In most planning or design problems, many outputs cannot be expressed in monetary terms. The decision rule should provide for the inclusion of these variables.

(3) The point-of-view stated in the objectives must be reflected in the decision rule.

(4) The decision criterion must be capable of identifying that alternative which is best or optimal in terms of the state of objectives.

The decision criteria listed in Table 2 are those indicated by the results of the "importance rating" analysis as having the greatest influence on design decisions made by the Forest Service for their roads. As with the input variables, it was estimated that the decision criteria receiving a "weighted" mean importance rating greater than 3.50 were of the greatest significance and should be included in the proposed system.

Optimization Process

The optimization phase of a pavement management system is concerned with quantifying the outputs that have been predicted for the various alternative solutions and selecting the best alternative according to the decision criteria defined for the system.

There are numerous analytical techniques used to arrive at optimum combinations of equipment operation, material, maintenance procedures, etc., using the constraints of the system and an objective function such as the minimization of cost or time. Some widely used analytical techniques include linear programming, dynamic programming, and linear graphics.

An optimization model similar to that developed under Texas Highway Research Project 123 and used in FPS-3 (Ref 1) would probably be best for a low-volume road pavement design and management system because of its use of overall cost as a basis for determining optimal designs. This model uses a

TABLE 2. DECISION CRITERIA

Cost

  (a) Initial (4.95)*

  (b) Maintenance (4.18)

  (c) Operational (3.83)

  (d) User (3.74)

Funds

  (a) Available (4.73)

  (b) Probability of additional (4.24)

  (c) Type (3.61)

Safety (dust) (4.42)

Environmental Impact (4.42)

Function of the Road (4.35)

Stage Construction (4.19)

Administrative Requirements (4.00)

Confidence Level (3.90)

* (x.xx) = "weighted" mean importance rating

modified branch and bound technique with the principal that if a design is more expensive and at the same time has less strength than some other design then it cannot produce a better design and is therefore discarded.

CHAPTER 5. A CONCEPTUAL PAVEMENT MANAGEMENT SYSTEM

In Chapters 3 and 4 the basic requirements of a general pavement management system were presented in terms of its major subsystems. An attempt was then made to evaluate these basic components individually and, where possible, to define their composition for use in a design and management system for low-cost Forest Service roads. Because of the many complex factors involved in such a system, it was difficult to define the make-up of some of these major subsystems (structural design and system outputs). In these questionable areas recommendations are made as to how the problems might be treated. The intent of this chapter is to further develop these recommendations then combine them with the other subsystems in presenting a conceptual pavement management system for low-volume Forest Service roads.

Structural Design Models

As suggested in the previous chapter, because of the many dissimilarities in behavioral characteristics and design criteria between paved and unpaved roads, it may ultimately be advantageous to incorporate two separate structural design models into the low-volume road management system. Separating the structural models for these two types of roads serves two main purposes. First, it affords more accuracy on distress predictions, and second, it allows separate serviceability functions to be considered for the different pavement types. In addition, it may make it possible to present a simpler, more useful system for routine use.

A pavement structural design model consists of physical models used to simulate the real world load response, of a pavement throughout the analysis period. Three basic kinds of models are used to accomplish this for most pavement structures:

(1) Traffic models consist of a traffic equation used to predict the amount of traffic which will have passed over a road after any length of time, usually in terms of a single equivalent axle load.

(2) Structural capacity models determine the strength of the resistance to the environment of the different pavement structural designs being evaluated.

(3) Performance models use the results of traffic and structural capacity models to predict the behavior of the pavement, at any time, in terms of its serviceability or ability to serve traffic.

Paved Roads

The Forest Service presently uses the "AASHO" Pavement Design Method as presented in Chapter 50 of their Transportation Engineering Handbook (Ref 29) for the structural design of their paved roads. In evaluating alternative structural designs under a simulated real world environment this pavement design method incorporates the three basic kinds of physical models described above. Its traffic model, equation (1), uses traffic equivalence factors (e_i) to convert the number of vehicles in mixed traffic (N_T) by percentage of axles in each load group (P_i) to a total equivalent 18-kip single-axle load that will travel over the pavement during its analysis period.

$$W_{T_{18}} = N_T \sum_{i=1}^{n} P_i e_i \tag{1}$$

The structural capacity model used in the AASHO design method is given by equation (2). This model sums the products of the thickness of the individual pavement layers (D_i) and the relative strength of the material in each layer, represented by layer coefficients (a_i), over the total structural depth to obtain the pavement's structural number (SN), indicating its capacity to resist distress.

$$SN = a_1D_1 + a_2D_2 + \ldots + a_nD_n \qquad (2)$$

The AASHO performance model (Ref 7) is based on empirical relationships derived from the AASHO Road Test, supplemented by theory and by data developed from current practices of highway construction agencies. This model, equation (3), predicts the present serviceability of a pavement as defined by Carey and Irick (Ref 6), in terms of riding quality.

$$G_t = \beta (\log \omega_T - \log \rho) \qquad (3)$$

where:

G_t = a function of the ration of loss in serviceability at time t to the potential loss taken to a point where $p_t = 1.5$

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

ω_t = axle load application at end of the time t.

ρ = a function of design and load variables that denotes the expected number of axle load applicaltions to a serviceability index of 1.5.

p_t = serviceability at end of time t.

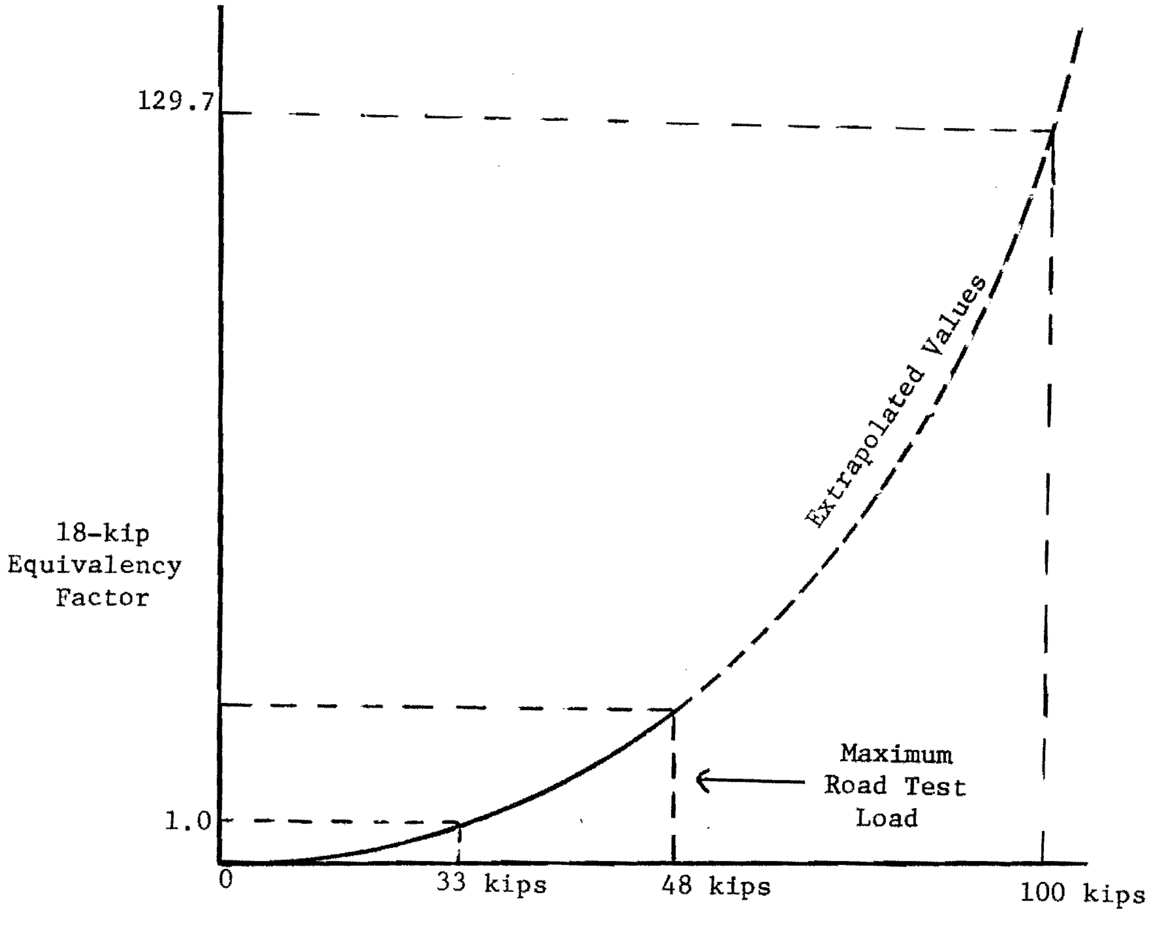
Although the AASHO pavement design method is considered by many highway agencies to produce a superior structural design, as indicated by its wide use, it does have some deficiencies, especially when it is applied to low-volume Forest Service Roads. For example, the equivalence factors used in the traffic model, equation (1), to convert mixed traffic loads to a common denominator of 18-kips were empirically developed using a function of the relationship of loads to pavement damage. Therefore, these equivalence factors are reasonably accurate over the range of loads applied at the Road Test, but are little more than guesses for extrapolations beyond this point (see Fig 8). Because many Forest Service roads receive loads substantially larger than those applied at the AASHO Road Test, the total equivalent 18-kip single axle load ($\omega_{T_{18}}$) obtained using the traffic model may be erroneous for these roads, considering the questionable equivalence factors that must be used in its calculation.

Another limitation of the AASHO pavement design method as applied to low-volume Forest Service roads is that, although this method does provide a Regional Factor (R) for adjusting designs to various climatic conditions, a more extensive characterization of the climate and its effect on the pavement structure should be included in the design. The reason for this being that moisture and temperature have a more pronounced effect on the performance of thin asphalt pavements, such as those built by the Forest Service, than on thicker pavements, as typically used for highways (Ref 11).

After evaluating these and other deficiencies of the AASHO pavement design method in its application to low-cost Forest Service paved roads and considering other alternative structural design methods, the project research staff believes that the structural design models presently used by the Forest Service in designing their paved roads could be used in the initial pavement management system and would produce satisfactory results, but upon further development of the system this design method would require revision to correct some of its major deficiencies.

Unpaved Roads

For design of their unpaved roads the Forest Service presently uses a modified AASHO procedure. The modifications are based on data accumulated by the U.S. Army Engineer Waterways Experiment Station. In this design



Tandem Axle Load (kips)

Fig 8. Equivalency factors for various axle loads.

method the required subgrade structural number (SN) is calculated using the AASHO traffic and performance models, then inputing this structural number into a "gravel equivalency" chart, developed by the Corps of Engineers, a total equivalent aggregate thickness is calculated that will protect against a rut in excess of two inches.

In evaluating this design procedure for use in the Forest Service pavement management system, major deficiencies were found in a number of areas. As was the case for paved roads, this unpaved road design method is weak in the areas of total load predictions, because of its application of the AASHO traffic equivalency factor concept to loads in excess of those applied at the Road Test, and characterization of climatic conditions and their effect on pavement performance.

In addition to these limitations, this structural design method, with its use of the AASHO performance equation to calculate the required subgrade structural number (SN), quantifies pavement serviceability in terms of PSI or, in other words, riding quality. As stated in the previous chapter on system requirements, the purpose of most low-volume Forest Service roads, especially those that are unpaved, is to provide a means of moving traffic at the least cost to both the road user and the road builder. The use of riding quality as a measure of performance does not take into account what, considering the purpose of Forest Service roads, should be a major decision criteria, that being the <u>cost</u> of the pavement structure. This deficiency was shown in the results of the "importance rating" by the fact that as a decision criteria, riding quality received a relatively low importance rating when compared to that of pavement cost.

Although this modified AASHO design procedure could be incorporated into the structural design subsystem of the Forest Service pavement design and management system, an alternative design model that would better represent critical design criteria for unpaved roads should be seriously considered in its place.

When evaluating alternative design methods for this purpose some major points that should be considered are:

(1) The models should accurately characterize the external forces which act on the pavement, namely the loads and the environment.

(2) The input variables used by the model should be relatively easy to obtain and should represent those factors that are critical to the design of unpaved roads.

(3) Distress modes predicted by the model should be those characteristic to unpaved roads, for example, pot holes, rutting, gravel loss, looseness of gravel, loss of cross-sectional shape, corrugations, and dust.

System Output Function

In evaluating the form of system output function to be used in the low-volume pavement management system, it is important to keep in mind that we are dealing with two different types of roads, paved and unpaved, and that the distress modes and magnitudes of distress found on them may not be the same under similar conditions of load and environment. For example, critical distresses on a paved road may show up as cracking, rutting, and surface disintegration, while those on an unpaved road may be found to be gravel loss, pot holing, rutting, and excessive dusting. Therefore, since a pavement's wear-out function or serviceability must be expressed as a function of these measurable distresses, the wear-out functions for paved and unpaved Forest Service roads will necessarily be different.

In such a system as will be developed for the Forest Service, it is essential that a means be provided for comparing the relative performance of pavements on different types of roads. This means that it will be necessary to find a common denominator to which the wear-out functions for both paved and unpaved roads can be related. It should be stressed that this common denominator must be defined in accordance with what the various pavement management activities are trying to achieve as an end product. For low-volume Forest Service roads, this means that the common denominator should be relatable to the optimum cost of serving traffic needs, since this is the objective in providing most Forest Service roads. Once this common denominator has been decided upon, it will be necessary to develop relationships that equate it to the different wear-out functions for paved and unpaved roads.

