AN APPROACH TO PAVEMENT MANAGEMENT IN VIRGINIA

by

K. H. McGhee
Senior Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

The report summarizes the objectives and benefits of formal pavement management systems and outlines an approach believed by the author to be practical for Virginia. The management of Virginia interstate pavements and a proposed random-sampling plan for the primary and secondary systems are discussed. Five recommendations directed at initiating a pavement management system are offered. Perhaps the most important of these deals with the immediate establishment of a pilot management system for the interstate network.

Projected costs of pavement management range from $100,000 to $200,000 for the development of a system, depending upon the level of commitment, and approximately $90,000 in annual operating costs.

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INTRODUCTION

Recent downward trends in highway revenues have led to a need for upgraded long-range planning techniques for programming major maintenance activities. Highway administrators and engineers nationwide foresee a decline in the level at which highway facilities can be maintained. Matching maintenance needs with funds available will be even more difficult in the years to come than has been the case historically. For these reasons, many highway agencies, including the Federal Highway Administration, are directing efforts toward the development and implementation of pavement management systems (PMS's). While such systems may be as complex or as simplistic as local requirements permit, all have as one goal the capability recently expressed by one federal highway administrator:

> "Predicting future funding needs for pavements and providing top-level management with data to indicate what level of service can be maintained within each funding level."(1)

Within the above overall objective, at least several specific benefits of a PMS to highway administrators were identified at a recent workshop sponsored by the Federal Highway Administration.(2) Among those benefits provided are:

1. Improved performance monitoring and forecasting,
2. objective support for legislative funding requests,
3. identifiable consequences of various funding levels,
4. improved administrative credibility,
5. a basis for cost allocation to highway users, and
6. improved engineering input for policy decisions.

While the objectives and benefits of a PMS have been identified, no widely accepted definition for such a system has been given. Generally, however, it is safe to say that a PMS is an ordered and objective process whereby the most serviceable pavements possible are provided at the lowest possible cost to the users. In fact, the Utah Department of Transportation, one of the pioneers in formal pavement management, was able to show legislators that a high level of pavement maintenance was cost-effective over a 20-year analysis period.(3)

Historically, funding levels in Virginia have been such as to provide overlays or other needed maintenance on major highways prior to public recognition of serious pavement deterioration. The establishment of major maintenance priorities under this historical situation has been a subjective activity where the consensus of a group of engineers carries heavy weight.(4) Now, the recognized reduced funding levels and tendencies toward program budgeting point to the need for more refined prioritizing techniques and to the development and use of a data bank for long-range planning such as would be provided by a formal PMS.

While the case for formal pavement management is being made, recognition should be given to the fact that the high level at which Virginia's highway system has been maintained in the past is sufficient evidence that pavements have been managed and managed efficiently in spite of the absence of hard data documenting rates of pavement deterioration, long-range system needs, and required future funding levels. An effective PMS would permit continued good management and provide the planning and funding information needed.

The FHWA, in a recent review of the Department's pavement management activities, recognized the current good management yet pointed to the need for a more formal procedure. Finally, the "Hansen" study of the Department has recommended the adoption of formal pavement management processes.(5)

It is the rationale of establishing a useful and practical PMS in Virginia that the present document is intended to address.

SCOPE OF PAVEMENT MANAGEMENT

Effective long-range planning of activities associated with pavement ownership requires many varied inputs and involves several of the major divisions of the Department.

Often referred to as pavement "life-cycle costing", the management process would draw on at least the following sources of information or data banks:

1. Pavement design information, including thickness and sources of materials and design traffic.
2. Pavement construction cost data.
3. In-service traffic data, particularly 18-kip-equivalent axle loadings.
4. Pavement maintenance data, including descriptions and costs of major maintenance activities.
5. Pavement condition information, including surface distress, ride quality, and skid resistance.

Several of the above subunits of a management system have been developed and, to some degree, are functional. Others, including the pavement condition and traffic inventories, are in early stages of development. Still others, not listed above, may be perceived by management when a functional PMS goes on line.

