IMPLEMENTING A PAVEMENT MANAGEMENT SYSTEM IN THE FOREST SERVICE

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During the last six years, the University of Texas at Austin and the U.S. Forest Service have developed and implemented a Pavement Management System (PMS) called LVR into two Regions of the Forest Service. This PMS is capable of designing asphalt and aggregate surfaced roads by considering material, traffic, environmental and economic characteristics. The LVR system has been in use by various Forests to design both recreational and logging roads. Roads have been designed in some Forests of Oregon, Louisiana, Arkansas, Montana and Georgia. Estimates of the savings in both engineering and construction are presently being assembled and evaluation of the system by the user engineers are being solicited. To date a number of programming errors have been discovered and corrected. However, even with these typical implementation problems, most of the user engineers are satisfied with the design process. In several of the Forests, the roads that have been designed will be monitored bi-yearly to determine if the roads are performing as predicted by LVR. Of particular significance are the comments from the user engineers who indicate that the program greatly increases their analytical capabilities and ability to obtain good life cycle estimates for a larger number of candidate designs than would otherwise be possible. After detailed evaluation of the implementation in these two Regions, the Forest Service will make a decision on service-wide implementation.

Introduction

The basic mission of the Forest Service is to carry out Federal responsibility for the wise use of forest and related watershed lands. These lands comprise one-third of the land area of the United States. The Forest Service has direct management responsibility for approximately 757,000 km^2 (187 million acres). The lands are managed for five different and sometimes conflicting purposes:

1. Timber
2. Watershed
3. Forage
4. Wildlife
5. Recreation

To carry out its management responsibilities the Forest Service is building one of the largest and most complex transportation systems in the world. Table 1 gives the magnitude of the road portion of the transportation system along with some generalized cost information. Road building and transportation administration are an important and integral part of the resource management process in the Forest Service.

Table 1. Kilometers and investment of the Forest Service transportation system.

Category	Kilometers[1]/	Approximate Investment (Dollars)
Existing Road System	353,600	3,572,000,000
Planned Additional Kilometers	185,600	6,960,000,000
Approximate Kilometers Constructed or Reconstructed Annually	16,000	379,000,000[2]/
Maintenance	353,600	61,000,000[2]/

[1]/ 1 km = 0.6 mile
[2]/ FY 1978

The surfacing for such an extensive road system represents a sizeable investment. For the 16,000 km (10,000 miles) of roads to be constructed or reconstructed in 1979, the cost of surfacing will be approximately $75,000,000. Costs of this magnitude require constant analysis and scrutiny. Engineers must assure themselves that the investment in surfacing is being spent wisely and efficiently. However the search for cost effectiveness and efficiency is severely hampered by the lack of specific surfacing design procedures for low volume roads.

For the most part present day pavement design technology was developed from and for roads carrying much higher volumes of traffic. Major research programs on pavement design were conceived, sponsored, and formulated to solve problems relating to high type pavements. Design theories and test roads paid scant attention to aggregate surfaced or bituminous surface treated roads. Yet these type roads make up the vast majority of the Forest Service transportation system.

In the early 1970's the Forest Service adopted a modified version of the AASHTO Interim Guide as the basis for determining structural design thickness for aggregate surfacing. The modification was based on a combination of (1) the AASHTO structural design equations (1), and (2) the thickness design charts developed by the U.S. Army Corps of Engineers for unsurfaced roads and airfields (2). For bituminous surfaced roads the Forest Service design procedure is essentially the same as the AASHTO Interim Guide.

Although a surfacing design procedure was adopted into Forest Service management procedures, it was readily apparent the procedures did not adequately treat nor consider many variables, constraints, and uncertainities. Furthermore, because road design in the Forest Service is decentralized, the surfacing design process was often greatly influenced by the prevailing practices that existed at many different geographic locations. Surfacing design was not being done in a uniform, consistent manner.

A critical review of the aforementioned factors led to the conclusion that a significant problem existed in surfacing design in the Forest Service. The factors can be summarized as follows:

1. Approximately $75,000,000 million dollars was being spent annually for surfacing on Forest Service roads.
2. Existing structural design procedures were inadequate and not responsive to low volume road situations.
3. Decentralized operations were resulting in inconsistent, non-uniform and widely varying procedures for structural design.