To represent pavement failure in this system using a function of the cost of serving traffic needs as the common denominator, a maximum cost level could be designated above which it is felt that the pavement would no longer adequately serve its intended purpose. This maximum acceptable cost level could then be converted to its corresponding levels of distress on the wear-out functions for both paved and unpaved roads assuming that a relationship based on previously observed data could be developed for this purpose. When the distress measurements for a road reach this level on its corresponding wear-out function, the pavement can be said to have failed and would require some type of maintenance to lower its distress to a level corresponding to an acceptable cost of serving traffic needs. This pavement failure concept is illustrated in Figure 9.

The following is a discussion of an idea developed by the project staff as to how a function for the cost of serving traffic needs on a Forest Service road might be defined and how a model relating it to a distress wear-out function could be developed. This idea is a result of information obtained

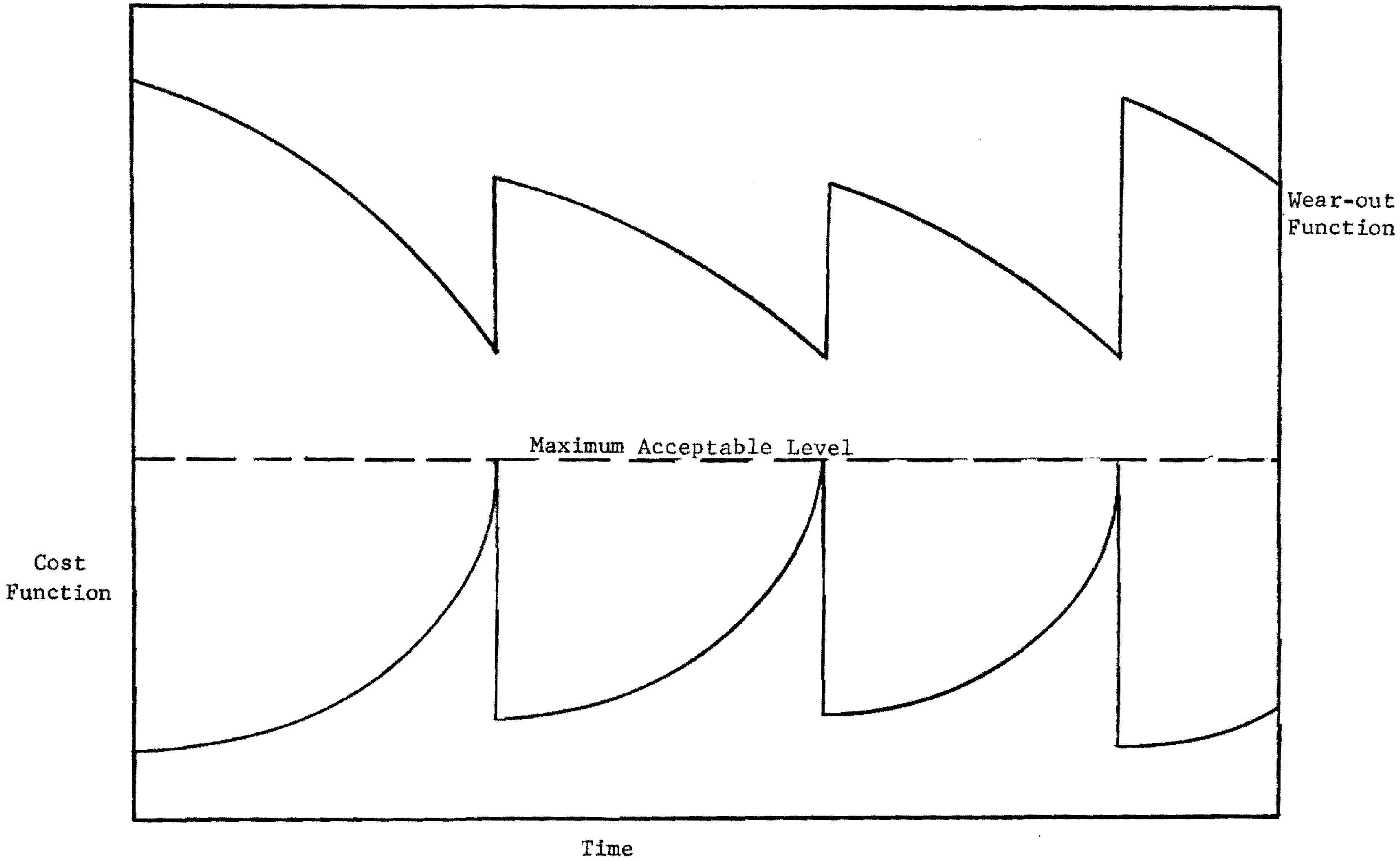


Fig 9. Pavement failure concept for Forest Service roads.

through interaction with Forest Service personnel and the review of literature on low-volume road research being carried out in some of the developing countries of the world.

In attempting to define a cost function that can be used as a common denominator for comparing the relative performance of pavements on Forest Service paved and unpaved roads, it will first be necessary to look at the total cost of a pavement design. For Forest Service roads, this total cost can be divided into four basic cost factors, (1) an initial construction cost, which includes the cost of planning, designing, and constructing the pavement; (2) a maintenance cost, which includes the cost of routine maintenance and the cost of resurfacing or overlaying excessively worn pavements; (3) a user's cost, which involves the cost to the user in terms of fuel, lost time, wear on vehicles, and damage to cargo due to a decrease in serviceability of the pavement, in addition to a factor for comfort, convenience, and safety; and (4) an environmental cost including the effect of such factors as dust, mud, and erosion on the environment.

In deciding which of these cost factors should be used in the cost function, it must be kept in mind that, by definition, this cost function, or common denominator, is to be relatable to the wear-out functions of pavement and unpaved roads; therefore, it should vary as a function of varying distress in a pavement. In other words, changes in the level of distress in a pavement must be accompanied by changes in the cost function for that pavement. As illustrated in Figure 10, initial construction cost is a constant for a given pavement regardless of increasing distress and therefore can not be expressed as a function of distress. Similarly, while the cost of maintaining a pavement to a desired distress level does increase with increasing distress, it may, in reality, be constant over certain ranges

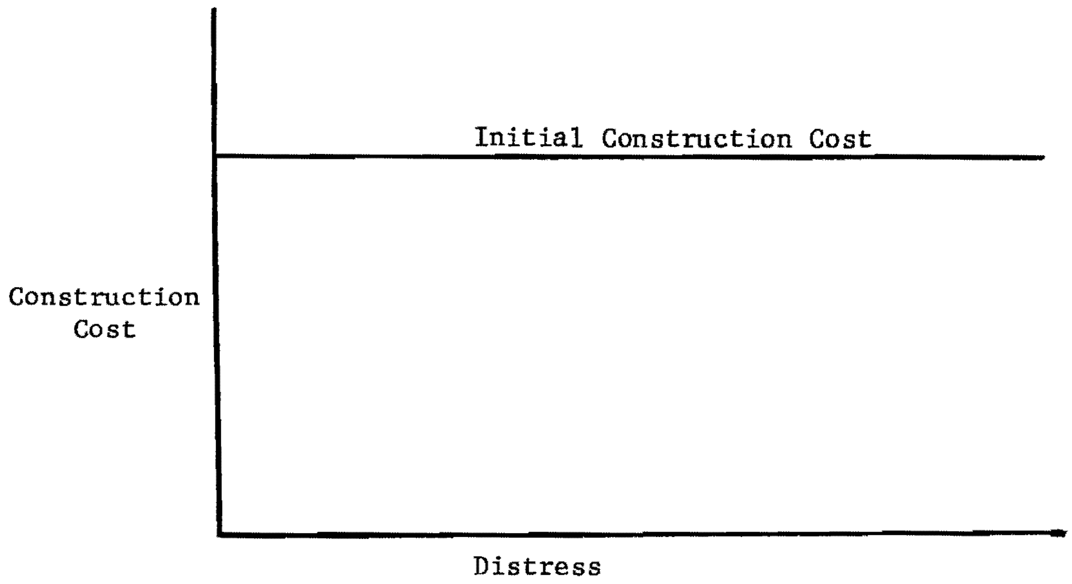


Fig 10. Construction cost as a function of distress.

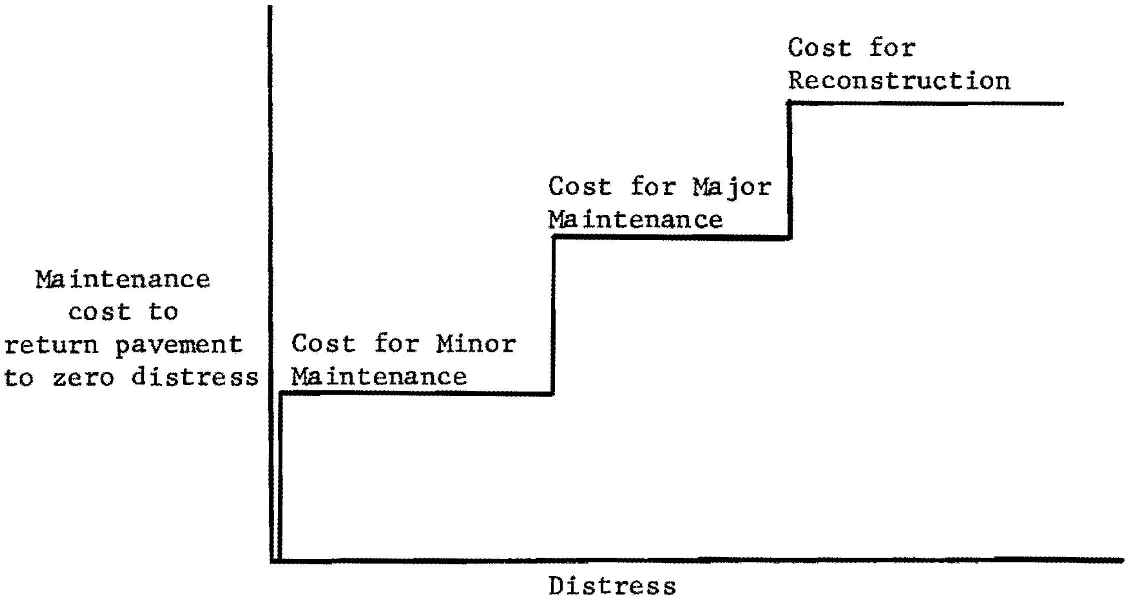


Fig 11. Maintenance cost as a function of distress.

of distress, as illustrated in Figure 11. Therefore, it would also be difficult to express maintenance cost usefully as a function of distress. It has been demonstrated by members of the British Transportation Road Research Laboratory in recent research carried out on low-volume roads in Kenya (Ref 21), that user's cost does vary with varying distress in a pavement structure, and, therefore, can be related to the wear-out function of a pavement as illustrated in Figure 12. Although research has not been done to support any conclusions, it was pointed out by Forest Service personnel that from field observations made, it was found that environmental cost also varies as a function of distress, and therefore, should be used in the cost function.

From this evaluation of the cost factors involved in pavement design of low-volume Forest Service roads, it seems that a combination of user's cost and environmental cost might best be used to define the cost function common denominator for comparing the performance of paved forest roads to that of unpaved forest roads.

In developing a model that would equate this cost function to a distress wear-out function, a procedure similar to that used by the Road Research Laboratory in Kenya (Ref 21) to develop a similar relationship could be used. In this Kenya study, two separate areas of field work were undertaken in the research to determine vehicle operating costs (essentially user's cost) as a function of road characteristics. First, experimental studies were conducted in which numerous measurements of fuel consumption and vehicle speed were taken at different distress levels on a number of pavement types. Then, using a multiple regression analysis technique, empirical relationships were derived that permitted the calculation of speed and fuel consumption as a function of pavement distress. In addition to these experimental test studies, a survey of road users was conducted

