DEVELOPMENT OF A PAVEMENT MANAGEMENT SYSTEM FOR VIRGINIA

Final Report on Phase I

Application and Verification of a Pilot Pavement Condition Inventory for Virginia Interstate Flexible Pavements

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

Recent trends in highway funding and increased emphasis on maintenance brought about by aging highway systems have demonstrated the need for improvements in pavement management. The study reported here addresses some of the earlier phases in the development of a pavement management system for the state of Virginia. Among the issues discussed are the development of an adequate data base and the implementation of a condition rating system. While the system envisioned is applicable to all Virginia pavements, such application on only the interstate system is discussed.

Among the major findings are the following:

1. The condition inventory method used differentiates among candidate projects for the establishment of maintenance replacement priorities.

2. A 5% random sample of pavements is adequate for condition monitoring purposes.

3. A significant portion of the interstate system is below par in structural capability as a result of inordinate increases in truck traffic and axle loads and age.

4. Continued increases in traffic and axle loads will significantly reduce the service life of traditional overlays.

5. The condition rating system will provide management with an objective approach to pavement management, including documentation of the funding required for maintenance replacement.

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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 (FHWA), are directing efforts toward the development and implementation of pavement management systems (PMSs). While such systems may be as complex or as simple 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 this overall objective, at least several specific benefits of a PMS to highway administrators were identified at a 1980 workshop sponsored by the FHWA.(2) Among these benefits 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.

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, a study of the Department by R. J. Hansen Associates, Inc. recommended the adoption of formal pavement management processes.(5)

The rationale of establishing a useful and practical PMS in Virginia was addressed in a 1981 report by the author.(6)

As pointed out in the earlier report, 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 these subunits of a management system have been developed and, to some degree, are functional, while others are in early stages of development. Additionally, it is expected that some others, not listed above, will 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 consequences 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% of the total centerline mileage.(7)

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, both a network approach, utilizing a random sampling process, and a project approach, utilizing full sampling of the system, are combined.

APPROACH

Background

The AASHO road test conducted in the late 1950s provided the foundation for effective long-range planning of pavement expenditures.(8) 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.