Forest Service managers assessed this situation and recognized the need for an indepth comprehensive review to determine whether surfacing design could be strengthened and substantially improved throughout the service. The first step in this comprehensive review was to initiate a study to define the problem and the ramifications of that problem. This study took the form of an analysis to determine if a systems approach was appropriate for the design and analysis of Forest Service roads.

Problem Identification and Definition

The first step was to further identify and explore the problem by acquiring detailed background information and investigating the present state-of-the-art for surfacing design in the Forest Service as well as other low volume pavement design concepts. An assessment of the Forest Service needs for a pavement management system showed that emphasis was placed on (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 of low-volume forest road designs as compared with the design of "higher type" roads.

Following detailed identification of the problem, work was begun to formulate a conceptual system for designing and managing the surfacing of Forest Service roads. Wherever possible pavement management subsystems for low-volume roads were defined. 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 subsystems definition.

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

In order to determine the relative significance of the variables discussed at this session, a rating and ranking of the pertinent ideas and their importance to the proposed pavement management system were completed by the conference attendees. The results of this "importance rating" were then analyzed and the information obtained was used in developing a conceptual pavement management system for Forest Service Roads (3 and 4).

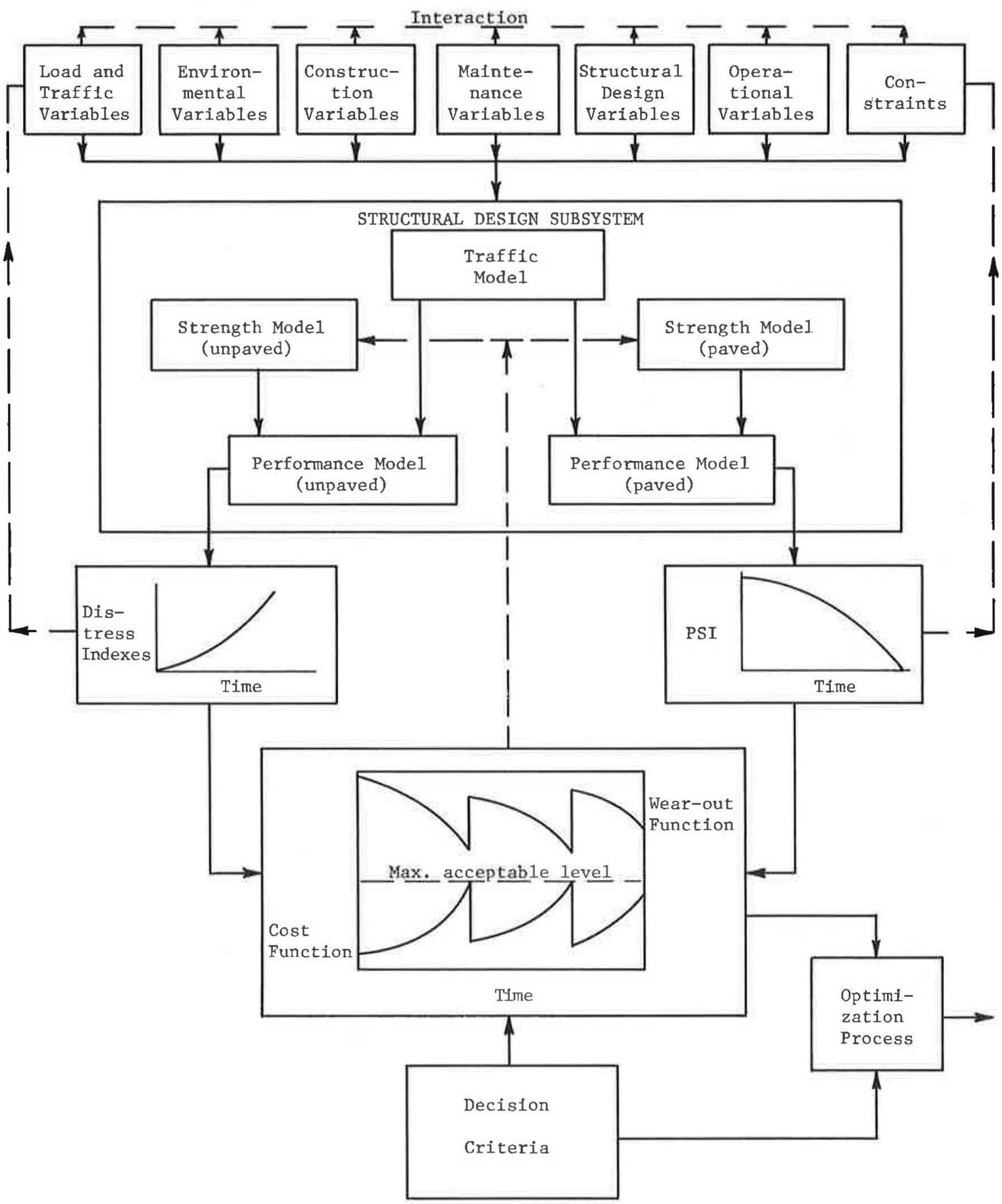
Conceptual System

The combination of structural design models, output representation, and evaluation criteria with the previously defined major components of a pavement management system for low-volume Forest Service roads resulted in the conceptual system as shown in Figure 1.

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. A structural strength for a design of given materials and layer thickness values are calculated using one of the two strength models. This information is then used in a performance model to determine (1) the wear-out function of the structure in terms of either distress or a present serviceability index, and (2) the performance of the structure in relation to a cost function in 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

Figure 1. Conceptual pavement management system.



models in Figure 1. 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 goes through an optimization process and then is evaluated, compared, and arrayed for the subsequent decision.

LVR Program Capabilities