From a practical standpoint, a PMS could function at the level or levels desired by management. Generally, such systems provide feedback for at least two categories of decisions: those involving projects and their priorities for maintenance and those involving total highway networks and the funds needed to maintain them. Clearly, it is conceivable that the administration might wish to leave project decisions to the discretion of local engineers who are the ones most familiar with the pavements under their jurisdictions. At the same time, it is evident that network-wide decisions such as determining needed revisions in funding levels and the consequence of those levels must be centralized responsibilities.

The two approaches, project and network, have somewhat different requirements in that a great deal of detailed information is needed for decisions on a project-by-project basis while the feedback for network analysis can be derived from a random-sampling plan. Texas, for example, has found that statistically valid and valuable information can be derived from a sampling of as little as 0.5 percent of the total centerline mileage.[6]

Since the final scope and purpose of a PMS must be defined by management, the succeeding sections of this discussion are directed at the development of a system adaptable to both project and network management. This being the case, the network approach is outlined with the understanding that project analysis is merely a focus of the network system onto individual projects.

ESSENTIALS OF PAVEMENT MANAGEMENT

The AASHO road test conducted in the late 1950's provided the foundation for effective long-range planning of pavement expenditures.[7] During that test a system of pavement rating on a scale of from 0 to 5 was developed with the following designations.

0 to 1 Very Poor
1 to 2 Poor
2 to 3 Fair
3 to 4 Good
4 to 5 Very Good

The system was developed from series of subjective ratings of various pavements by a panel of road users and was transformed into an objective present serviceability index (PSI) where physical measurements such as roughness, rutting, cracking, and patching are the principal determinants. Further road test studies showed that a pavement performs in the manner indicated in Figure 1, where the vertical scale is PSI and the horizontal scale may be either time or accumulated traffic loads. Typically, a pavement loses serviceability (deteriorates) very slowly for several years, then enters a period of rather rapid decline toward total failure. This period of rapid decline is marked by the presence of cracking and deformation, and by a decrease in ridability. As indicated in Figure 1, an overlay at some time after the period of rapid deterioration begins can restore the pavement to where a new cycle begins.

Virginia pavements presently are designed to provide a PSI of no less than 2.5 over a 20-year design life. Typically, an overlay is required in from 6 to 10 years to avoid an excessive loss in PSI. A sampling of Virginia pavements reviewed for resurfacings during 1980 showed a range in PSI values from approximately 2.1 for a low trafficked primary highway to approximately 3.8 for an interstate.

It is important to note that the serviceability rating system discussed above reflects the user's perception of pavement serviceability. Another approach, which appears to be preferred by Virginia engineers, is to base pavement ratings on engineering characteristics of the pavement. Such ratings, tempered by some measure of pavement ridability, which reflects a user's perception of a pavement's serviceability, have a time or traffic relationship similar to that shown in Figure 1 for PSI ratings. This approach, known in Virginia as the pavement maintenance rating (MR),[8] will be discussed in some detail in a later section.

The step from consideration of an individual project to a network analysis involves the development and implementation of a valid sampling plan where a network central tendency of pavement condition as a function of time or traffic can be identified. Then, projections of funding needs can be based on projections of maintenance needs. Since pavement design parameters materially influence the shape of the condition-time curve, it is possible to predict mean ratings as a function of traffic loadings, pavement strength, and time. Such predictions can be used to examine the consequences of various funding levels and, if the economic climate permits, to optimize the expenditure of maintenance monies. A scenario for interstate pavement management in Virginia is discussed later.