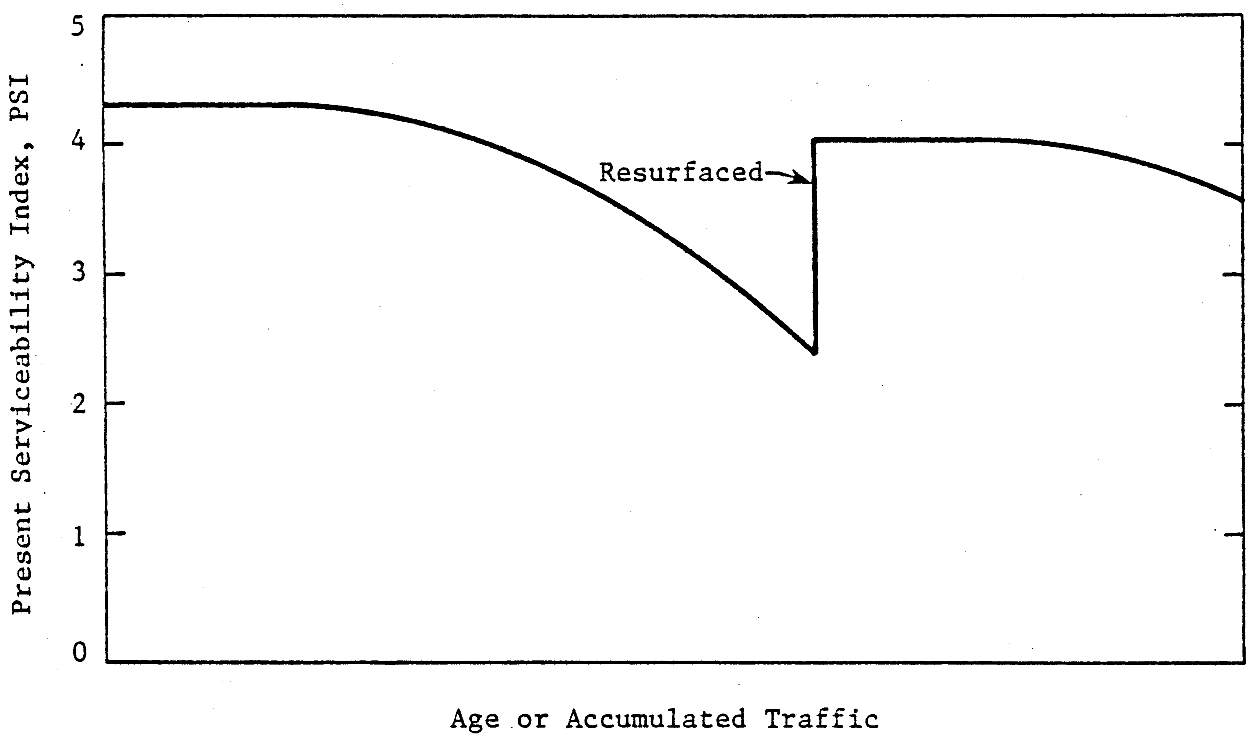


Figure 1. Typical pavement performance curve.

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 that 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), has been described in an earlier report(9) and forms the basis for the present study.

In mid 1981 the Department's management made a commitment to proceed with the development of a data base for pavement management on the interstate system. This commitment included condition ratings, roughness tests, and dynaflect deflections on all interstate flexible pavements. The deflection work is intended to identify any section of roadway requiring special attention because of a failure of the base or other materials.

Development of the data base was undertaken upon recommendation of a pavement management steering committee appointed by State Maintenance Engineer C. O. Leigh. The committee recommended a one-time inventory of pavement deflections and biennial condition surveys and roughness tests on interstate pavements.(10)

Distress Ratings

In preparation for distress ratings of the interstate system, each of the eight district engineers was requested to appoint a three-man rating team. While there were some variations, most engineers appointed teams consisting of one person each with a background in construction, maintenance, and materials. Twenty-six members of these teams attended a 2-day training session conducted by the author in July 1981. Materials used in the training session and the attendance roster are given in Appendix A. Highlights of the training session consisted of—

1. a discussion of distress types and definitions of their severity levels and frequencies of occurrence,
2. a discussion of the pavement rating method,
3. field trials of the rating method where four pavements having a range of conditions were rated by all teams, and
4. a concluding discussion of the field trials including comparisons of ratings by the various teams on the four pavements.

Condition rating tests on the interstate pavements commenced immediately after the training session and were completed by November 1981. Ratings were conducted on each mile of pavement in each direction and were inclusive of all pavement between posted mile markers.

Concurrent with the ratings by district teams, the author rated a 5% random sample of the entire system to provide verification of the system and to assess the possibilities of utilizing small samples to predict the condition of the system.

All field data sheets were submitted to the author for screening and analysis prior to initiation of automated data processing efforts.

Roughness Inventory

All roughness tests were performed with Mays meters on the posted 1-mile increments of interstate pavement. The three meters used were calibrated to a standard course near Charlottesville and each was used to perform approximately one-third of the tests. Testing was coordinated by the Research Council and was completed concurrently with the condition ratings. Tests were conducted only on the outside or traffic lane with bridge roughness being omitted.

Roughness data were first analyzed by the Research Council then submitted to the Information Systems Division for incorporation in an inventory printout to be discussed later.

Deflection Inventory

Dynaflect deflection tests were conducted at 1/4-mile (0.4 km) intervals on the traffic lane and were reported for the same 1-mile (1.6 km) increment used for condition ratings and roughness tests.

Tests were conducted in late 1981 and early 1982. These data also were analyzed by the Research Council then forwarded to the Information Systems Division.

RESULTS OF CONDITION INVENTORIES

Detailed results of the interstate inventory are available in the form of a computer printout entitled "Virginia Department of Highways and Transportation, Pavement Management Data," similar to Appendix B. On this printout, each mile segment of interstate pavement is listed by mile marker with a full description of district, residency, county, and direction of travel. In addition, the surface mix type and the date that surface was applied are listed. Each of the above items are historical data available from files in the Department.