The pavement management system that was developed for the U.S. Forest Service consists of a single computer program, identified as LVR, that can be used to design asphalt concrete, surface treated, and aggregate surfaced roads. However, since the program will only design for a single road surface type at a time, in order to compare an aggregate surfaced road with a bituminous surfaced road, it is necessary either (1) to make a run for an aggregate surface, modify the input data slightly and rerun the program for a bituminous surface, or (2) to stack both sets of input data and obtain separate outputs for bituminous surfaced and for aggregate surfaced designs in one run of the program.

A brief description of the capabilities of the program follows, however details of the program and the various options are described in Reference 5.

Bituminous Surfaced Roads

The bituminous surfaced road design portion of the program uses the AASHTO structural design equation for flexible pavements (1, 6, and 7). This equation, which is currently being used by the U.S. Forest Service (8), is based on the concept of the Present Serviceability Index (PSI) of a pavement.
Using the bituminous surfaced road model, the user can design and compare single and multi-layered pavement structures of either asphalt concrete or bituminous surfaced treated surfaces.

Aggregate Surfaced Roads

Like the bituminous surfaced road design previously described, the aggregate surfaced design uses the current U.S. Forest Service method which is based on a combination of the AASHTO structural design equation for flexible pavements (1, 6, and 7), and the U.S. Army Corps of Engineers Thickness Design Charts (2). This method has been further modified to account for aggregate loss in the aggregate surface layer due to traffic action.
Failure of a candidate structure is defined as any of three events representing the time at which (1) the PSI reaches the minimum acceptable level, or (2) a 5.08 cm (2-inch) wheel path rut develops, or (3) the reduced thickness of the surface layer due to aggregate loss reaches a minimum acceptable value as specified by the user. This triple failure criteria is discussed later.
Using the aggregate surface design model, the user can design and compare single and multi-layered structures of either of two strategies of aggregate surfaced road. One strategy is the use of only aggregate surfacing during the design period; whereas the second strategy provides for a post construction bituminous surface treatment at a later time during the analysis period.

Failure Criteria

The principal surfacing material of Forest Service roads is aggregate. Bituminous surface treatments and asphalt concrete are used to a lesser extent. These surfacing materials fail in vastly different ways. Because of this problem, separate sets of failure criteria are used by the program for bituminous and aggregate surfaced roads.

Bituminous Surfaced Roads Failure Criterion

The performance of bituminous surfaced roads is based on the results of the AASHTO Road Test as presented in the 1972 Edition of the AASHTO Interim Guides for Design of Pavements (1) and in NCHRP Reports 128 (6) and 139 (7). In these reports, failure of a bituminous surfaced road is defined as the time at which the Present Serviceability Index of a pavement reaches the minimally acceptable value, P_t. This concept is demonstrated pictorially in the top portion of Figure 2.