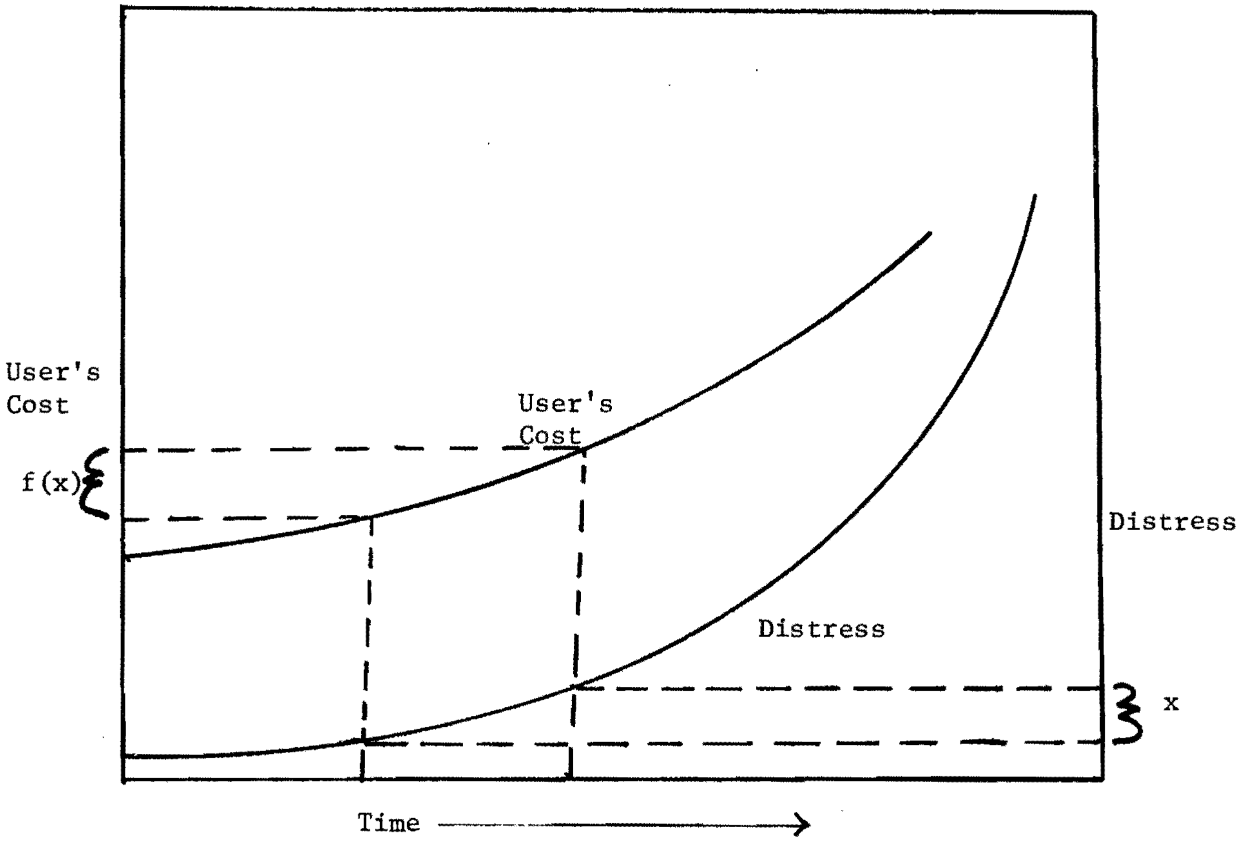


Fig 12. User's cost as a function of distress (Ref 21).

to obtain data by other cost inputs such as tires, vehicle maintenance and depreciation. As with the data for the experimental studies, a series of relationshps was also developed which would permit the calculation of the wear, maintenance, and depreciation as a function of the pavement characteristics.

An experiment and survey similar to that described above seems to be a feasible alternative to developing relationships between a cost function consisting of user's costs and environmental costs and the wear-out functions for paved and unpaved Forest Service roads.

A Conceptual System

The combination of these ideas for structural design models and output representation and evaluation with the previously defined major components of a pavement management system for low-volume Forest Service roads could result in a system similar to that structured in Figure 13.

As can be seen in the diagram, the first step in the systems design process is the collection of all necessary input data. Once this is completed a summation of the predicted traffic and loads that will travel over the proposed road during the analysis period is calculated using the traffic model with pertinent input data. Depending on what type of surfacing is specified, a structural strength for a design of given materials and layered thickness values will be calculated by one of the two strength models. All this information will then be utilized in one of the performance models, again depending on surfacing type specified, to first determine, as an intermediate step, the wear-out function of the structure in terms of either a distress index for unpaved roads or a present serviceability index for paved roads, and finally to determine the performance of the structure in relation to a cost function

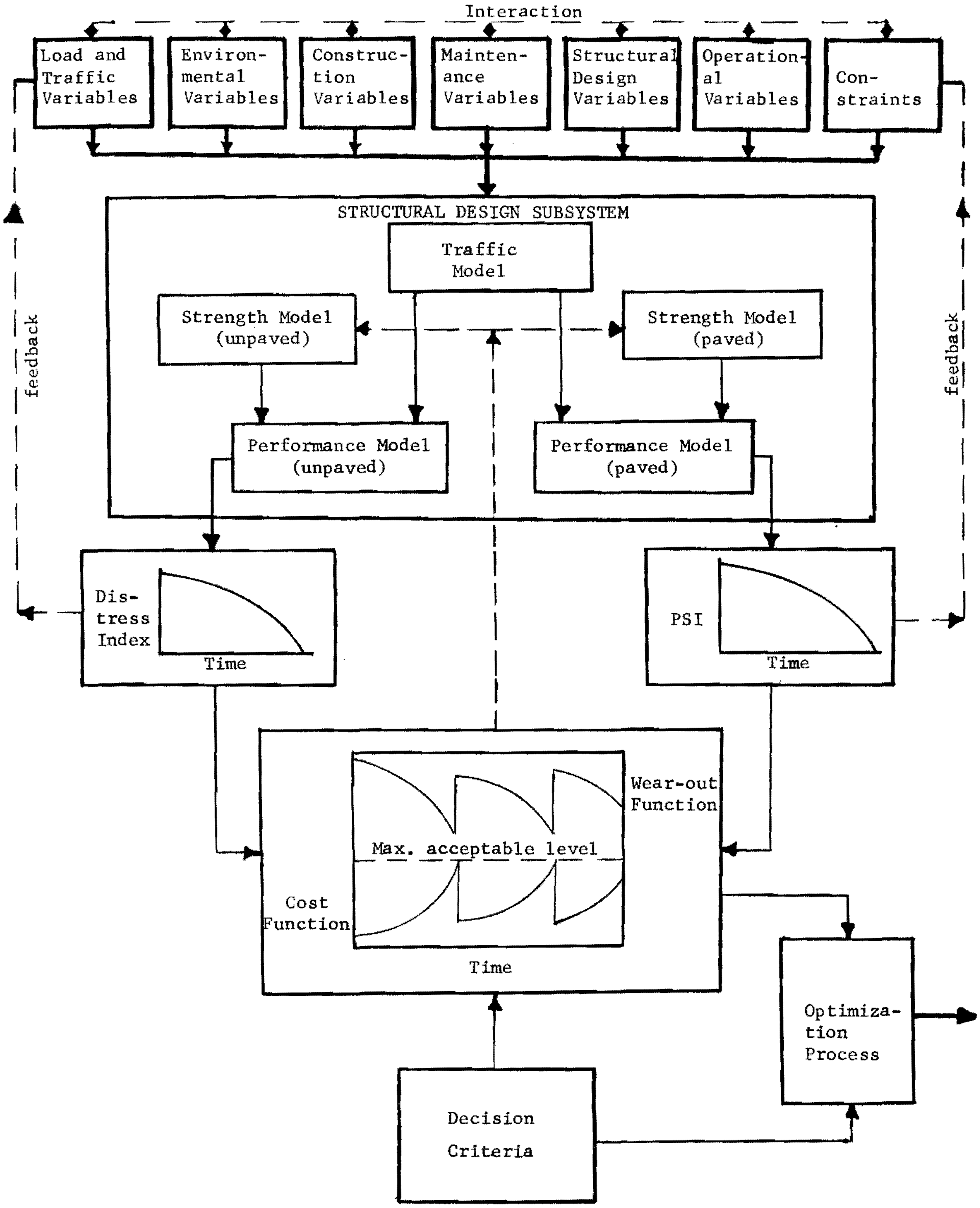


Fig 13. Conceptual system for low-cost roads.

of serving traffic needs.

When the measurable distress on a road reaches a level corresponding to a maximum acceptable cost level as determined by the decision criteria, some form of maintenance will be required to return the structure to an acceptable distress level. The structure is then re-evaluated according to the type of maintenance designated, and the extended life of the pavement is determined. This re-evaluation process is indicated by the dotted line from the serviceability-age history to the strength models in Figure 13. This process of extending the life of the pavement through maintenance activities is continued for the predesignated design life of the road structure.

The total design and management evaluation process can be carried out for many different design and maintenance strategies, each one going through the optimization process where they are evaluated, compared and arrayed for the final decision.

While only conceptual, the system described above does illustrate the basic requirements of a pavement management system for low-volume Forest Service roads. Development of a working system for such a situation is indeed feasible, but because of the lack of past research in the area of low-volume road design, considerable effort on the part of both the project research staff and the Forest Service will be required in future work towards its complete development.

As an example of what the printout for a computerized version of the proposed low-volume pavement management system could be made to resemble, some sample problems using the FPS-3 computer program developed at The University of Texas are presented in Appendix C.

Future Development

The actual development of the Pavement Management System will be a staged process. The first step will be to pull together the existing models and methods used by the Forest Service and to synthesize a simple working method which not only accounts for structural design and traffic, but which gives some consideration to user's costs and maintenance.

In addition, of course, some type of decision criteria are needed and hopefully some type of optimization routine will be developed as soon as feasible. In a sense we will have therefore, a stepwise development of the low-cost road system. At some early date it will be desirable to start implementation of the system and to provide interaction between the development and upgrading of the concept and its use in the field. Ultimately, the Forest Service will provide most of the improvements that will be so vital to the system development.

The concept can perhaps be summarized in Figures 14 and 15. As indicated in Figure 14, the basic building blocks or new and future developments involve the basic knowledge and methods currently used by the Service. While they are not perfect, they do synthesize some of the historical experience of the Forest Service and thus provide needed knowledge.

Likewise, the available operating systems for pavement management (Item B, Fig 14) provide another major building block since the experience of developing, using, and modifying these systems will be invaluable in the future development of the Low-Volume Road Management Systems (LOVORS). Item C represents the basic conceptual application of PMS to low-cost roads which has synthesized over the past three years among persons such as Pelzner, Taylor et al of the Forest Service and Hudson et al of the pavement research field.

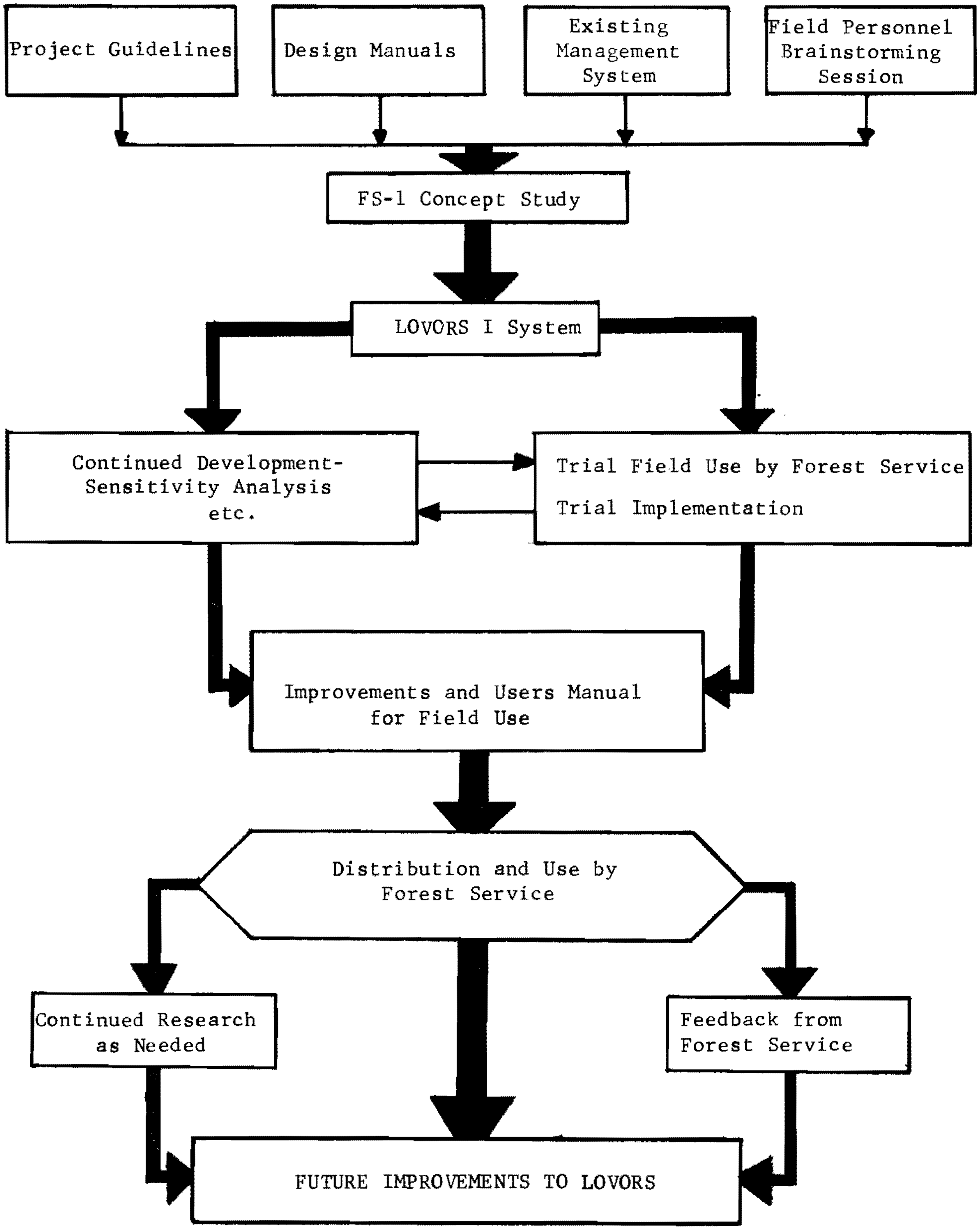


Fig 15. Detailed development of Forest Service Pavement Management System.