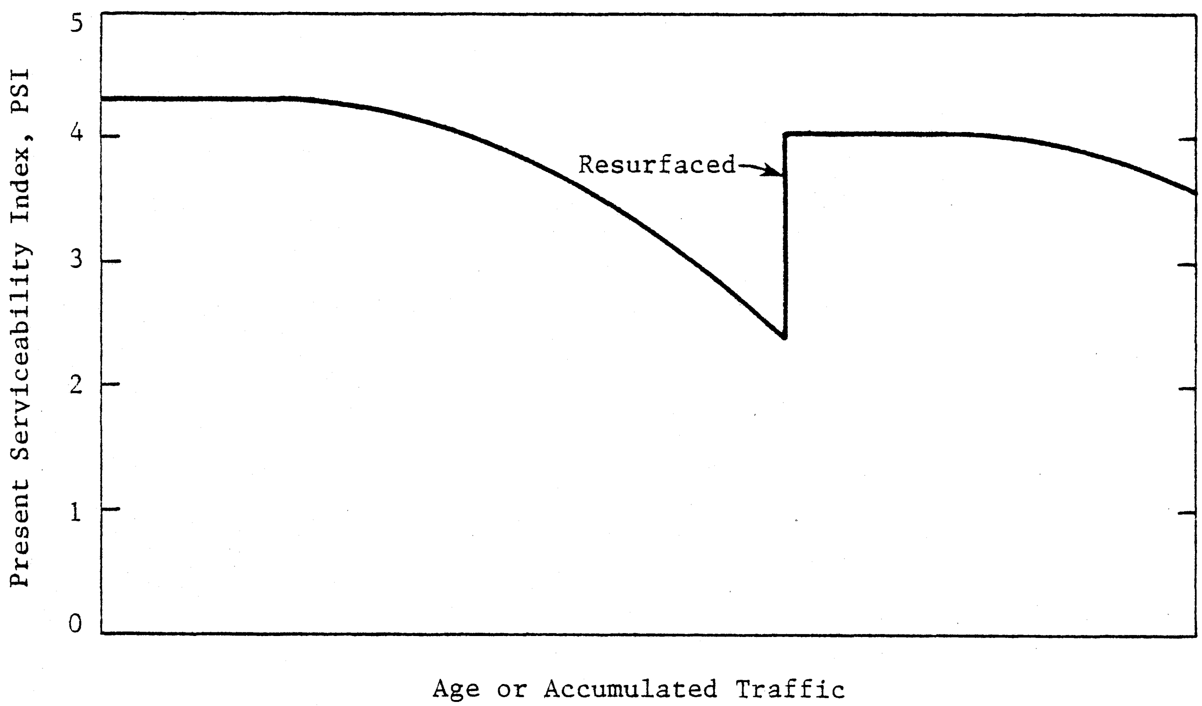

Figure 1. Typical pavement performance curve (after reference 3).

PAVEMENT DATA SYSTEM DEVELOPMENT

While the thrust of pavement management efforts is toward implementation of the whole management package, the first essential step is to provide a pavement data system around which management activities can revolve. Haas and Hudson provide a suggested framework for the development and implementation of such a data system as indicated in Figure 2.[9] One familiar with Virginia's activities will recognize that many of the elements within that framework exist, and that much of the needed effort relates to the refinement of existing subsystems while some relates to the development of new subsystems. The author envisions the following major tasks in the development and implementation of a workable data system.

1. Refinement and unification of existing computer systems (skid data, pavement cross section information, cost data, etc.) such that these systems will be useful in the pavement management process. Among the major efforts within this task will be the adaptation of existing systems to where a uniform method of project descriptions and locations is employed. Now, some systems use milepost references while others use landmarks such as roadway intersections.

2. Refinement and implementation of the present pavement maintenance rating system for selection of maintenance priorities. This system has been used in several districts for the past three years, and it has been revised once to improve the correlations between raters who consider pavement distress, ride quality, and traffic volume.

3. Development of a statewide condition inventory system. This task would demand the greatest effort, because there is currently no condition inventory with the exception of data on skid resistance.

4. Development of a framework for PMS implementation.

Condition Inventory Subsystem

While tasks 1, 2, and 4 will require some effort, their detailed consideration will be delayed for discussion with management of the Department. Task 3, the condition inventory subsystem, would provide the foundation of the proposed PMS and is in need of early development. While the full development and refinement of such a system may require years of effort, a rather simplified initial effort is proposed below.