Aggregate Surfaced Roads Failure Criteria

Unlike a bituminous surfaced road with its single failure criterion, the performance of an aggregate surfaced road is based on a triple failure criteria. The first component of the triple criteria is the PSI concept which is applied in the same manner for aggregate surfaced as for bituminous surfaced roads.
The second component of the triple failure criteria is related to rutting. Failure in this case occurs at the time when a 5.08 cm (2-inch) rut develops in the wheelpath. This criterion was developed and reported (2) by the U.S. Army Corps of Engineers and is discussed in more detail in Reference 5.
The third and final component of the triple failure criteria is based on failure due to excessive aggregate loss, which results when the thickness of the top layer is reduced to a user specified minimally acceptable level. The amount of aggregate loss as a function of time is either predicted by the Lund (9) aggregate loss model or specified directly; the choice is based on user preference. The aggregate loss models are discussed in more detail in Reference 5.
The resulting failure time is then the minimum of the times calculated from:

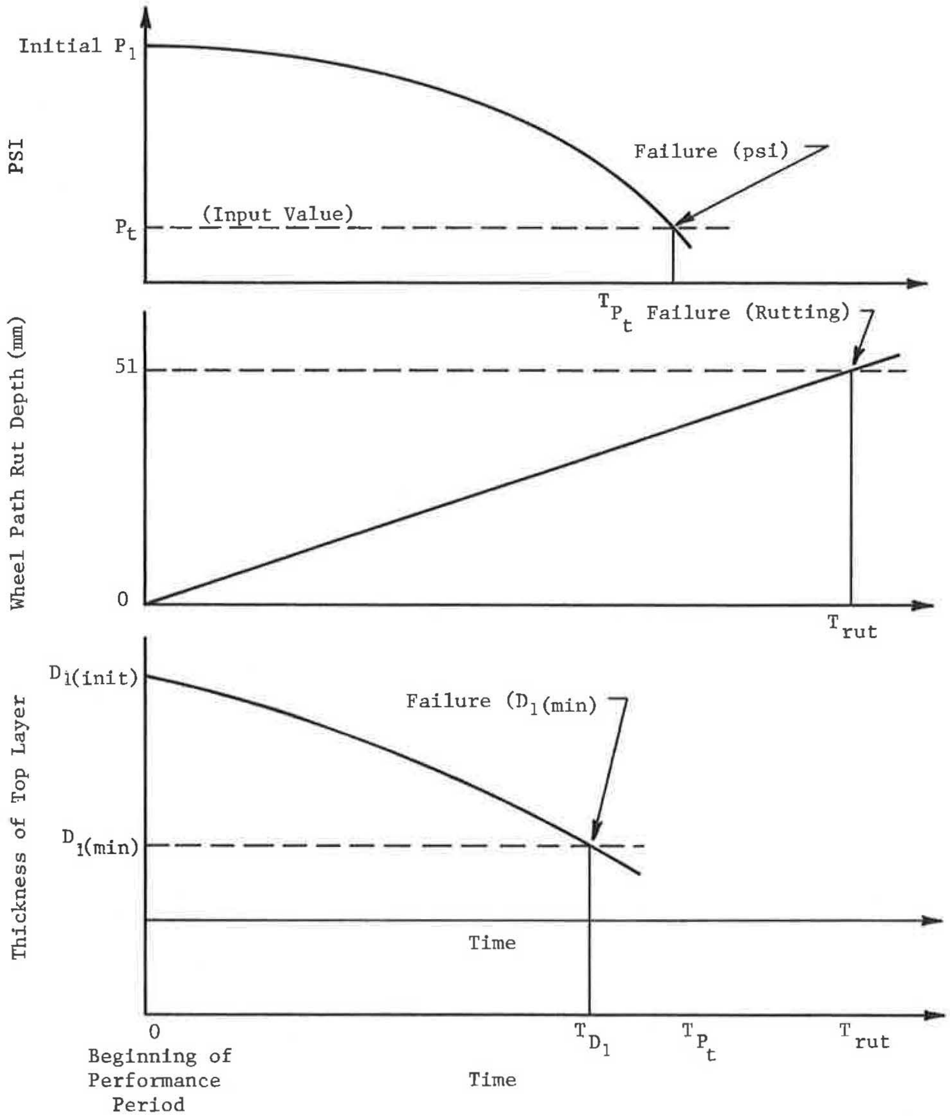
1. The rutting model as used by the U.S. Forest Service which involves computing the failure time due to rutting as the maximum of either
   a. The failure time predicted by way of the rutting model briefly discussed above or
   b. The failure time predicted by the AASHTO performance model.
2. The time at which excessive aggregate surfacing loss has occurred.