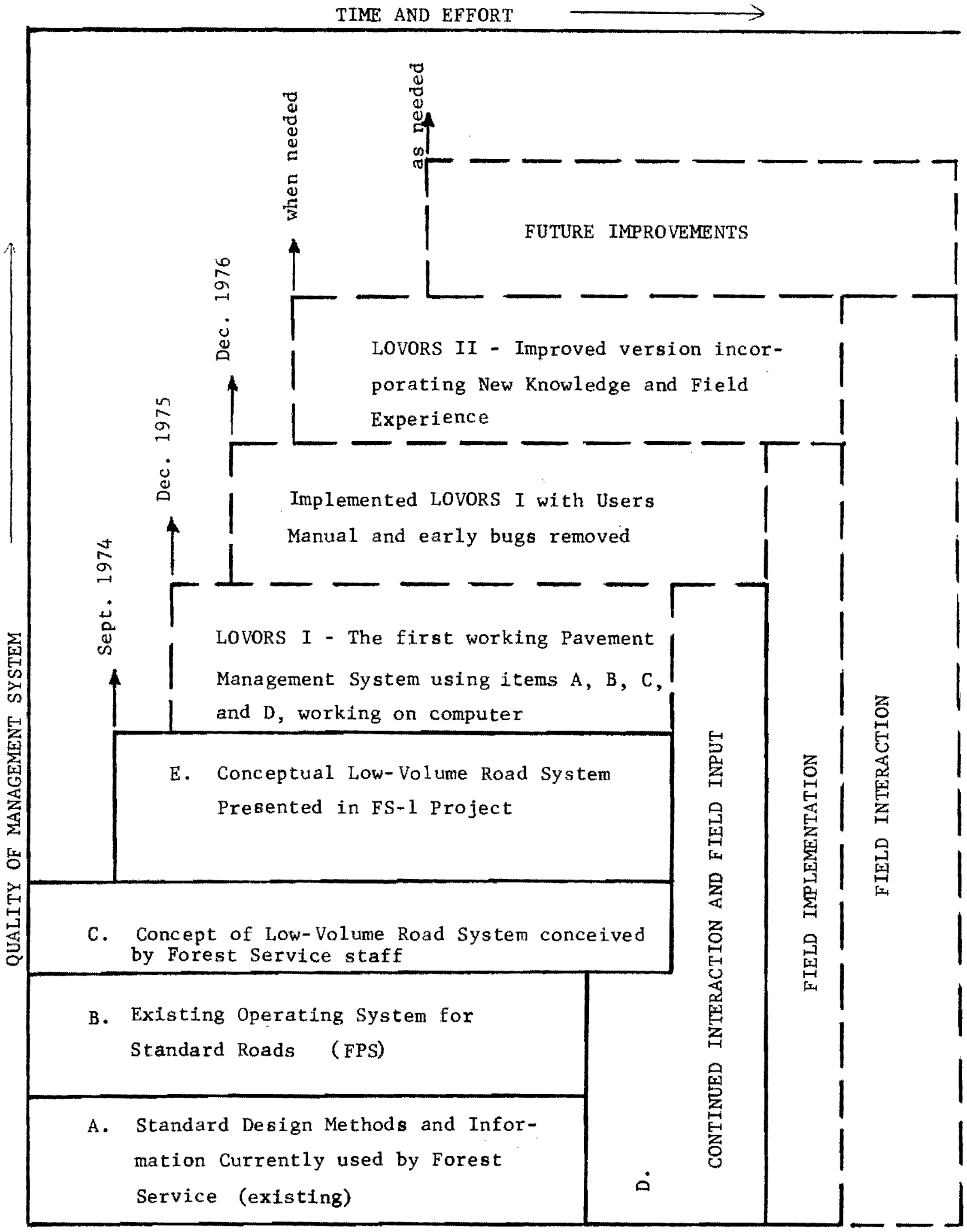


Fig 14. Major phases in the development of the Forest Service pavement management system.

Continued interaction and input into the problem from the field (Item D) as typified by the Project brainstorming session held in Austin in March 1974 and discussed in detail herein, has provided the last basic foundation block needed for the initial conceptual system outlined herein.

The Conceptual Low-Volume Road Management System presented herein (Item E) is the synthesis of the major foregoing items with of course, significant input from other sources and references. We feel that this basic foundation document provides the perspective and direction needed to develop the initial working system which we have tentatively dubbed LOVORS I, indicating it is the first in a series of improved versions which may some day be developed.

It is anticipated that LOVORS I would result from Phase II of the current research activity between The University of Texas and the U. S. Forest Service. Figure 17 outlines in detail how these developments might proceed. Future improved elements in LOVORS are hypothesized in dotted lines in Figure 9.

CHAPTER 6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Because of the development of new information in the pavements field during the past decade, the complexity of the interaction of design variables has become better understood and the need for a systematic approach to the problem of pavement design and management has become evident. Thus, through the application of systems engineering to pavement design, a number of conceptual and working pavement management systems have been developed in recent years. This report presents the results of a study to examine and define a conceptual pavement design and management system for low-volume roads, in particular Forest Service roads.

Summary

As presented in Chapter 2, an essential first step in the development of the conceptual system was an identification of the problem through its recognition and definition. Problem recognition was facilitated by acquiring background information and investigating the present state-of-the-art of Forest Service and other low-volume pavement design concepts. An assessment of the Forest Service needs for a pavement management system found that emphasis was placed on the needs of (1) optimizing the total pavement investment, (2) providing pavement performance prediction methods for planning purposes, (3) optimizing resource management efforts, (4) providing a tool for evaluating the effectiveness of specific pavement designs, and (5) unifying design efforts within the Forest Service. Problem definition was achieved by detailing the special constraints and considerations characteristic to the design of low-volume forest roads as compared with that of "higher type" roads.

Following the identification of the problem, it was possible to begin the actual work of formulating the conceptual system. After an extensive examination of pavement management systems that had been previously developed for "higher type" roads, it was decided that the FPS type of working Pavement Design System developed in Texas offered an excellent conceptual base from which a pavement design and management system could be formulated for low-volume Forest Service roads. In evaluating FPS, the project staff first divided it into its major components: inputs, a structural design subsystem, system outputs, decision criteria, and an optimization process. An attempt was then made to define each of these subsystems as they would be used in a low-volume road pavement management system. Where definition of a subsystem was not possible because of the need for further research, relevant questions and ideas were formulated for consideration in the eventual development of the subsystem definition.

An essential part of the initial evaluation of subsystems was the interaction and exchange of information between the research staff and Forest Service personnel that took place during the March 20-24 "brainstorming session." Many ideas and discussions were presented at this meeting including those on (1) system input variables, (2) decision criteria, (3) terminology, (4) pavement performance, (5) the decision making process within the Forest Service, (6) pavement failure, and (7) special constraints and considerations for Forest Service roads.

In order to help comprehend the relative significance of the variables discussed at this session a rating of the pertinent ideas discussed therein as to their importance to the proposed pavement management system was completed by the conference attendees. The results of this "importance rating" were then analyzed by the project staff and the information obtained was used to great extent in further defining and detailing the major components of the proposed system.

The intent of Chapter 5 is to further develop the ideas presented in Chapter 4 on structural design and system outputs, and then to combine these ideas with the other subsystems in presenting a conceptual pavement management system for low-volume Forest Service roads. Here it was suggested that because of the many dissimilarities in behavioral characteristics and design criteria between paved and unpaved roads, it may be advantageous to incorporate two separate structural design models into the proposed system. This would afford more accuaracy on pavement distress predictions and allow separate serviceability functions to be considered for the different pavement types.

When developing a serviceability function for representing the system output, the purpose of the roads designed and managed by the system must be accounted for. This means that for low-volume Forest Service roads serviceability should be relatable to the optimum cost of serving traffic needs. This optimum cost function can be represented as a function of user's cost and environmental cost. The development of relationships between the cost function and the serviceability wear-out functions of both paved and unpaved roads will allow for comparisons to be made of the performance of pavements on different types of roads.

A combination of the ideas for structural design models and output representation with the other subsystems defined in Chapter 4 could result in a conceptual system similar to the one structured in Figure 15.

Conclusions and Recommendations for Future Research

The general conclusion of this report, based on the past year's research, is that the development of a pavement design and management system for low-cost, low-volume Forest Service roads is indeed feasible. However, it must be kept in mind that because of the lack of past research in the area of low-volume road design, considerable effort will be required in future work towards the system's complete development. As in this initial phase, phase II of this project, the actual development of the pavement design and management system including mathematical models and other information needed for optimization, will rely heavily on the interaction and experience of Forest Service personnel.

Major areas of research recommended for Phase II are:

(1) In order to insure positive communication, a set of definitions for the terms and concepts used in the project's development should be agreed upon and used by all those involved with the project.

(2) A further evaluation of system input variables and decision criteria should be conducted. This evaluation should include a study of the feasibility of quantifying and collecting data for certain variables, in addition to an examination of variable interaction and its effect on system models.

(3) In developing the system's mathematical models, special attention should be given to the performance prediction model for unpaved roads. The distress modes predicted by this model should be those characteristic to unpaved roads, i.e., potholes, rutting, gravel loss, looseness of gravel, etc.

(4) In order to facilitate the defining of pavement failure for an unpaved road, it will be necessary to develop a scale by which the condition of such a road may be measured. Because this "serviceability index" should be defined in accordance with the objective of providing the road, serious thought should be given to the uses of some type of cost function for this purpose. Such a function could use such costs as environmental cost and user's cost as its parameters.

(5) Once a useable serviceability index has been developed, it will be necessary to define minimum levels of acceptability for the different types and classes of Forest Service roads. One way this could be done is by questioning the road users for their opinions on what is an acceptable level of serviceability.

(6) It is recommended that because of the large variability that exists in the as-constructed properties of pavement materials and the considerable amount of uncertainty in traffic forecasting, an examination of the statistical reliability of input variables and system models be conducted. The results of such a study should indicate whether or not these stochastic variations should be considered in the pavement management system.

(7) Once the models for the system have been developed, a sensitivity analysis should be performed on them by evaluating the amount of response in a model due to a unit change in the parameters. This sensitivity analysis should establish the relative significance of the input variables and promote confidence and reliability in the models.

In addition to these areas of needed research, it is recommended that, because of the many variables that would be included in a pavement management system for low-volume Forest Service roads, a computer program be developed to analyze the design problems and to generate feasible design alternatives, or in other words, to implement the system. The use of a computer would expand the number of possible designs by generating a large number of alternatives, and also, permit the storage of a large amount of pavement behavior data that could be used to modify and improve the existing design models.

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APPENDIX A. DEFINITIONS

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1. Pavements are structures that use subbase, base and surface courses placed singly or in combination on a subgrade to support the traffic and distribute the loads to the road bed.

2. A paved road has a pavement structure that uses a bituminous surface course. This bituminous surfacing may range anywhere from a chip seal to an asphaltic concrete.

3. An unpaved road is a road that does not use bitumin in its surface course. Two basic types of unpaved roads are gravel roads and natural earth roads.

4. Performance is a measure of the accumulated service provided by a facility, i.e., the adequacy with which a pavement fulfills its purpose.

5. Serviceability is the ability of a specific section of pavement to serve traffic in its existing condition.

6. A system is something which accomplishes an operational process; that is, something is operated on in some way to produce something. That which is operated on is usually input; that which is produced is called output, and the operating entity is called the system.

7. Behavior is the immediate reaction or response of a pavement to load, environment, and other inputs. Such response is usually a function of the mechanical state, i.e., the stress, strain, or deflection, which occurs in response to the input.

8. Distress is the visable consequences or the pavement responses when carried out to their limiting values.

9. Maintenance is the act of attempting to keep something in its present condition. For unpaved roads maintenance may take the form of regravelling or moto-grading. For paved roads patching, sealing, and overlaying may be included in the maintenance routine.

10. Model is a system of postulates, data, and inferences presented as a mathematical description of a conceptual reality.

11. Feedback is the collection and reversion of the pavement distress or limiting response data to the data bank for use in analysis, maintenance studies, rehabilitation scheduling, etc.

APPENDIX B. SUMMARY OF FS-1 "BRAINSTORMING SESSION"

APPENDIX B. SUMMARY OF FS-1 "BRAINSTORMING SESSION"

Summary of
FS-1 "Brainstorming Session"
Joe C. Thompson Conference Center
Austin, Texas
March 20-22, 1974

On March 20-22, 1974, a conference was held at the University of Texas between research Project FS-1 staff members and the U. S. Forest Service personnel. The purpose of this meeting was two-fold: (1) to familiarize Forest Service field personnel with Project FS-1 in hopes that their background, experience and interest in the project would stimulate future input on their part, and (2) to discuss the potential problem areas in the conceptual pavement management system as seen by both the project staff and the Forest Service.

RUNDOWN OF EVENTS

Introduction to Pavement Management Systems

The conference began with welcoming presentations by Dr. W. R. Hudson, Director of Research, for the Council for Advanced Transportation Studies, and Mr. Hudson Matlock, Chairman of the Civil Engineering Department of the University of Texas. Dr. Hudson then gave a general presentation on Pavement Management Systems (PMS).

Gerald Peck, Engineer of Roadway Design with the Texas Highway Department, followed with a discussion of the uses of PMS on highways in Texas. Mr. Peck described the three main elements of the THD's PMS as: (1) design analysis process, (2) pavement feedback data, (3) personnel and equipment. He also emphasized the fact that the PMS provides information on all stages of pavement management including: (1) programming, (2) design, (3) construction, (4) operation, and (5) retirement. Mr. Peck also stated that although the THD's PMS is now being used, it is only being used to a limited extent on low cost state roads. In the future, it will be used more and more on the Farm to Market Road system which is composed of relatively low cost roads.