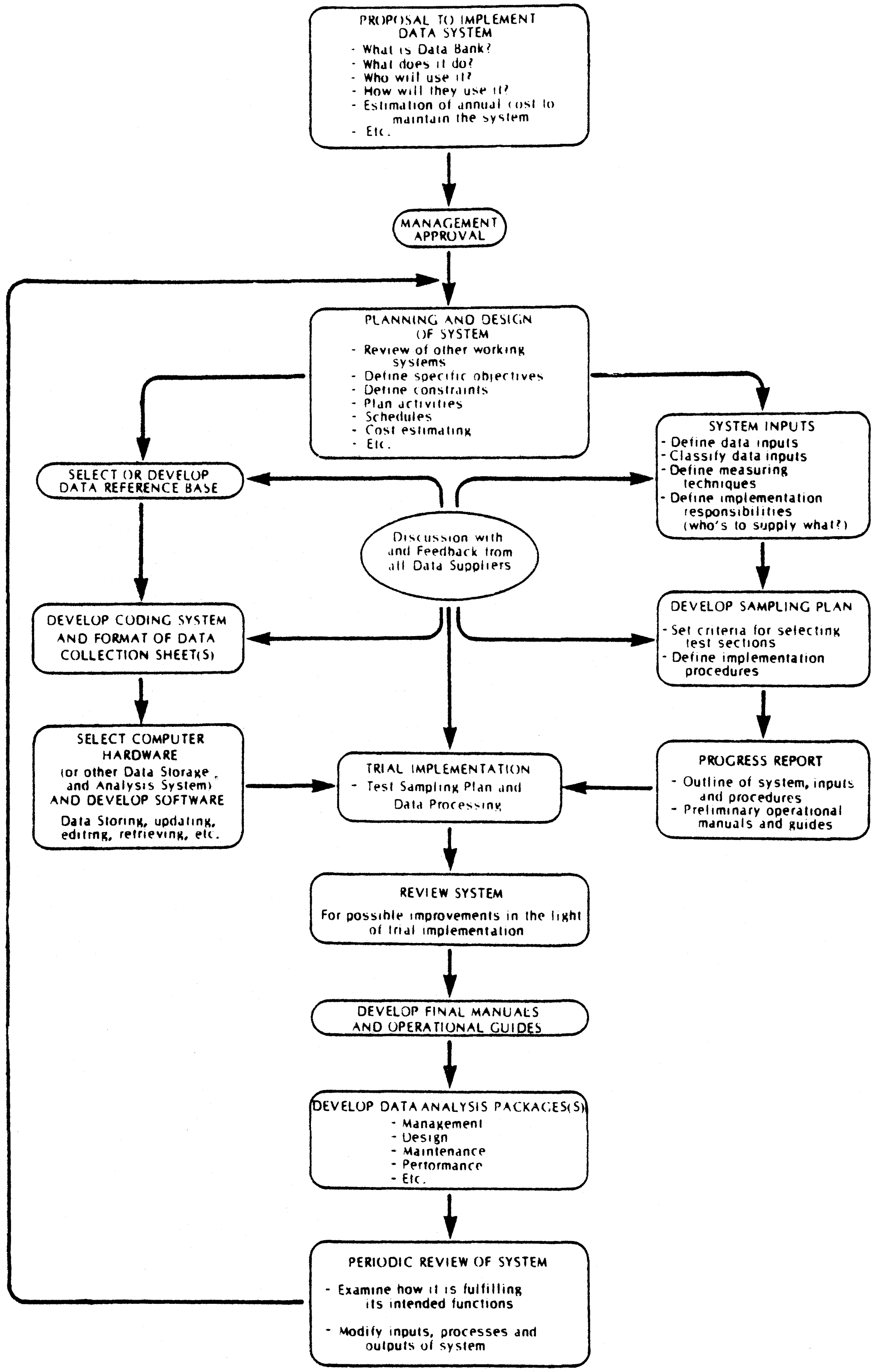

Figure 2. Basic steps in developing and implementing a pavement data system. After Haas and Hudson.[9]

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What to Measure

There are three elements of pavement condition one may wish to measure depending upon the information desired and budgetary restraints. These are pavement distress, pavement structural integrity, and pavement ride quality. Although distress and ride quality often are combined into a composite measure of serviceability, for the present discussion these elements will be considered separately.

Pavement Distress

Pavement distress may be quantified by any of a number of methods, most of which use subjective evaluation expressed in numerical terms to determine deduct points for different frequencies and severity levels of various types of distress.

The method used experimentally in Virginia for several years, and mentioned earlier, is a deduct system wherein a pavement with no distress is assigned a value of 100 points, while those programmed for resurfacing fall in the 60-to 70-point range.(8) Trials of this system in several districts have shown that different raters will rate the same pavements in similar priority rankings, but at different rating scores depending upon individual biases. The basic system requires a person to ride slowly through the roadway section under consideration and assign subjective rating scores to the whole section. Approximately 5 minutes are required to rate one-mile pavement sections. Then, a process of mental averaging of the overall pavement condition is followed. This system, with some modifications, will be useful in the pavement management process.