The rutting model, like the AASHTO performance model, was originally intended to be used to compute the design thickness needed to carry a certain number of 18-kip (80 kN) equivalent single axle loads under given circumstances. Given the thicknesses of the layers, the layer coefficients, and other necessary information, however, both models can be used to compute the number of 18-kip (80 kN) equivalent single axle loads which will have been accumulated when failure occurs. The number of these loads, then, can be converted to failure time by using a non-linear traffic model. An illustrative application of the triple failure criteria is shown in Figure 2.

Implementation Procedure

The procedure for implementing LVR into Forest Service usage is visually described by the flow chart in Figure 3. The basic philosophy in this procedure was to (1) begin the trial usage at an early stage for "hands on" experience, (2) utilize experience of the Forest Service users as a guide for program revisions, and (3) conduct model analyses at the same time in order to improve the program.
To initiate the implementation, the first training session was held with Region 6 users in Portland, Oregon on December 20 and 21, 1976. During trial usage the program was examined to determine if everything was working properly. Interaction between Forest Service users and University of Texas project staff was very important in working out "bugs", developing the confidence of the users, and in answering various procedural questions. This interaction provided the information needed for revisions in the program.
After the trial usage was under way, the project staff began to make a more detailed analysis of the program. Information from the trial usage was helpful in selecting areas of needed study. It soon became apparent that the

Figure 2. Failure criteria for bituminous and aggregate surfaced roads (4).



P_t ~ minimally acceptable level of PSI
$D_{1(init)}$ ~ Initial thickness of top layer
$D_{1(min)}$ ~ minimum allowable thickness of top layer
T_{P_t} ~ Time at which psi equals P_t
T_{rut} ~ Time at which a 51 mm (2 in.) rut develops in the wheelpath
T_{D_1} ~ Time at which thickness of top layer equal D_{1min}

rutting and aggregate loss models would have to be studied in more detail. A sensitivity analysis on the program played a major role in examining LVR input variables. The sensitivity analysis was used to make program revisions and to analyze the significance of input variables.

Other activities during the implementation period involved conducting training sessions in several other Forest Service Regions, developing a user's manual, and providing a detailed documentation of the LVR program.

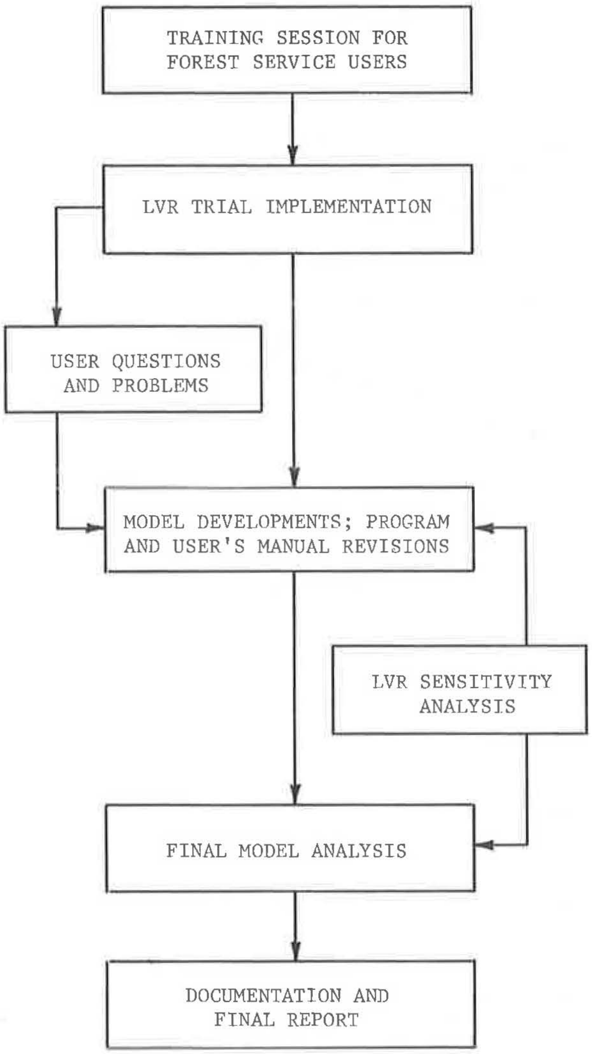
LVR Training Sessions

A total of four training sessions were given by the project staff to introduce LVR to new Forest Service users. Two of these sessions were held in Portland, Oregon (Region 6), one in Atlanta, Georgia (Region 8), and one in Missoula, Montana (Regions 1, 2, 3, 4 and 9). A total of 70 Forest Service "students" attended the sessions.