Other columns on the printout are inventory items as discussed later.

Distress Ratings

Condition ratings as described in Appendix A are based on a system wherein all pavements are visually examined and deduct points are subtracted from a base of 100 to arrive at a rating score called the distress maintenance rating (DMR). Clearly, a new pavement or a pavement recently resurfaced will have a DMR of 100 or very little below. The system is structured such that the minimum score attainable even on the worst road is 45.

As indicated in Appendix B most interstate pavements have DMR scores between 90 and 100, although some few scores are in the 70 to 90 range. While these data will be discussed in detail later, the verification and analysis of differences between rating teams are discussed below.

Average DMRs for each district are summarized in Table 1, where three listings are given. The first of these is the total sample (all pavements rated by the district teams), second are the average ratings by the district teams of 5% samples randomly selected by the author, and third are the author's ratings of the 5% samples. Note in this table that N_1 is the total miles of pavement rated for each district, $N_{2 \& 3}$ is the total miles contained in the random sample, DMR_1 is the distress rating for the total sample with a standard deviation of σ_1, and DMR_2 and DMR_3 are the district and research ratings for the 5% samples with sample standard deviations of S_2 and S_3, respectively. In

Northern Virginia, the absence of mile markers on I-395 caused sufficient confusion to prohibit definitions of a 5% random sample where the author could be sure he was rating the same section of roadway rated by the district team.

Table 1

Distress Maintenance Ratings
(December 1981)

District	N_1	DMR_1	σ_1	$N_{2\&3}$	DMR_2	S_2	DMR_3	S_3
Northern Va.*	65	86.0	4.0	6	-	-	87.3	6.2
Bristol	239	93.2	8.4	15	92.6	8.4	93.1	6.2
Salem	205	94.0	3.5	12	94.3	2.1	93.6	5.6
Richmond	176	96.1	3.6	6	95.8	3.3	94.0	3.2
Suffolk	44	98.7	1.7	4	98.5	2.4	93.2	3.7
Fredericksburg	67	96.2	3.1	4	94.8	2.9	92.4	7.6
Culpeper	111	97.0	2.7	7	94.4	3.6	93.6	5.8
Staunton	472	93.6	8.3	27	93.3	7.7	92.2	7.2

*Note that in Table 1 and the subsequent discussions the Northern Virginia Division is considered as a separate district.

The analysis of the data in Table 1 yielded two important findings:

1. Within a district, the 5% random sample almost precisely predicted the overall rating for the district. Only in Culpeper was the difference between the full sample and the random sample even remotely significant and, in that case, the random sample was too small to provide any degree of confidence that the differences were real. While this finding has little relevance to interstate pavement ratings (because all pavements in this system are rated), it is highly indicative that a 5% sampling and rating scheme envisioned for secondary roads will be fully capable of estimating the condition of that system. (11

2. A comparison of district and research ratings showed that Northern Virginia and the Bristol, Salem, and Staunton districts rated pavements in the same manner as the author. In those cases, there were no significant differences between the district ratings and those conducted by the author. While the Richmond, Suffolk,

Fredericksburg, and Culpeper results suggest that teams in those districts tended to rate on the high side, statistically the results were inconclusive because of large variations in the author's results and the small number of ratings comprising the 5% sample. Although this trend should be examined closer in future ratings, it will be shown later that the suggested differences do not have a significant impact on the indicated condition of the total interstate system. Small differences between teams may become important if one wishes to compare districts. For the ensuing discussion it will be assumed that all teams rate pavements on a common basis.

Roughness Inventory

The results of Mays meter roughness tests for all interstate flexible pavements are listed on the computer printout (Appendix B) in two ways. The first is roughness in inches per mile, which is designated RR_{55} and indicates roughness tests conducted at 55 mph (88 km/hr.). The second listing is a variation of the traditional AASHTO present serviceability index (PSI) utilizing a 0 to 5 scale to indicate the worst to best conditions. For purposes of this study, the index is designated serviceability rating (SR) and is calculated through a mathematical transformation of Mays meter results as described by Walker and Hudson.(12) Thus, the SR has only a roughness input while the PSI uses roughness, cracking, and patching as inputs.