Structural Integrity

The structural integrity of a pavement is usually measured with one of several types of dynamic testing units. The unit used in Virginia for about 15 years is the dynaflect, a trailer-type device propelled by a van or pickup and capable of relatively rapid tests if tests are not too frequent. Speed in the testing mode is 3 to 4 mph, with about one-minute stops at each test site. Between jobs, the device is moved at highway speeds.

Structural testing is most helpful in instances where there is little knowledge of a pavement's true cross section or where a pavement is not performing as expected. In those instances, the data developed can be very helpful in projecting the load-carrying capability of the pavement or in identifying reasons for subpar performance and determining optimum maintenance strategies.

Most agencies do not maintain pavement structural inventories because of the relatively high costs (primarily for traffic control) involved. It is also for this reason that a statewide structural inventory is not recommended at this time for Virginia. If the data bank on pavement cross sections yields insufficient information on pavement structures, a full testing program might be advisable at a later date. Interstate pavements, because of their limited mileage, high traffic volumes, and high investment costs, may be considered for structural inventorying at an early date. Such an inventory of all interstate flexible pavements with measurements at 1/4-mile intervals would require approximately one year with personnel, equipment, and traffic control costs amounting to approximately $50,000.

Ride Quality and Serviceability Measurements

Response-Type Road Roughness Measurement Systems — Measurements of pavement ride quality usually are made with a passenger car instrumented to measure the vehicle's response to pavement roughness rather than directly measuring the pavement profile. Many agencies have concluded that vehicle response is the critical measurement because it provides an indication of what highway users feel as they travel over pavements. With the appropriate data-processing accessories, these response-type instruments cost approximately $6,500 each. Such instruments are so dependent upon the vehicle in which they are mounted that meticulous and frequent calibration is required, if measurements are to be meaningful over long periods of time and if differences between vehicles are to be accommodated.

A recent NCHRP publication on response-type road roughness measurement (RTRRM) systems points out that the long-term costs of maintaining calibration may well balance the high initial cost of the profilometer-type instrument discussed later.[10] The same report discusses the three following points that concern RTRRM systems and bear directly on the total pavement management concept.

1. Road Condition Surveys— RTRRM systems are adequate for routine monitoring of highway networks and providing general indications of their serviceability. They give highway officials an overall picture of the condition of the road network and indicate the current demand for maintenance.

2. Maintenance Prediction and Allocation— Since the random error of an RTRRM system is related to specific features of an individual road, the system's application in monitoring the condition of an individual road cannot be established directly. Pavement management decisions that pivot on differences in serviceability of less than 0.2 PSI should be supported by two RTRRM systems or by profilometer output.

3. New Construction Acceptance— RTRRM systems have recently seen use in the rating of new pavements for the purpose of accepting or rejecting a contractor's work, including the determination of bonuses or penalties. RTRRM systems, in their present designs, are challenged beyond their capacity in such applications.

The Department now owns three RTRRM systems (Mays meters) that produce data needing manual reduction. Upgrading these devices to provide computer-accessible output would cost approximately $5,000 each for a total of $15,000. The device, with proper attention to calibration, would be capable of handling pavement management needs as indicated above. They would not, by themselves, provide data of sufficient integrity to allow comparisons of Virginia pavements with those of other states. Also, such data may not be as useful in developing justifications for federal-aid funding as would data from the more precise profilometer. For these reasons, if the decision is made to use RTRRM devices in pavement management, it would be highly desirable to calibrate those devices against a profilometer.

Direct Profile Measurement

The most popular and versatile means of direct profile measurement is provided by the surface dynamics profilometer (SDP) developed by General Motors in the early 1960's. This device incorporates means for direct measurements in each wheel path of a travel lane. Instrumentation, including an on-board computer, is fully enclosed in a van normally operated by a 2-man crew. The SDP is internally calibrated so that calibration expense is not a factor.

Among the uses of the latest version SDP are:

1. Measurements of true pavement profile,
2. calibration of RTRRM devices,
3. estimates of overlay thicknesses required to restore serviceability, and
4. acceptance testing of ride quality on pavement construction or maintenance.