Usually, the first day of the session included project background, a discussion of the systems approach, discussions of the models included in the program and a detailed discussion of the LVR User's Manual. The second day usually included discussion and coding of an example problem, which was prepared and executed by the participants, and scheduled time for selected individual problems of interest.

At some of the sessions, the students had difficulties setting up input files at the Forest Service Computer Center, located in Fort Collins,

Figure 3. LVR implementation flow chart.



Colorado. As a result of this problem, many of the participants indicated a desire for more "hands on" time with the computer in order to make runs using data brought from their respective Forests. At each training session an evaluation was conducted to get feed back on the adequacy of teaching aids, handout materials and presentation techniques. The results of this evaluation showed that the methods, materials and techniques were very satisfactory. In general, the project staff felt that the training sessions went very well, the participants were very cooperative and eager to learn about to use the new program. Some participants suggested future sessions be offered to refresh experienced users and introduce new ones.

LVR Model Modifications

An important benefit of the implementation procedure was the feedback of Forest Service user experience with LVR. This feedback often pointed out modifications that were necessary to correct or improve the program. Listed below is a summary of some of the changes that were made in the program as a result of this feedback.

Deflection Design Procedure. At the request of Region 6, a deflection design procedure being used in that Region was incorporated into LVR. The model was developed by Region 6 using regression analysis techniques. The model is set up to predict the time of pavement failure in a manner similar to that of the AASHTO model previously incorporated into the program. The deflection model uses pavement deflection data as obtained from a Dynaflect, and, as presently structured, is for use only with bituminous pavements.

Structural Model for Aggregate Roads. As a result of a request from the Ouachita National Forest, a change was made in the AASHTO structural model as it applies to aggregate surfaced roads. The change involved the layer checking scheme that insures the surface layer is adequately thick to support the loads for the soil support value of the underlying granular layer on the subgrade. Since the surface layer for an aggregate road does not perform the same function, structurally, as the surface layer of an asphalt road, this check was deemed inappropriate and is now bypassed when designing aggregate surfaced roads.

Non-Traffic Deterioration Parameters. During the early sensitivity analysis, certain effects caused by non-traffic deterioration parameters were noted and documented. It was determined that when the program indicates that there are no feasible designs for a given set of input data, it may be because the swelling clay parameters P2P (minimum level of PSI due to non-traffic deterioration) and BONE (rate of deterioration) force the serviceability index to drop to the unacceptable level of P2 too quickly. If P2P is less than P2, it may be impossible to remedy this by relaxing any of the constraints related to cost, traffic, or construction. To inform the user of this situation when it occurs, the following message was incorporated in the program: "Non-traffic deterioration parameters are too restrictive for all possible designs. Decrease time to first overlay or reconsider values for P2, P2P, and Bone."

Changes in Program Code. Minor modifications were made, usually the result of queries or "bugs," found in the execution of the program. Examples where changes were made include the cumulative traffic model, the cumulative aggregate loss function, and the rehabilitation strategy for aggregate surfaced roads. As these problems were exposed, the program code was checked to determine if the models were executing correctly. Corrections were made and the program was rerun to verify that it was operating properly.

Documentation

A User's Manual was prepared during the development phase of this project. The manual was continuously updated as changes occurred in the program or suggestions were made to improve the input instructions. To aid in understanding the LVR program, and to make changes in the program easier, a three level documentation of LVR was also developed for the Forest Service.

A detailed computer-generated flow chart, along with a complete cross-referenced listing on the Fortran code, is provided primarily for the computer analyst or engineer who wants to know either exactly how the program operates or desires to make a model change for updating the program. The second level of the documentation is for the engineer who wants to have a knowledge of where the different models are located within the program, but does not want to go through the very detailed flow chart. This includes a brief description of each subroutine and a list of key models along with appropriate references on model development. For the engineer/administrator who is interested only in the general logic of how the program works, a conceptual flow chart was developed with brief explanations of the subroutines. These different levels of documentation should provide appropriate coverage of the program for each of the anticipated types of users of the documentation.