The results of roughness tests are summarized by districts in Table 2, where both the average roughness and the standard deviation (σ) are given. Again, there is no intention to compare districts and, in fact, there are good reasons for what appear to be significant differences in average roughnesses between districts. For example, in Northern Virginia, Suffolk, and Fredericksburg, where average roughnesses somewhat exceeded the statewide average, there are significant mileage of old concrete pavements which have been overlaid and thus are reflected in the flexible pavement roughness values. Such pavements normally are rougher than true flexible pavements because of reflected joint problems and slab movements. Conversely, Richmond and Culpeper appear, on the average, to have somewhat smoother pavements than the statewide average. This is no doubt a reflection of the heavy use of slurry seals, which historically provide a better than average ride for reasons the author cannot explain.

Table 2

Mays Meter Roughnesses
(December 1981)

District	N	RR_{55}, in./mi.	σ
Northern Va.	62	81.6	10.1
Bristol	233	74.8	12.2
Salem	199	73.9	12.5
Richmond	175	68.6	11.3
Suffolk	36	83.6	12.4
Fredericksburg	53	88.3	22.6
Culpeper	102	69.1	12.9
Staunton	460	76.6	13.6
State	1,320	75.0*	13.0

*Weighted Average

1 in./mi. = 1.6 cm/km

It is perhaps the statewide average of 75 in./mi. (120 cm/km) that is most indicative of the ride quality of interstate pavements. This average compares very favorably with construction roughness standards used in the state, where 75 in./mi. (120 cm/km) is considered to be a good ride. On the basis of these standards only about 3% of interstate pavements fall within the "rough" category of greater than 100 in./mi. (160 cm/km). Interestingly, there is no statistically significant relationship between roughness values and DMR values.

The 5% random sampling process applied to roughness tests yielded the statewide results given in Table 3, where average roughness for both the full sample and the random sample are listed.

Table 3

Comparison of Full Interstate Flexible
and 5% Sample Roughness Values

Sample Size, mi.	RR_{55}, in./mi.	σ	Percent Exceeding 100 in./mi.
1,320	75.0	13.0	3.0
76	76.0	15.1	5.6

1 in./mi. 1.6 cm/km
1 mi. = 1.6 km

Note that again the 5% sample did an excellent job of predicting values for the entire system. There was no significant difference in average roughness values between full system testing and the random sample testing. The random sample indicated slightly more rough pavement, with 5.6% predicted to have greater than 100 in./mi. (160 cm/km) roughness as opposed to a measured 3.0%.

Deflection Inventory

Results of the deflection inventory also are listed on the computer printout such as the example in Appendix B. In that printout two parameters are given, the deflection (d_o) under a 9,000 lb. (4,090 kg) wheel load and the spreadability (s) indicative of the shape of the deflection basin as defined by Vaswani.(13)

While these results will be discussed in some detail later, it is generally true that the structural capacity of a pavement is inversely related to the deflection and directly related to the spreadability.

USES OF INVENTORY DATA

Once condition inventory and descriptive data are in automated files, there will be virtually unlimited uses for the information. In the following section, the author has attempted to describe some of those uses as they would be applicable to pavement management and the scheduling of maintenance replacement activities.

Distress Ratings

Prioritization

Clearly, a major use of pavement condition inventory data is the establishment of priorities for action. Thus, field engineers with distress rating results on hand would give those highway segments in the worst condition a high priority. Generally, however, to provide the best use of funds, it is necessary to establish an action level above which pavements normally would be permitted to serve without major maintenance effort (such as resurfacing).