While it is possible to use the SDP directly for roughness inventory purposes, most agencies do not find the relatively low travel speeds of about 20 mph practical or safe. For this reason, most inventories are done with the RTRRM devices, with the SDP being used to maintain calibrations.

Major disadvantages of the SDP are its high cost and the high quality personnel needed for its operations. The cost of the newer SDP's, with built-in computer capabilities, is approximately $250,000. A capable 2-man crew would be required for operation. However, this crew might not be used full-time for the SDP and could be available for some RTRRM testing.

While an effective PMS can be made operational without a profilometer, the device is highly desirable because of its multiple uses and the improved reliability of data from roughness devices calibrated to it.

Sampling Plan

Because the magnitude of Virginia's highway system virtually precludes total sampling of all pavements, a statistically valid sampling plan is necessary. Such a plan must provide information permitting valid conclusions concerning the condition of total highway networks (interstate, primary, and secondary), yet must involve a reasonable and manageable amount of testing and evaluative field work. The plan also must provide the capability to detect changes in pavement condition with time and accumulated traffic volume.

Again, studies performed in Texas show that only a very small, properly stratified random sample of a highway network can yield the information necessary for projections of needed funding levels and consequences of reduced funding. Such samples will not, however, permit the prioritizing of individual projects.

While final definitions of an appropriate sampling plan would require additional study, the following paragraphs summarize some of the author's thoughts concerning the three highway networks in Virginia.

Interstate System

The interstate system comprises some 1,100 miles of well-defined roadway identified by a physical milepost system permitting easy location of roadway features and construction limits. There is also a good data bank of construction and maintenance costs as well as limited performance data for this system. With this background material, and in view of the high investment costs, the interstate system lends itself well to full sampling. Thus, a pilot study encompassing a trial pavement management system could be undertaken on the full interstate system. Full sampling of this system would permit project as well as network analysis of the data.

Primary System

The primary system consists of approximately 8,000 roadway miles, approximately 1,750 miles of which are divided roads. Since most of the divided portions were built first as two-lane roads, the effective mileage, in terms of variations in pavement characteristics, is closer to 10,000 miles. The primary system does not have physical mileposts, although nearly all roads have been referenced to a county milepost system for accounting purposes. Further, construction and maintenance costs are not generally as well defined as for the interstate system.

Although much work would be required to establish a valid sampling plan, it would appear that approximately a 10% sample of roadway in one direction would be appropriate. Then, some 1,000 miles of roadway would make up the stratified random sample. Stratification would be needed to ensure that all sampled roadways would not fall within one region of the state. For example, it may be feasible to evaluate 10 percent of the primary roads in each county or in each residency.

Finally, it should be noted that random sampling will not permit the prioritizing of individual primary roadway segments, because 90 percent would not fall within the sample. Local engineers could, however, evaluate those pavements they wish to consider at any given time.

Secondary System

While the secondary system consists of about 44,000 miles of roadway, about 14,000 miles are not hard surfaced and may not be appropriate for consideration. Most of the comments relative to the primary system apply to the secondary as well. Approximately a 3 percent stratified sample of roadway miles would provide about 900 miles of paved roadway and appears to be a manageable sample.

A SCENARIO OF INTERSTATE PAVEMENT MANAGEMENT FOR VIRGINIA

It is anticipated that an implemented first generation pavement management process would function somewhat within the framework outlined below for the interstate highway system. Similar approaches could be applied to the primary and secondary systems.

1. An MR-time curve for the interstate system would be defined through evaluation of all interstate flexible pavements. This evaluation would consist of the development of the MR's for each project through condition ratings and ride tests. All projects would then be grouped by accumulated traffic or time, and a point would be plotted for each age or traffic group. It should be noted that new pavements or newly resurfaced pavements will have an MR of 100 if they are not too rough.

2. The level of maintenance funding would be studied and any decline in pavement rating would be related to the level of funding.

3. Project the funding needed to (a) maintain the system at its current level for the next two bienniums, or (b) improve the rating by some selected percentage over the next two bienniums.

4. Project the consequences of reductions in funding levels.

5. Furnish the information developed to the district engineers so that if they choose, they can establish priorities for major maintenance of pavements under their jurisdictions.