Trial Implementation

The trial implementation of the LVR program was designed to give Forest Service engineers, planners, and managers an opportunity to use and evaluate the program over a period of time. Trial implementation would also test the program, reveal problems, and provide useful experience under Forest Service applications in various parts of the country.

Implementation was initiated in Regions 6 and 8. Training sessions were held in December of 1976 for Region 6 and March of 1977 for Region 8. These two regions provided a range of Forest Service road types. Because of high timber resources in Region 6 the transportation system consists of mostly log hauling roads. The design condition in Region 6 usually involves heavy axle loads and relatively high traffic volumes. In Region 8, on the other hand, there is a relatively low volume of log hauling traffic, but high recreational use of the Forest Service transportation system. Also, because of high timber resource values, Region 6 tended to have more money available for roadway construction and maintenance than Region 8. It was felt that Regions 6 and 8 would provide a wide range of conditions for implementing the LVR program.

During the implementation period, there was increased interest from other regions to use LVR. Because of this interest, trial implementation of LVR was expanded to include certain other regions. It was felt that this additional implementation would benefit the study by increasing the experience base of the trial implementation, and at the same time benefit the Forest Service by introducing more users to the new system. The project staff conducted a training session in October of 1977 in Region 1 (Missoula, Montana) which included engineers from Regions 1, 2, 3, 4, and 9. Subsequent follow up discussions with these regions indicated that the program was being implemented in a number of forests in these respective regions.

During the implementation period the project staff served as consultants to users who had questions or problems with the program. This interaction served two purposes. First, it assisted the user in his understanding and operation of the program, and secondly, it was a valuable feedback source for analyzing problems and making changes to the program.

Results of Implementation

During the trial implementation of LVR, over 70 Forest Service personnel from 30 forests and 7 Regions were introduced to the program. This represents a cross-section of planners, engineers, and managers currently working in many different parts of the country. With this amount of exposure, it was felt that LVR would be tested against most, if not all, possible applications of Forest Service usage.

To ascertain the type of usage that LVR had received and any additional needs for model revision and development, the project staff conducted a questionnaire survey with some of the users in all Regions where LVR had been introduced. Depending on the Region, this survey was generally sent out after one year of trial implementation. The following is a general summary of the comments from the questionnaire.

LVR Usage

The general response from Forest Service personnel around the country was the belief that LVR was a good program and that more frequent use was expected in the future. However, the program had received less than the planned amount of use. Some users had problems with data processing, some did not have the time or resources to experiment with the program, while others did not as yet have authorization to use LVR. In some cases, trained personnel had been transfered to other duties since the training session and were no longer designing pavements. Three or four users simply did not like the program, but they were a small minority. Most gave the overall program high marks and said they planned to use it more in the future.

Problems with Models

The reply from most users concerning bituminous surfacing design was very favorable. Most had satisfactory results and few problems in executing the program. For aggregate surfaced roads, however, many users had unsatisfactory experiences. Problems ranged from unreasonable designs to excess computer execution time. Many questioned the accuracy of the aggregate loss and rut depth models which had also been of concern to the project staff and future actions are being considered by the Forest Service to correct this problem.

One common item mentioned by many users was the intention to use deflection design methods more in the future. With the number of new aggregate surfaced roads to be built, and an interest in determining overlay strategies for existing bituminous roads, it was suggested that the deflection model be expanded and improved.

Suggestions from Forest Service personnel concerning changes and additional capabilities of the models were very useful. The suggestions ranged from providing input for dust abatement cost to interaction with the Forest Service computer based Road Design System (RDS). These suggestions are being considered for present and future development.

Management's Opinion

To secure the opinion of Forest Service management, the questionnaire study included representatives of every Regional Office that participated in the trial implementation. In general, the response was very favorable towards the program, and as at the forest level, these users planned to make more use of LVR in the future.

One familiar concern was having adequate personnel and resources to spend the extra time often necessary when implementing new methods. Another concern involved the ability of the Regional Office to maintain in-house staff capable of training new users and handling user problems.

One very important comment involved the maintenance of the program itself. It was stated that considerable attention will be required to keep the models up to date, and if this is not done on a continuing basis, the program may become obsolete in 3 to 5 years. This comment is also applicable to any design method.