Following this presentation, Dr. McCullough talked about the application of the PMS and how it could be used by the Forest Service to design and maintain their road system. A short discussion among the group on the PMS in general followed this presentation. The major point brought out in this discussion was that most people have different ideas as to what constitutes "failure" of a pavement. It was agreed that developing a definition for "failure" is an important work item in the conceptual study of the PMS for the Forest Service roads.

Inputs

The workshop continued with a discussion of the variables necessary to input into the PMS. Six categories of input variables as seen by the Project staff were presented: (1) load and traffic, (2) environmental, (3) construction, (4) structural design, (5) maintenance, and (6) constraints. It was then agreed that a seventh category of inputs was required, that of operational variables. A comprehensive discussion of each category of inputs was then conducted which resulted in the addition of several variables to the lists already prepared by the project staff for each category. (See Table B.1)

Throughout the discussion of these input variables, concern was expressed about their variability. The fact was brought up that subgrade materials and, therefore, subgrade properties, will vary considerably over the length of a forest road. The actual uniformity of construction materials was also questioned. It soon became evident that in this PMS it will be necessary to investigate these and other possible variations and to develop methods for considering them in the design.

While discussing these input variables, the fact was brought up that it would be difficult to quantify a number of them; for example the skill level of personnel as construction variables, or area sensitivity as an environmental variable. An idea for solving this problem was suggested by Haywood Taylor. He cited an article on Semantic Differentials, with the idea of quantifying all factors by three variables: (1) good or bad, (2) frequency, and (3) potency, as an example. The reference for this article is Psychology Today, "Semantic Differential," p. 58, November 1973.

Definition of Pavement

Also while discussing the input variables concern was expressed for the definition used by the project staff of the term "pavement." A great majority of the Forest Service personnel used different names for what the project staff called the "pavement." Some of these terms were pavement structure, structural section, and structural element. It was therefore decided that a term for "pavement" should be phrased and used by both the project staff and Forest Service personnel consistently. It was agreed also that there was a need to coordinate other key word definitions that may be in conflict.

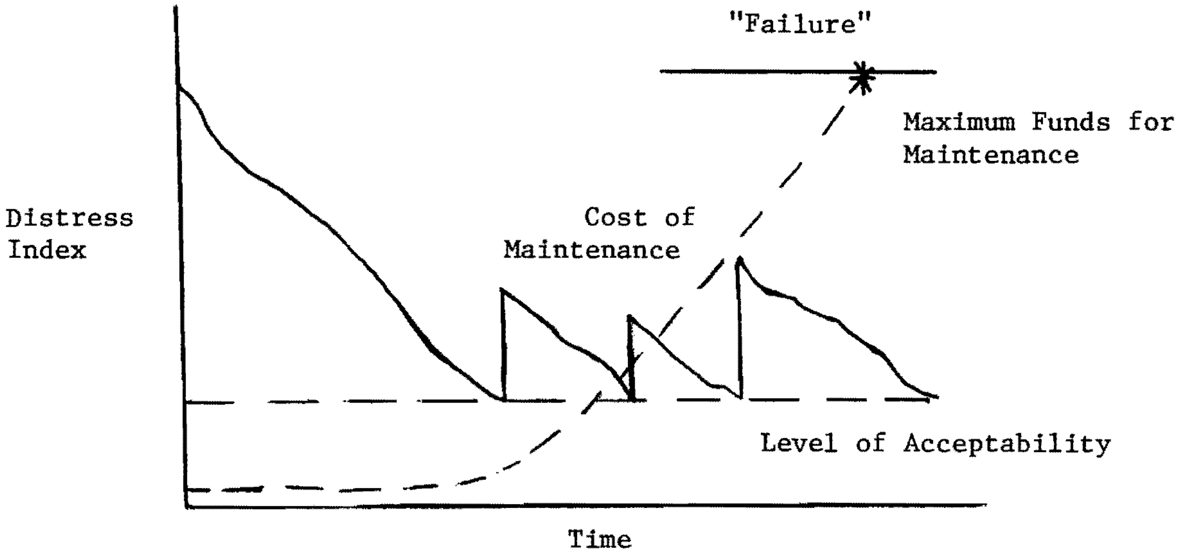
Decision Criteria

A discussion of decision criteria pertinent to the Forest Service PMS followed that of the input variables. Revisions to the list developed by the project staff were made, although no feelings as to the importance of the individual items to the decision making process was expressed at this time.

(See Table B.2).

Performance

Following this discussion of decision criteria, Dr. Hudson conducted a discussion on distress, failure, and performance of pavements as applied to the PMS. Here he presented an idea for defining failure of a Forest Service road. This idea is illustrated as follows:



In this concept, failure of the pavement is a function of the total cost of maintenance for a particular road. As this total cost of maintaining the pavement above a minimum serviceability or distress level increases it will eventually reach a predesignated maximum level of fund available for maintenance of that road. At this point, the pavement is said to have failed, and it would be necessary to either close or reconstruct the road.

During this discussion, a question was raised about who would determine the minimum distress level. Should the Forest Service determine this for a particular type of road or should it be decided separately for each road by the intended user of the road? It was mentioned that Oglesby at Stanford University has determined a consensus of the level of maintenance preferred by low cost road uses. Questions also were brought up as to how a road's serviceability level could be measured. If a mechanical rater was used, such as a profilometer or a Mays Meter, at what speed could it be run to insure consistency of measurement on the different types of forest roads? Many other ideas were suggested for determining serviceability and failure of Forest Service roads. These are presented later under "Ideas for 'Pavement Failure' on Forest Service Roads."

Decision Process

The conference continued with a discussion of the present decision making process within the Forest Service. The way the process works is that if a Forest Ranger feels a road should be built from one place to another he submits his idea to the Forest Engineer (FE). The FE then decides which of the requested roads actually needs to be built, and then puts them into his general improvement program. The FE also decides the type of roads to be built and what type of surfacing they are to have. He need not okay his decisions with the Supervisor unless extra money is needed to construct the roads. Therefore, the decision to build roads is made at the Forest Engineer level. Once a decision to construct a road has been made the FE prepares an agreement document with a timber purchaser. While the timber purchaser is building the road, an Engineering Representative (ER) of the Forest Service inspects and controls the quality of construction being done. This ER usually reports to the FE although sometimes he reports to the Chief Ranger. For roads built under public works contracts, the ER is replaced by a Contracting Organization Representative (COR), who has the same duties as the ER does on a timber purchaser road, although it was generally agreed that the COR must follow the specifications more closely than an ER probably would be required to. Therefore, the quality of work is usually better on a road built under a public works contract.

As for decisions about road maintenance, the Ranger makes the decision to do minor maintenance, but for a major maintenance project the same process is followed as for the construction of a new road. The funds for maintenance are limited to a certain amount each year as opposed to those for new construction which are a function of the amount of timber sold during the year.

Special Constraints and Considerations

Throughout the meeting Forest Service personnel brought up a number of ideas as to special constraints and considerations that must be kept in mind when developing a PMS for the National Forest Service. A short presentation of each of these important ideas follows.

(1) Unpredictable Traffic on Forest Service Roads. When designing a road, it is necessary for the designer to know the kind and amount of traffic the road will be expected to carry. Because Forest Service roads have a variety of users, i.e., loggers, hunters, and recreationalists, the exact use of the road is difficult to predict over its entire life. Therefore, the type and values of design input variables to be put into the system may be difficult to determine, leading to an inadequate road.

(2) "Prudent Operator" Concept. Although timber purchasers build a majority of the forest roads, the Forest Service can to a certain extent dictate the type and quality of road to be constructed. This is done through the use of the "prudent operator" concept which allows

the Forest Service Engineer to require a timber purchaser to build a road to the quality that a prudent operator would construct the road, therefore enabling the Forest Service to maintain a higher quality of roads.

(3) Who Will Use PMS? There may be some problem in considering the quality of people that will use the PMS. GS-4 and GS-5 technicians will be collecting the necessary data, but will they actually be inputting it into the system and designing the road? Who will make the decisions, as to what design will be implemented for a particular road? Will the Forest Engineer use the PMS to predict future maintenance and plan budgets?

(4) Control of Timber Traffic on Forest Service Roads. Because the Forest Service controls the size of the timber sale, it is in a position to control the number and size of loads travelling across its timber roads.

(5) Fatigue Failure. Because of the small number of loads carried across timber roads, it is nearly impossible for any of them to experience failure caused by excess fatigue.

(6) Classes of Traffic on Forest Service Roads. A forest road will generally carry three classes of traffic during its lifetime:

(a) logging trucks -- during production years,
(b) recreational -- after production years, and
(c) Forest Service personnel -- during and after production years.

The type of traffic on a road is a function of the time and rate at which the timber purchaser chooses to harvest.

(7) The Influence of Surface Type on Traffic. The number of vehicles travelling across a road is influenced to a great extent by the

type of surfacing on the road. A road will probably receive more traffic if it is paved with asphalt than if it were left unpaved.

(8) Does Black Paving a Forest Service Road Increase Safety? The question of safety comes up when considering whether or not to black pave a road that was originally gravel. If a gravel road, whose geometric design was determined by the speeds attainable on such a pavement, were to be black paved, its accident rate would probably increase due to the higher speeds allowed by smoother pavement.

(9) The PMS for Forest Service Roads. Mr. Haywood Taylor suggested three questions that must be asked when planning a road:

(a) Is it economically sound?
(b) Is it socially acceptable?
(c) Is it politically acceptable?

Questions that must be kept in mind when considering the PMS for the Forest Service are:

(a) Will it work?
(b) What are implementation costs?
(c) What are the benefits?
(d) Who will want to use it?
(e) Who will accept it?

(10) It is important to keep the system simple. If the PMS is too complex for the average Forest Engineer to use, then it is of no value to the Forest Service. It was suggested that the PMS be implemented in stages, in order to make its total comprehension easier.

TABLE 1. INPUT VARIABLES

Load and Traffic Variables

- Number of Applications (4.72)*
- Distribution of Traffic
  - (a) seasonal changes (4.58)
  - (b) annual changes (3.53)
- Characterization-Distribution of Loads on Vehicles (4.54)
- Total Load (4.37)
- Type of Loading (4.32)
- Axle Spacing (3.86)
- Tire Pressure (3.68)

Construction Variables

- Quality Control
  - (a) material (4.62)
  - (b) compaction (4.60)
  - (c) thickness (4.58)
  - (d) moisture and temperature (3.97)
- Personnel-Skill Level (4.16)
- Road Geometrics (3.93)
- Equipment
  - (a) availability (3.66)
  - (b) environmental impact (3.49)

Maintenance Variables

- Level of Maintenance (4.45)
- Type of Rehabilitation
  - (a) gravelling (4.14)
  - (b) overlaying (4.11)
  - (c) sealing (3.90)
- Available Funds (3.96)
- Road Users (3.79)

Constraints

- Maximum Allowable Cost
  - (a) initial construction (4.60)
  - (b) total maintenance (4.17)
  - (c) user's
- Design Life of Road (4.50)
- Minimum Layer Thickness (4.49)
- Environmental Constraints (4.35)
- Minimum Time Until First Major Maintenance (4.28)
- Minimum Time Between Major Maintenance (4.23)
- Constraints from Management (4.23)
- Political Constraints (4.16)
- Prudent Operator Constraints (3.56)

Environmental Variables

- Drainage
  - (a) surface drainage (4.38)
  - (b) subsurface drainage (4.60)
- Freeze-Thaw Cycle (4.21)
- Soil Type (4.11)
- Topography (3.93)
- Rainfall
  - (a) amount (3.81)
  - (b) seasonal distribution (3.79)
  - (c) intensity (3.56)
- Area Sensitivity to Lanslides (3.50)
- Temperature Range (3.36)

Structural Design Variables

- Subgrade Properties
  - (a) strength (4.87)
  - (b) permeability (4.27)
  - (c) gradation (4.12)
- Type and Quality of Paving Material Available (4.58)
- Layers
  - (a) thickness (4.58)
  - (b) arrangement (4.34)
  - (c) number (3.74)
- Stabilization Policy (4.28)
- Cross-Section (3.95)
- Frost Design (3.82)
- Testing Equipment Available (3.55)

Operational Variables

- Controls on Road Use (4.40)
- Time Lag in Obtaining Funds (4.00)
- Operational Planning and Enforcement
  - (a) allowance for major hauling (4.20)
  - (b) snow removal (3.77)

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*(x.xx) = "weighted" mean importance rating