A rough approximation of the pavement condition-time relationship mentioned in step 1 above can be derived from data collected during an extensive survey of interstate pavements in 1975.[11] The average DMR (a maintenance rating based only on observed pavement distress) for interstate flexible pavements in 1975 is plotted in Figure 3 as a function of average pavement age. Only those pavements which had not been resurfaced as of June 30, 1975, are included. It may be noted that the decline in maintenance rating is a straight-line function of pavement age such that the average rating declines by 1.55 units per year. If one wishes to use this information for pavement management purposes, it can be determined that to maintain the average rating at 90 it is necessary to resurface interstate pavements once each 6.5 years. On a continuing basis, this means that 16.7 percent of interstate flexible pavements should be resurfaced each year to maintain an average rating of 90 under 1975 conditions. Clearly, this example may not be applicable under present conditions of increased traffic loading, additional aging of the interstate system, and resurfacings applied since 1975.

Finally, it should be noted that over a period of several ratings, possibly every other year, much better data will be available to document long-range projections of pavement condition and needed funding levels.

COSTS OF PAVEMENT MANAGEMENT

Effective pavement management is not an expensive undertaking in terms of total highway expenditures. In fact, some agencies have found that benefits of their PMS more than offset the costs of operating the management system.[3] Per mile costs of pavement management vary from state to state within a wide range of from \$4 to \$50, depending upon the mileage sampled and the type of tests and evaluations performed. Unpublished data from an NCHRP project show a per mile cost of \$4 per year in California for 47,000 lane miles of pavement sampled every other year. Studies consist of condition surveys and roughness tests. Arizona, on the other hand, shows an annual cost of \$50 per mile for 6,200 miles sampled annually for roughness and condition and every 30 months for deflection.

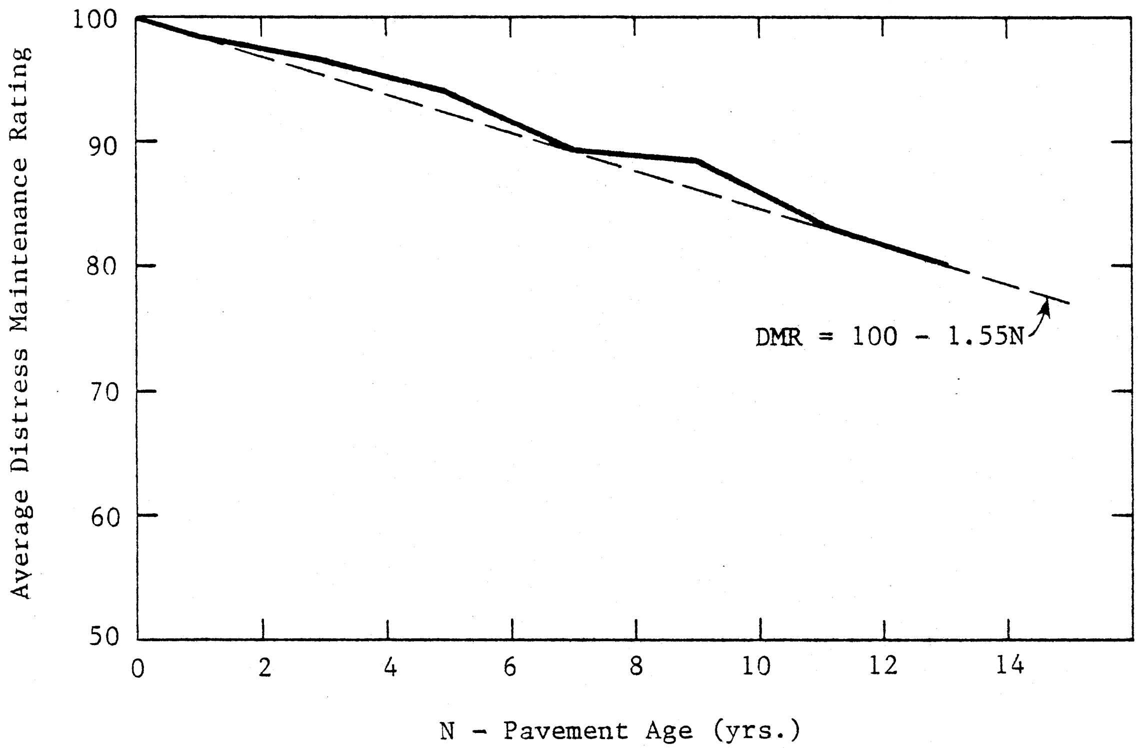

Figure 3. DMR vs. surface age. Projects not overlayed prior to 1975 interstate system.