In an effort to arrive at a realistic action level for distress rating, the author analyzed all 1,379 DMR ratings for interstate flexible pavements and determined that approximately 10% fell below a rating of 85. A rating of 85, then, was selected as the hypothetical action level for the first round of maintenance replacement efforts on interstate system flexible pavements. Such a level, based on a 10 percentile rating, is consistent with historical objectives (not normally met) of the Department to provide resurfacings on 10% of the system each year. While the 10 percentile level is chosen for this first effort, there is no reason to assume that resurfacing 10% of the system each year is optimum pavement management. As will be shown later, some pavements will require action in a shorter time while others will last longer. In fact, an earlier study of Virginia interstate pavements showed that historically resurfacings have been applied on an average of 8 1/2 years.(14)

In developing the computer package for the inventory, Information Systems personnel provided for a deficiency indication on all pavement sections having a DMR of less than 85. Thus, the printout clearly indicates those pavements considered to be deficient in 1981. An examination of that printout shows that the deficient mileage ranges from none in several districts to 71 miles (114 km) in the Staunton District. It further shows that statewide many miles were of borderline acceptance (DMR of 85 to 90) in late 1981. Doubtlessly, many of these would be classified as deficient by the time resurfacing work could be scheduled.

Mileages actually scheduled for resurfacing during late 1981 and 1982 are summarized in Table 4 by district. For comparison purposes, the average 1981 DMR and the mileages of pavement considered deficient also are listed for each district. It should be kept in mind that in developing the 1981-82 resurfacing schedules, operations personnel did not necessarily use the inventory data although they were available to them in raw form.

Nevertheless, the work done was reasonably consistent with the needs indicated by the assumed 85 DMR. All districts scheduling resurfacings programmed a preponderance of those pavements rating on the low side of the average DMR for the district.

Table 4

1981 DMR Values and
1981-82 Resurface Mileages

District	Average 1981 DMR	Deficient Miles	1981-82 Resurface Miles	Average DMR
Northern Va.	86	30	5.8	77
Bristol	93	40	58.8	84
Salem	94	1	20.9	91
Richmond	96	0.	40.2	93
Suffolk	99	0	0	N/A
Fredericksburg	96	0	0	N/A
Culpeper	97	0	0	N/A
Staunton	94	71	66.7	80

1 mi. = 1.6 km

System Evaluation

A second use of condition inventory data is to evaluate the interstate highway system as a whole. For example, it can easily be shown that the 1981 DMR values for the entire interstate system averaged 94.1 and that 10.3% of those values, representing some 142 direction miles (227 km) of pavement, were below 85. If one assumes that 10% of pavements rating below 85 is an acceptable level of interstate system maintenance, then future ratings will permit an assessment of how well that level is being maintained in the face of continuing pavement deterioration as partially offset by an ongoing resurfacing program.

Clearly, if the next rating, scheduled for 1983-84, shows the overall pavement condition to be declining, one could argue that the resurfacing effort needs to be strengthened. Conversely, an improvement in the overall condition could suggest that resurfacing monies might be better spent elsewhere. Either happening might also suggest that the desired level of maintenance needs to be redefined. Determination of the optimum, or most cost-effective, level of maintenance may require several series of ratings coupled with the evaluation of pavement performance trends and rehabilitation strategies and their costs over the time of those ratings.

Projection of Future Needs

It is probably in the projection of future resurfacing needs that the pavement condition inventory data are of most potential value. Such projections may be essential for the documentation of funding requests, in response to legislative inquiries, or in the assignment of road user costs.

Methodology

The projection of future pavement condition requires the definition of condition versus time or traffic curves, commonly known as performance curves as discussed earlier and shown in Figure 2. In analyzing the road test results the AASHO assumed that pavement deterioration is generally related to traffic through an equation of the form

$$g = A\ ESAL^{B}, \quad (1)$$

where g is a distress function denoting loss in serviceability, as indicated in Figure 3, ESAL is the cumulative 18,000 lb. (8,170 kg) axle loading to produce g, and A and B are load and design variables for a particular pavement.(15) Expressed in logarithmic form, equation (1) is rewritten as

$$\log g = \log A + B \log ESAL. \quad (2)$$

Equation (2) is a straight line function with the intercept log A and slope B as indicated in Figure 3. Conceptually, point "C", the intercept with the log ESAL scale, is the point at which distress is initiated.