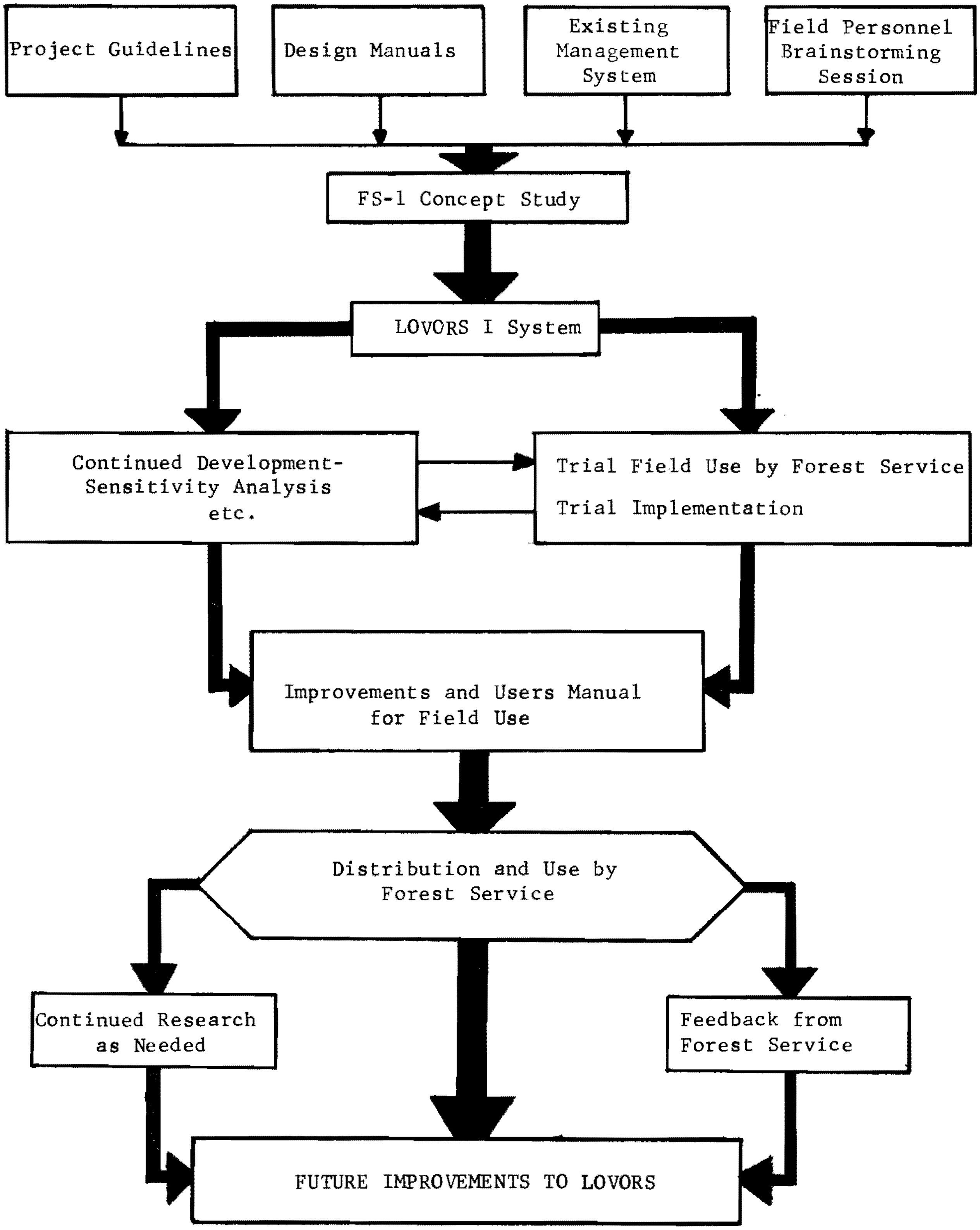


Fig 15. Detailed development of Forest Service Pavement Management System.

(11) Poor Regions and the PMS. Poor regions that have little timber and, therefore, build only very low cost unpaved roads must be considered in the PMS.

(12) Frost Heave on Gravel Roads. Frost heave is not a problem on gravel roads although it does create a problem on the thin asphalt surfaced pavements in some of the northern regions.

(13) Acceptance of PMS Design Models. Will proposed users of the PMS use it if the structural design model is not one that they like or are similar with?

(14) Collection of Input Data. It may be difficult to obtain input data. Historically, the Forest Service has had problems collecting data, i.e., conditions studies, etc.

(15) Separate Systems for Gravel and Black Paved Roads. Because of the vast differences in characteristics and behavior of gravel versus black paved roads, it may be necessary to use two separate systems in designing these two kinds of pavement, although there should be a method to compare the two different designs so that the optimum design can be used.

(16) Naming of PMS. The name of the PMS should be one that would promote favorable support for the system. Some suggestions by Mr. Haywood Taylor included:

  (a) "A Management System for Improving Forest Road Surfaces,"
  (b) "An Engineering System for Enhancing the Riding Surface of Forest Roads,"
  (c) "An Engineering System for Improving Traffic Flow on Forest Roads," and

(d) "A Procedure for Improving Surfacing Systems on National Forest Roads."

(17) Administrative Constraints. It may be difficult to develop a PMS that will cover the many different types of administrative constraints found in the various regions.

Ideas for "Pavement Failure" on Forest Service Roads

One of the major concerns expresses at the "brainstorming session" was that of developing an acceptable definition for "pavement failure" or, in other words, defining the point at which a pavement is no longer acceptable to its users. Previous definitions of failure have concerned themselves only with "high quality" pavements such as those constructed with asphalt concrete or portland cement. Because of the fact that the major portion of Forest Service roads are unsurfaced or aggregate surfaced, it will be necessary to develop a new definition of pavement failure that will take into account these "lower quality" pavements.

In addition to the idea of defining failure as a function of the total cost of maintaining the pavement above a minimum distress level, as mentioned previously, there were a number of other ideas suggested for measuring serviceability and defining failure of pavements on Forest Service roads.

When an aggregare road is accepted after its initial construction it has a definite template cross-section shape in conformance with its plans and specifications. It should also have, within reasonable limits, the specified thickness of aggregates. As time goes by aggregate loss takes place as well as loss of original template shape. These are two measurable parameters that could be used to determine present serviceability levels. Failure of the aggregate road will occur when a predesignated unacceptable point of aggregate loss and loss of shape is reached.

Serviceability or failure of an aggregate road can also be expressed in terms of the speed at which a logger can get across the road. If the road is at a distress level for which it takes "too long" for a logger to get across it, so that he does not make the breakeven point with his costs, then the pavement has failed.

Other ideas for measuring serviceability and defining failure of an aggregate road include (1) evaluation of aggregate gradation, (2) measuring road roughness or riding quality, and (3) evaluation of ton-mile costs of hauling.

Follow-Up Rating Analysis

On the last day of the meeting it was agreed that it would be advantageous to follow up the session with a rating analysis of the pertinent ideas that were discussed. The information received by this analysis would be of great importance in developing the conceptual PMS for the Forest Service.

Evaluation of Meeting

In the opinion of the project staff this "brainstorming session" was very successful in accomplishing the objectives set forth. A large portion of the credit for this must go to the Forest Service Personnel attending the meeting. The tremendous amount of input from them along with their concern for the development of the proposed system will enable us to better evaluate the needs of the Forest Service while preparing this pavement design and management system concept.

It is hope that further interaction between the Forest Service and the project staff will be possible, especially with regard to the follow-up rating analysis to be performed by attendees of the conference.

TABLE B1. INPUT VARIABLES

Load and Traffic Variables

Primary Variables

(1) Total Load
(2) Number of Applications
(3) Frequency of Loads
(4) Speed
(5) Tire Pressure
(6) Characterization-Distribution of Load
(7) Axle Spacing
(8) Type of Load
    (a) static
    (b) dynamic

Major Interaction Variables

(1) Distribution of Traffic
    (a) seasonal
    (b) annual
(2) Surface Wear Effect-Gravel Loss
(3) Lateral Distribution of Roadway Channelization

Environmental Variables

Primary Variables

(1) Rainfall
    (a) amount
    (b) intensity
    (c) seasonal distribution

(continued)

TABLE B1. Continued

- (2) Snowfall
  - (a) amount
  - (b) characterization
- (3) Temperature
  - (a) average
  - (b) range
- (4) Soil Type
- (5) Freeze-Thaw Cycle
- (6) Vegetation
- (7) Area Sensitivity
- (8) Exposure-North Side

Major Interaction Variables

- (1) Topography-Drainage
  - (a) surface
  - (b) subsurface
- (2) Snow Removal

<u>Construction Variables</u>

Primary Variables

- (1) Quality Control
  - (a) thickness
  - (b) smoothness
  - (c) compaction
  - (d) material
  - (e) moisture and temperature

(continued)

TABLE B1. Continued

- (2) Work Technique
  - (a) Forest Service appropriated funds
  - (b) timber sales
  - (c) regional specs
- (3) Equipment Availability
- (4) Exposure
- (5) Personnel-Skill level
- (6) Construction length

Major Interaction Variables

- (1) Topography-Geometrics
- (2) Equipment
  - (a) environmental impact
  - (b) adaptability

<u>Structural Design Variables</u>

Primary Variables

- (1) Subgrade properties
  - (a) k value
  - (b) ppermeability
  - (c) gradation
- (2) Type and Quality of Paving Material Available
- (3) Testing Equipment Available
- (4) Cross-Section

Major Interaction Variables

- (1) Stabilization Program
- (2) Frost Design

(continued)

TABLE B1. Continued

- (3) Layers
  - (a) number
  - (b) thickness
  - (c) arrangement

Maintenance Variables

- Primary Variables
  - (1) Level of Maintenance
  - (2) Road Users
  - (3) Available Funds
  - (4) Personnel
    - (a) force account
    - (b) timber purchaser
    - (c) contract
  - (5) Turn Over to Other Agency
- Major Interaction Variables
  - (1) Rehabilitation
    - (a) patching
    - (b) sealing
    - (c) overlaying
    - (d) gravelling
  - (2) Type of Equipment Required

Operational Variables

- Primary Variables
  - (1) controlled use

(continued)

TABLE B1. Continued

- (2) control on
    - (a) loading
    - (b) speed
- (3) Time Lag in Funds

Major Interaction Variables

- (1) Operational Planning-Enforcement
    - (a) snowplowing?
    - (b) major hauling allowed?

Constraints

- (1) Maximum Allowable Cost
    - (a) initial construction
    - (b) total maintenance
- (2) Minimum Layer Thickness
- (3) Minimum Time Until First Major Maintenance
- (4) Minimum Time Between Major Maintenance
- (5) Environmental Constraints
- (6) Political
- (7) Management
- (8) Prudent Operator Concept
- (9) Design Life
- (10) Fiscal Year

(continued)

TABLE B2. DECISION CRITERIA

Decision Criteria

- (1) Cost
  - (a) initial cost
  - (b) maintenance cost
  - (c) user cost
    - (i) timber purchaser
    - (ii) recreation
  - (d) operational cost
- (2) Funds
  - (a) available funds
  - (b) probability of additional funds
  - (c) type of funds
- (3) Riding Quality
- (4) Safety
  - (a) skid resistance
  - (b) dust
  - (c) geometric - shoulders
  - (d) guard rail - cross section
- (5) Administrative Requirements
- (6) Function of the Road
- (7) Service Requirements
- (8) Environmental Impact - Optimize
- (9) Confidence Level
- (10) Stage Construction

APPENIDX C. SAMPLE OUTPUTS FOR A PAVEMENT MANAGEMENT SYSTEM

APPENDIX C. SAMPLE OUTPUTS FOR A PAVEMENT MANAGEMENT SYSTEM

As an example of what the printout for a computerized version of the proposed low-volume road pavement management system could be made to resemble, some sample problems using the FPS-3 computer program developed at the University of Texas are presented here for illustrations. The FPS-3 program was developed specifically for "higher type" roads, i.e. major highways, therefore the inputs used in the program are not necessarily those that would be used to simulate conditions surrounding the design of a low-cost, low-volume road. However, where applicable in these sample problems, values for inputs to the program were chosen to typify the conditions that might be found on a low-volume forest road.

The sample outputs presented here represent alternative designs for two separate forest roads with different environments. Most of the input variables used to describe the design conditions for the two roads were held constant. Those that were varied include: (1) district temperature constant, (2) swelling clay parameter, (3) ADT at beginning of analysis period, (4) ADT at the end of the analysis period, (5) 10-year accumulated number of equivalent 18-kip axles, (6) routine maintenance cost, and (7) salvage value. Printouts of the input data used in the FPS model for the two roads are shown in Figures 16 and 17.