Overall, the Regional Office personnel showed a strong interest in continuing the use of LVR in the future. They were very aware of the importance of up-to-date information and model maintenance in the future performance of the program.

Expansion of Implementation

As a result of this trial implementation of LVR, the Forest Service now has the program operational in selected areas across the country. Because the short period of implementation has limited the usage of the program, the Forest Service plans to expand its implementation of the pavement management system. With more participation, an increased data base could be used to generate more meaningful and beneficial results. Throughout the questionnaire survey the users remarked about the importance of new pavement information. This was particularly true in two areas: aggregate road design and vehicle operating cost. Some stressed the importance of a standard road rating system. Others remarked about the unknown relationship between gravel loss, blading frequency, environment, material type, and traffic. Other users wanted information on vehicle operating costs, particularly when making economic comparisons between aggregate and bituminous surfaced roads. With LVR now operational for the Forest Service, it could be a focal point for gathering and analyzing new information during an expanded implementation period.

Forest Service Use of LVR

LVR is a natural asset to the forest engineer who is interested in maximizing the benefits of road surfacing while working within constraints of materials and cost. LVR allows the use of many kinds of constraints and decision criteria. This leads to various optimization techniques that can pick out favorable alternatives and simplify the final decision process.

Because of the large transportation system under Forest Service jurisdiction, LVR may also be an important tool for management and financial planning. The pavement management system allows the predicted performance characteristics of the surfacing to be used to predict future financial needs and manpower requirements. In many cases expenditures are based on immediate needs, and there is little opportunity to establish long-range plans. As a result there may be no funds for upgrading when a pavement deteriorates below a certain level. In other years, funds may be available, even though a pavement may not require upgrading. The capability of optimizing the expenditure of available funds is obviously an important one. The ability to consider many constraints and variables during design, to optimize available funds and materials for construction, and to assist in management and financial planning are important characteristics of LVR which will be particularly beneficial to the Forest Service users.

Summary

The procedure by which this pavement management system was developed has been long and arduous. However, the regularity and thoroughness of the interaction between Forest Service personnel and the researchers have provided significant information for use in development of the program and user's manual. The end result is that the LVR program provides the Forest Service with a powerful surfacing design and roadway management tool. Its eventual service wide implementation will result in significant additional time to enable the engineer to make project selection decisions using the best available objective information. The engineer should have more time to carefully evaluate the subjective factors affecting the acceptability of a design rather than spending available time making routine design calculations.

It should be emphasized that the program is operational at the Fort Collins, Colorado Computer Center and is receiving limited use in most of the Forest Service. Currently, certain improvements are under development and others, that are in response to implementation feedback, are being planned. Design of several projects has been completed and some jobs are already under construction. It is expected that a significant number of additional design projects will be completed using LVR during the next few years as service wide implementation is realized.

One other important feature of this work is that the program is modular in form and can be updated as new developments occur. This modular feature permits incorporation of new models into the program as they are developed. The strategy for development of new models comes from user feedback and sensitivity analyses.

In this research, we have successfully accomplished the completion of a conceptual study, the development of models necessary to complete the system program, and the completion of a trial implementation phase. Yet, the most difficult part of this work has not been completed: the accomplishment of service wide implementation of LVR which involves changing an established procedure in a very large engineering organization. Such a procedural change is always a time consuming and difficult process and is the part of improving design procedures where failure most often occurs. The researchers have finished their work and the sponsor representatives who are most familiar with the work have evaluated and accepted the product. Now, the engineer who has no vested interest in the work is confronted with a different procedure without the advantage of personal knowledge of the background of the work nor its capabilities. He now becomes the critical element in the implementation process. How he responds to the implementation attempts will be influenced by his perception of the value of the system to his own workload, and the availability of specialized training to teach him how to use the procedure and answer his questions on trial solutions. Such coordination and training support work will be critical in evaluating the probability for successful service wide implementation.

Acknowledgments

The success of this study is due in no small part to the contributions of the engineers and administrators of both the U.S.D.A. Forest Service and Council for Advanced Transportation of the University of Texas at Austin. Without their significant sacrifice of time and energy, the difficult cooperative decisions that were made could not have been made. The result of this work was the successful development of a pavement design and management system that met most of the objectives established for these projects. The assistance and cooperation of all those involved, including the student-engineers who provided valuable feedback, is gratefully acknowledged and the success of the projects was enhanced by these cooperative efforts.

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