For six agencies surveyed by the NCHRP, the average annual costs are around $20 per mile sampled for condition and ride quality. The costs for developing a management system average around $25 per mile sampled. A very approximate summary of projected PMS costs for Virginia is given in Table 1.

Table 1

Projected Costs of
Pavement Management for Virginia

	Cost Per Year for		
Cost Type	1981-82	1982-83	1983-84
Development	$ 50,000	$ 50,000	
Operations	75,000	100,000	$90,000
	$125,000	$150,000	$90,000

Note in Table 1 that substantial development costs are included for the first two fiscal years. It is anticipated that much of these costs can be incorporated in several HPR projects. Beginning in the third fiscal year, most development should be completed and the annual costs cover system operation and equipment amortization at a continuing annual cost of about $90,000 per year.

It should be noted in considering these cost estimates that they are very low for a highway system as large as Virginia's. Contributing to these lower costs is the random-sampling approach proposed for the primary and secondary networks. Virginia, which has been a leader for many years in applying statistical concepts to highway activities, would be one of the few states following this approach.

RECOMMENDATIONS

Consideration of the literature relative to pavement management practices, and of the present status of formal pavement management in Virginia, has led to the following recommendations.

1. The Department should proceed at the earliest date to upgrade its present pavement management practices through the development and implementation of a more objective and systematic approach to such management than is presently employed.

2. As a first step, an immediate evaluation of all interstate pavements through condition ratings, roughness tests, and deflection tests is recommended. This recommendation is made in the belief that the interstate system, where a good computer system of pavement elements and a good cataloging of maintenance expenditures are available, will provide data for an excellent pilot management system. It should be pointed out that condition evaluations may be made by construction or other personnel who may be experiencing temporary periods where the work load is lighter than normal.

3. A study of existing computer systems relative to their use for pavement management activities should be undertaken to ascertain the functional capabilities of those systems and to identify needed additions and revisions to them.

4. A mechanism for the development and implementation of a pavement management system should be provided through the establishment of a steering committee composed of high-level representatives of those divisions providing input to the system or expecting to make periodic use of its output.

5. Consideration should be given to the purchase of a surface dynamics profilometer for use both as a pavement management tool and a tool for the acceptance of the ride quality of newly constructed pavements.

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REFERENCES

1. Morgan, R., "Remarks by R. Morgan, FHWA - Pavement Management Conference", Charlotte, N. C., September 1980.

2. Report of Group A.5, "Feedback Information - Improving the Pavement Management Process", Pavement Management Workshop, Charlotte, N. C., September 1980.

3. Utah Department of Transportation, "Good Roads Cost Less", October 1977.

4. Cecchini, P. F., "Evaluating and Resurfacing Old Pavements in Virginia", Highway Research Record No. 327, Highway Research Board, 1970.

5. R. J. Hansen Associates, Inc., "Virginia Highway and Transportation Management", September 1980.

6. Mahoney, J. P., "Measuring Pavement Performance by Using Statistical Sampling Techniques", Transportation Research Record No. 715, Transportation Research Board, 1979.

7. The AASHO Road Test, Report 7, Summary Report, Highway Research Board, 1962.

8. Vaswani, N. K., "Overlay Design Method Based on Visual Pavement Distress", VHTRC 78-R26, Virginia Highway and Transportation Research Council, 1978.

9. Haas, Ralph and W. Ronald Hudson, Pavement Management Systems, McGraw-Hill Book Company, 1978.

10. National Cooperative Research Program, Report No. 228, Calibration of Response-Type Road Roughness Measuring Systems, Transportation Research Board, December 1980.

11. McGhee, K. H., "A Review of Pavement Performance on Virginia's Interstate System", VHTRC 77-R24, Virginia Highway and Transportation Research Council, 1976.