For each of the two different roads, two sample outputs are presented; the difference being a variance of one of the program inputs. For Road 1 the two outputs, Figures 18 and 19, represent a change in the "serviceability index of the initial structure" from 3.5 psi for output 1(a) to 4.5

```
PROB     1      FOREST SERVICE 1

        THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE

     MATERIAL          COST/C.Y.  SI.COEF. MIN.DEPTH MAX.DEPTH SALV.PCT.
 ASPHALTIC CONCRETE       5.00       .72       .50       4.50     20.00
 CRUSHED CINDERS          1.00       .35      2.00      14.00     50.00
 SUBGRADE                -0.00       .22     -0.00      -0.00     -0.00

  NUMBER OF OUTPUT PAGES DESIRED(4 DESIGNS/PAGE)                                  3
  NUMBER OF INPUT MATERIAL TYPES                                                  2
  MAX FUNDS AVAILABLE PER SQ.YD. FOR INITIAL DESIGN (DOLLARS)                  3.00
  LENGTH OF THE ANALYSIS PERIOD (YEARS)                                        10.0
  INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)                                7.0
  ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)                               10.0
  ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)                             1.90
  MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)                   20.0

  DISTRICT TEMPERATURE CONSTANT                                                32.0
  SERVICEABILITY INDEX OF THE INITIAL STRUCTURE                                 3.5
  SERVICEABILITY INDEX P1 AFTER AN OVERLAY                                      3.3
  MINIMUM SERVICEABILITY INDEX P2                                               1.5
  SWELLING CLAY PARAMETERS -- P2 PRIME                                         1.25
                              B1                                              .0900

  ONE-DIRECTION ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)               75
  ONE-DIRECTION ADT AT END OF ANALYSIS PERIOD (VEHICLES/DAY)                    100
  ONE-DIRECTION  10-YR ACCUMULATED NO. OF EQUIVALENT 18-KIP AXLES            300000

  MINIMUM TIME TO FIRST OVERLAY (YEARS)                                         2.0
  MINIMUM TIME BETWEEN OVERLAYS (YEARS)                                         2.0
  MIN TIME TO FIRST SEAL COAT AFTER OVERLAY OR INITIAL CONST.(YEARS)            1.0
  MINIMUM TIME BETWEEN SEAL COATS (YEARS)                                       1.0
  NUMBER OF OPEN LANES IN RESTRICTED ZONE IN O.D.                                 1
  NUMBER OF OPEN LANES IN RESTRICTED ZONE IN N.O.D.                               1

  C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE O.D. (MILES)                .50
  C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE N.O.D. (MILES)              .50
  PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)               10.0
  OVERLAY CONSTRUCTION TIME (HOURS/DAY)                                        10.0
  THE ROAD IS IN A RURAL AREA.

  PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN O.D. (PERCENT)            1.0
  PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN N.O.D. (PERCENT)          0.0
  AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN O.D. (HOURS)                       .120
  AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN N.O.D. (HOURS)                     .100
  AVERAGE APPROACH SPEED TO THE OVERLAY ZONE (MPH)                             30.0
  AVERAGE SPEED THROUGH OVERLAY ZONE IN O.D. (MPH)                             20.0
  AVERAGE SPEED THROUGH OVERLAY ZONE IN N.O.D. (MPH)                           20.0
  TRAFFIC MODEL USED IN THE ANALYSIS                                              3

  FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE MILE)                  80.00
  INCREMENTAL INCREASE IN MAINT. COST PER YEAR (DOLLARS/LANE MILE)            20.00
  COST OF A SEAL COAT (DOLLARS/LANE MILE)                                   2000.00
  WIDTH OF EACH LANE (FEET)                                                   12.00
  MINIMUM OVERLAY THICKNESS (INCHES)                                             .4
  ACCUMULATED MAXIMUM DEPTH OF ALL OVERLAYS (INCHES)                            3.0
```

Fig 16. Input data for Road 1.

```
PROB      1       FOREST SERVICE 1

        THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE

    MATERIAL         COST/C.Y.  ST.COEF. MIN.DEPTH MAX.DEPTH SALV.PCT.
ASPHALTIC CONCRETE      5.00       .72       .50      4.50      0.00
CRUSHED CINDERS         1.00       .35      2.00     15.00      0.00
SUBGRADE               -0.00       .22     -0.00     -0.00     -0.00

  NUMBER OF OUTPUT PAGES DESIRED(8 DESIGNS/PAGE)                                3
  NUMBER OF INPUT MATERIAL TYPES                                                2
  MAX FUNDS AVAILABLE PER SQ.YD. FOR INITIAL DESIGN (DOLLARS)                3.00
  LENGTH OF THE ANALYSIS PERIOD (YEARS)                                      10.0
  INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)                              7.0
  ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)                             10.0
  ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)                           1.90
  MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)                 20.0

  DISTRICT TEMPERATURE CONSTANT                                              29.0
  SERVICEABILITY INDEX OF THE INITIAL STRUCTURE                               3.5
  SERVICEABILITY INDEX P1 AFTER AN OVERLAY                                    3.3
  MINIMUM SERVICEABILITY INDEX P2                                             1.5
  SWELLING CLAY PARAMETERS -- P2 PRIME                                       1.18
                              BI                                            .0900

  ONE-DIRECTION ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)             50
  ONE-DIRECTION ADT AT END OF ANALYSIS PERIOD (VEHICLES/DAY)                   50
  ONE-DIRECTION  10-YR ACCUMULATED NO. OF EQUIVALENT 18-KIP AXLES          150000

  MINIMUM TIME TO FIRST OVERLAY (YEARS)                                       2.0
  MINIMUM TIME BETWEEN OVERLAYS (YEARS)                                       2.0
  MIN TIME TO FIRST SEAL COAT AFTER OVERLAY OR INITIAL CONST.(YEARS)          1.0
  MINIMUM TIME BETWEEN SEAL COATS (YEARS)                                     1.0
  NUMBER OF OPEN LANES IN RESTRICTED ZONE IN O.D.                               1
  NUMBER OF OPEN LANES IN RESTRICTED ZONE IN N.O.D.                             1

  C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE O.D. (MILES)              .50
  C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE N.O.D. (MILES)            .50
  PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)             10.0
  OVERLAY CONSTRUCTION TIME (HOURS/DAY)                                      10.0
  THE ROAD IS IN A RURAL AREA.

  PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN O.D. (PERCENT)          1.0
  PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN N.O.D. (PERCENT)        0.0
  AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN O.D. (HOURS)                     .120
  AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN N.O.D. (HOURS)                   .100
  AVERAGE APPROACH SPEED TO THE OVERLAY ZONE (MPH)                           30.0
  AVERAGE SPEED THROUGH OVERLAY ZONE IN O.D. (MPH)                           20.0
  AVERAGE SPEED THROUGH OVERLAY ZONE IN N.O.D. (MPH)                         20.0
  TRAFFIC MODEL USED IN THE ANALYSIS                                            3

  FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE MILE)                50.00
  INCREMENTAL INCREASE IN MAINT. COST PER YEAR (DOLLARS/LANE MILE)          10.00
  COST OF A SEAL COAT (DOLLARS/LANE MILE)                                 2000.00
  WIDTH OF EACH LANE (FEET)                                                 12.00
  MINIMUM OVERLAY THICKNESS (INCHES)                                           .4
  ACCUMULATED MAXIMUM DEPTH OF ALL OVERLAYS (INCHES)                          3.0
```

Fig 17. Input data for Road 2.

```
PROB      1       FOREST SERVICE 1

                            SUMMARY OF THE MOST OPTIMAL DESIGNS
                             IN ORDER OF INCREASING TOTAL COST

                            1      2      3      4      5      6      7
***************************************************************************
DESIGN NUMBER               2      2      2      2      2      2      2
INIT. CONST. COST        .361   .375   .431   .347   .444   .528   .403
OVERLAY CONST. COST      .411   .433   .269   .524   .307   .237   .337
USER COST                .012   .013   .008   .015   .009   .007   .009
SEAL COAT COST          1.454  1.430  1.634  1.494  1.624  1.648  1.674
ROUTINE MAINT. COST      .102   .109   .111   .105   .118   .125   .110
SALVAGE VALUE           -.098  -.109  -.110  -.109  -.121  -.124  -.110
***************************************************************************
***************************************************************************
TOTAL COST              2.241  2.251  2.342  2.377  2.381  2.422  2.422
***************************************************************************
***************************************************************************
NUMBER OF LAYERS            2      2      2      2      2      2      2
***************************************************************************
LAYER DEPTH (INCHES)
     D( 1)                 .5     .5     .5     .5     .5    1.0     .5
     D( 2)               10.5   11.0   13.0   10.0   13.5   14.0   12.0
***************************************************************************
***************************************************************************
NO.OF PERF.PERIODS          4      4      3      4      3      3      3
***************************************************************************
PERF. TIME (YEARS)
     T( 1)              2.594  2.781  3.656  2.406  3.906  4.719  3.219
     T( 2)              5.188  5.656  7.438  5.375  8.563  9.625  7.063
     T( 3)              8.156  9.500 11.594  9.344 13.750 15.094 11.375
     T( 4)             11.469 13.781  0.000 13.875  0.000  0.000  0.000
***************************************************************************
OVERLAY POLICY(INCH)
(EXCLUDING LEVEL-UP)
     U( 1)                 .4     .4     .4     .9     .9     .4     .9
     U( 2)                 .4     .9     .4     .9     .4     .4     .4
     U( 3)                 .4     .4    0.0     .4    0.0    0.0    0.0
***************************************************************************
NUMBER OF SEAL COATS        7      7      8      7      8      8      8
***************************************************************************
SEAL COAT SCHEDULE
   (YEARS)
   SC( 1)               1.000  1.000  1.000  1.000  1.000  1.000  1.000
   SC( 2)               2.000  2.000  2.000  2.000  2.000  2.000  2.000
   SC( 3)               3.594  3.781  3.000  3.406  3.000  3.000  3.000
   SC( 4)               4.594  4.781  4.656  4.406  4.906  4.000  4.219
   SC( 5)               6.188  6.656  5.656  6.375  5.906  5.719  5.219
   SC( 6)               7.188  7.656  6.656  7.375  6.906  6.719  6.219
   SC( 7)               9.156  8.656  8.438  8.375  7.906  7.719  8.063
   SC( 8)               0.000  0.000  9.438  0.000  9.563  8.719  9.063
***************************************************************************
```

Fig 18. Output 1(a).

```
  PROB     1      FOREST SERVICE 1

                      SUMMARY OF THE MOST OPTIMAL DESIGNS
                       IN ORDER OF INCREASING TOTAL COST

                            1      2      3      4      5      6      7
**********************************************************
DESIGN NUMBER               2      2      2      2      2      2      2
INIT. CONST. COST        .340   .403   .382   .424   .444   .465   .319
OVERLAY CONST. COST      .453   .262   .280   .254   .139   .130   .430
USER COST                .013   .008   .008   .008   .004   .004   .012
SEAL COAT COST          1.464  1.634  1.674  1.696  1.793  1.806  1.648
ROUTINE MAINT. COST      .106   .113   .110   .118   .125   .128   .101
SALVAGE VALUE           -.100  -.103  -.098  -.108  -.108  -.113  -.088
**********************************************************
**********************************************************
TOTAL COST              2.276  2.316  2.356  2.391  2.397  2.420  2.423
**********************************************************
**********************************************************
NUMBER OF LAYERS            2      2      2      2      2      2      2
**********************************************************
LAYER DEPTH (INCHES)
     D( 1)                 .5     .5     .5     .5     .5     .5     .5
     D( 2)                6.5    8.0    7.5    8.5    9.0    9.5    6.0
**********************************************************
**********************************************************
NO.OF PERF.PERIODS          4      3      3      3      2      2      4
**********************************************************
PERF. TIME (YEARS)
     T( 1)              2.594  3.906  3.406  4.406  4.969  5.531  2.281
     T( 2)              5.313  8.063  7.063  9.188 10.344 11.687  4.688
     T( 3)              9.219 12.844 11.250 14.625  0.000  0.000  7.469
     T( 4)             13.750  0.000  0.000  0.000  0.000  0.000 10.656
**********************************************************
OVERLAY POLICY(INCH)
(EXCLUDING LEVEL-UP)
     O( 1)                 .4     .4     .4     .4     .4     .4     .4
     O( 2)                 .9     .4     .4     .4    0.0    0.0     .4
     O( 3)                 .4    0.0    0.0    0.0    0.0    0.0     .4
**********************************************************
NUMBER OF SEAL COATS        7      8      8      9      9      9      8
**********************************************************
SEAL COAT SCHEDULE
   (YEARS)
   SC( 1)               1.000  1.000  1.000  1.000  1.000  1.000  1.000
   SC( 2)               2.000  2.000  2.000  2.000  2.000  2.000  2.000
   SC( 3)               3.594  3.000  3.000  3.000  3.000  3.000  3.281
   SC( 4)               4.594  4.906  4.406  4.000  4.000  4.000  4.281
   SC( 5)               6.313  5.906  5.406  5.406  5.969  5.000  5.688
   SC( 6)               7.313  6.906  6.406  6.406  6.969  6.531  6.688
   SC( 7)               8.313  7.906  8.063  7.406  7.969  7.531  8.469
   SC( 8)               0.000  9.063  9.063  8.406  8.969  8.531  9.469
**********************************************************
```

Fig 19. Output 1(b).

psi for output 1(b). For Road 2 the outputs, Figures 20 and 21, are for two different types of base material; crushed cinder is used in output 2(a), while bank run gravel is used in 2(b). Figure 22 compares the serviceability-age histories of the second most optimal design for outputs 1(a) and 1(b), while Figure 23 does the same for outputs 2(a) and 2(b).

```
  PROB     1      FOREST SERVICE 1

                       SUMMARY OF THE MOST OPTIMAL DESIGNS
                        IN ORDER OF INCREASING TOTAL COST

                          1      2      3      4      5      6      7
*********************************************************************
DESIGN NUMBER             2      2      2      2      2      2      2
INIT. CONST. COST      .319   .306   .375   .361   .347   .292   .264
OVERLAY CONST. COST    .288   .345   .262   .307   .280   .403   .430
USER COST              .005   .006   .004   .005   .005   .007   .007
SEAL COAT COST        1.619  1.619  1.634  1.624  1.674  1.609  1.648
ROUTINE MAINT. COST    .065   .065   .067   .070   .066   .063   .061
SALVAGE VALUE         0.000  0.000  0.000  0.000  0.000  0.000  0.000
*********************************************************************
*********************************************************************
TOTAL COST            2.297  2.340  2.342  2.367  2.371  2.374  2.410
*********************************************************************
*********************************************************************
NUMBER OF LAYERS          2      2      2      2      2      2      2
*********************************************************************
LAYER DEPTH (INCHES)
    D( 1)                .5     .5     .5     .5     .5     .5     .5
    D( 2)               9.0    8.5   11.0   10.5   10.0    8.0    7.0
*********************************************************************
*********************************************************************
NO.OF PERF.PERIODS        3      3      3      3      3      4      4
*********************************************************************
PERF. TIME (YEARS)
    T( 1)             2.969  2.781  3.969  3.719  3.469  2.531  2.156
    T( 2)             6.219  6.438  8.469  8.625  7.313  5.313  4.500
    T( 3)            10.187 10.906 14.000 14.844 12.000  8.656  7.281
    T( 4)             0.000  0.000  0.000  0.000  0.000 12.687 10.687
*********************************************************************
OVERLAY POLICY(INCH)
(EXCLUDING LEVEL-UP)
    O( 1)                .4     .9     .4     .9     .4     .4     .4
    O( 2)                .4     .4     .4     .4     .4     .4     .4
    O( 3)               0.0    0.0    0.0    0.0    0.0     .4     .4
*********************************************************************
NUMBER OF SEAL COATS      8      8      8      8      8      8      8
*********************************************************************
SEAL COAT SCHEDULE
   (YEARS)
   SC( 1)             1.000  1.000  1.000  1.000  1.000  1.000  1.000
   SC( 2)             2.000  2.000  2.000  2.000  2.000  2.000  2.000
   SC( 3)             3.969  3.781  3.000  3.000  3.000  3.531  3.156
   SC( 4)             4.969  4.781  4.969  4.719  4.469  4.531  4.156
   SC( 5)             5.969  5.781  5.969  5.719  5.469  6.313  5.500
   SC( 6)             7.219  7.438  6.969  6.719  6.469  7.313  6.500
   SC( 7)             8.219  8.438  7.969  7.719  8.313  8.313  8.281
   SC( 8)             9.219  9.438  9.469  9.625  9.313  9.656  9.281
*********************************************************************
```

Fig 20. Output 2(a).

```
  PROB       1        FOREST SERVICE 1

                                       SUMMARY OF THE MOST OPTIMAL DESIGNS
                                        IN ORDER OF INCREASING TOTAL COST

                            1      2      3      4      5      6      7
************************************************************************
DESIGN NUMBER               2      2      2      2      2      2      2
INIT. CONST. COST        .236   .208   .333   .319   .278   .222   .361
OVERLAY CONST. COST      .467   .564   .244   .252   .324   .467   .130
USER COST                .008   .009   .004   .004   .005   .008   .002
SEAL COAT COST          1.454  1.430  1.638  1.648  1.634  1.598  1.806
ROUTINE MAINT. COST      .062   .063   .070   .068   .067   .062   .075
SALVAGE VALUE           0.000  0.000  0.000  0.000  0.000  0.000  0.000
************************************************************************
************************************************************************
TOTAL COST              2.226  2.274  2.290  2.292  2.308  2.357  2.374
************************************************************************
************************************************************************
NUMBER OF LAYERS            2      2      2      2      2      2      2
************************************************************************
LAYER DEPTH (INCHES)
     D( 1)                 .5     .5     .5     .5     .5     .5     .5
     D( 2)                6.0    5.0    9.5    9.0    7.5    5.5   10.5
************************************************************************
************************************************************************
NO.OF PERF.PERIODS          4      4      3      3      3      4      2
************************************************************************
PERF. TIME (YEARS)
     T( 1)              2.969  2.594  4.969  4.656  3.719  2.781  5.656
     T( 2)              5.344  5.563  8.625  8.063  6.250  5.000 10.031
     T( 3)              8.250  9.219 13.094 12.156 10.062  7.594  0.000
     T( 4)             11.781 13.812  0.000  0.000  0.000 10.750  0.000
************************************************************************
OVERLAY POLICY(INCH)
(EXCLUDING LEVEL-UP)
     O( 1)                 .9    1.9     .4     .4     .4     .9     .4
     O( 2)                 .4     .4     .4     .4     .9     .4    0.0
     O( 3)                 .4     .4    0.0    0.0    0.0     .4    0.0
************************************************************************
NUMBER OF SEAL COATS        7      7      8      8      8      8      9
************************************************************************
SEAL COAT SCHEDULE
   (YEARS)
   SC( 1)               1.000  1.000  1.000  1.000  1.000  1.000  1.000
   SC( 2)               2.000  2.000  2.000  2.000  2.000  2.000  2.000
   SC( 3)               3.969  3.594  3.000  3.000  3.000  3.781  3.000
   SC( 4)               4.969  4.594  4.000  4.000  4.719  4.781  4.000
   SC( 5)               6.344  6.563  5.969  5.656  5.719  6.000  5.000
   SC( 6)               7.344  7.563  6.969  6.656  7.250  7.000  6.656
   SC( 7)               9.250  8.563  7.969  7.656  8.250  8.594  7.656
   SC( 8)               0.000  0.000  9.625  9.063  9.250  9.594  8.656
************************************************************************
```

Fig 21. Output 2(b).

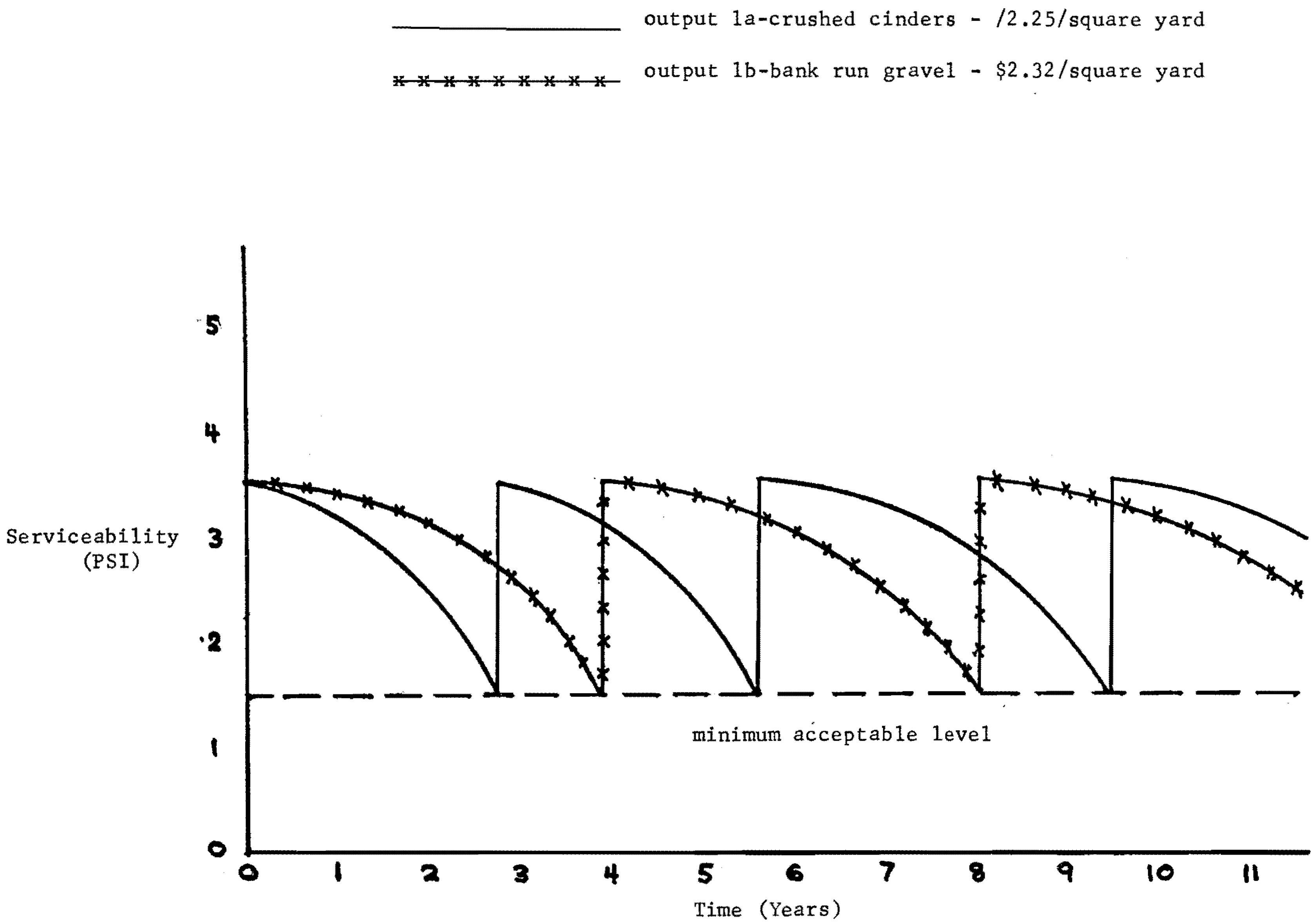


Fig 22. Sample serviceability-age histories for road number 1.

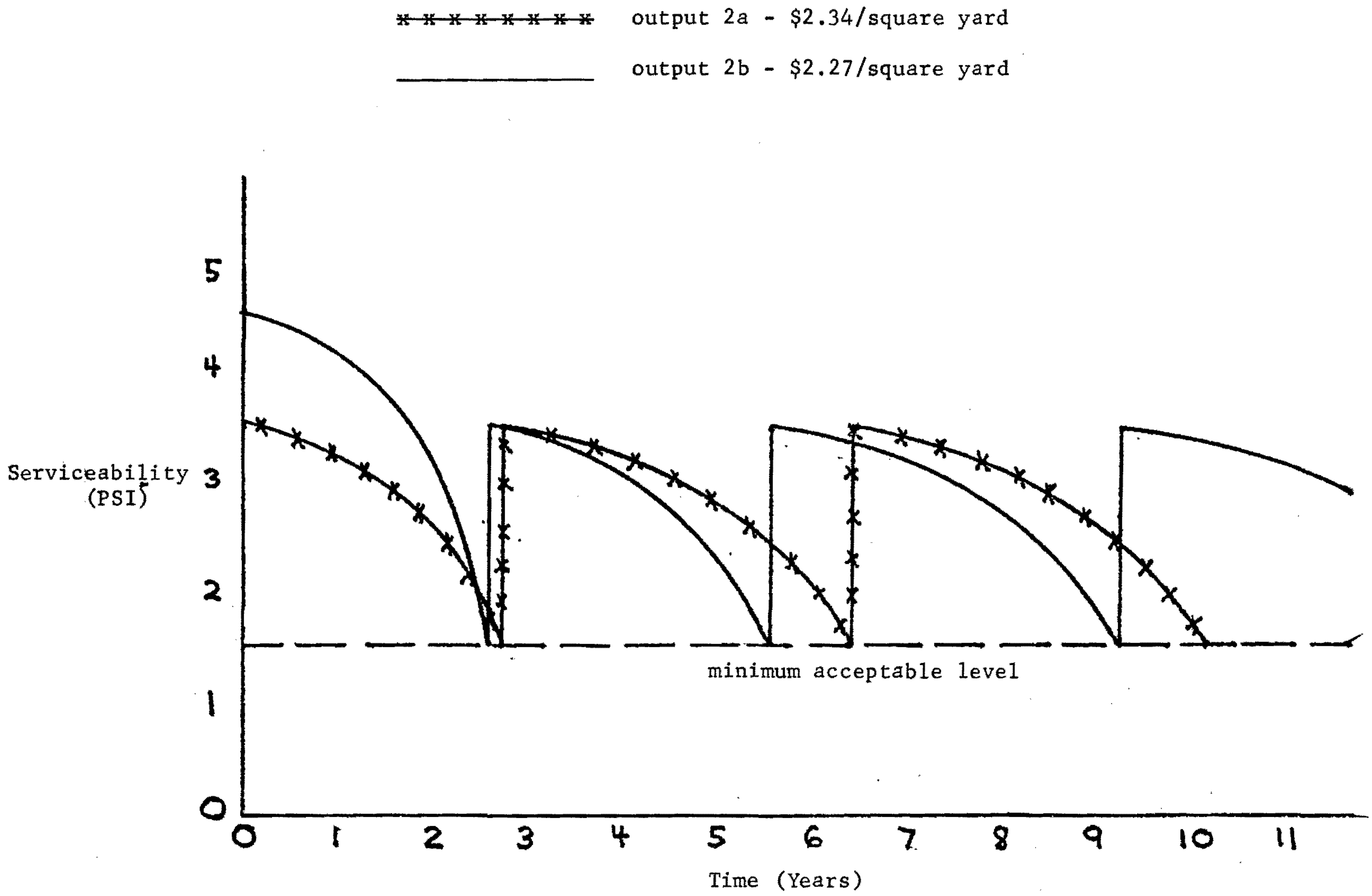
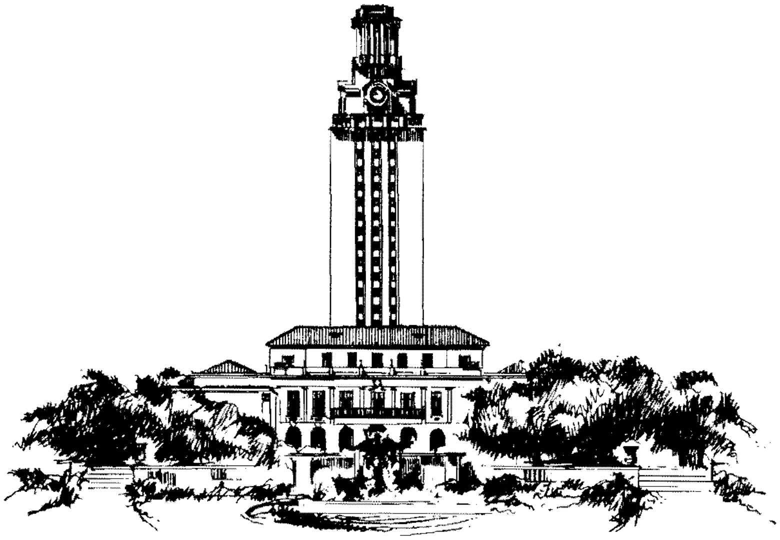


Fig 23. Sample serviceability-age histories for road number 2.



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