Since the ESALs sustained by a pavement can be estimated,(16) the definition of equation (2) requires the determination of slope B and either A or C. Theoretically, there are at least two methods of accomplishing this task for a given pavement.

1. One can mechanistically estimate C from load information and assumed fatigue properties of the paving materials, then use a single condition rating to determine the slope. This method is considered to be highly unreliable because of known large variations in properties of materials.

2. One can use two or more condition ratings and define the curve between points. Inconsistencies between ratings make this method less than perfect, and Washington State recently reported the normal use of at least three ratings to define performance curves.(17) The use of this second method in Virginia will necessarily be delayed until at least one more rating of the interstate system is conducted.

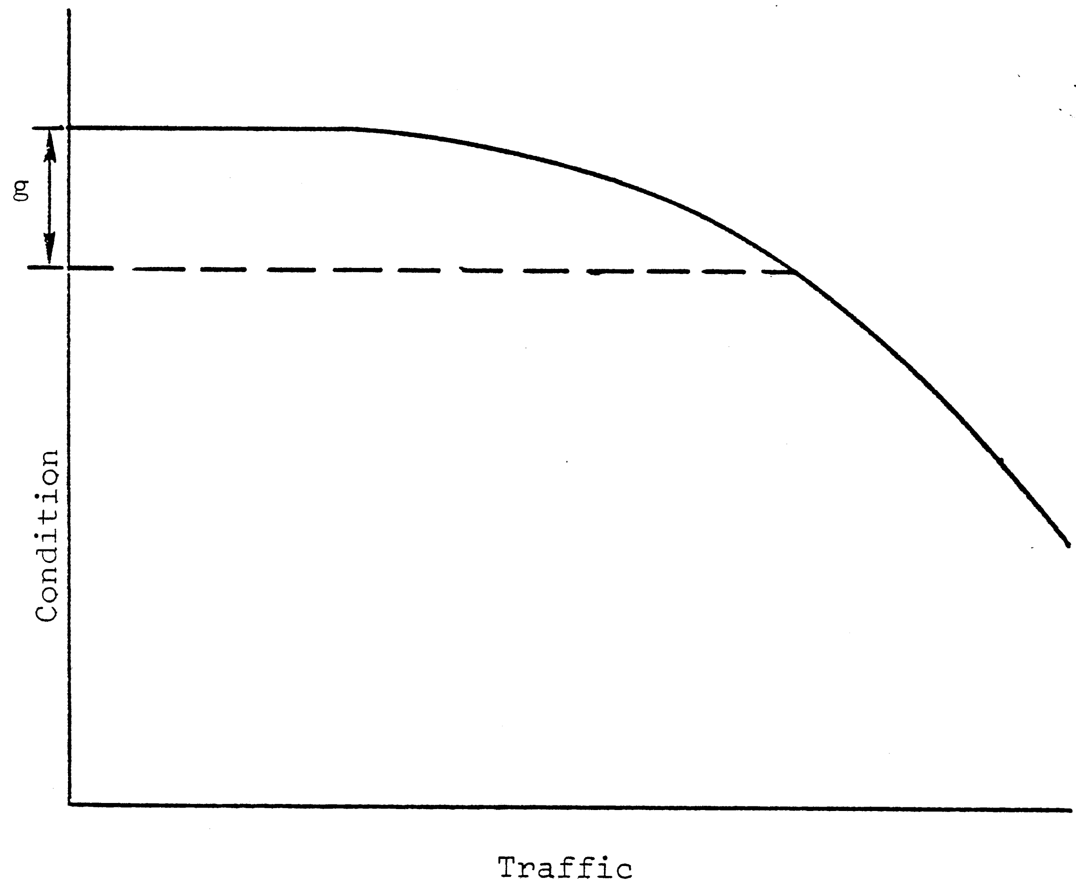


Figure 2. Typical pavement performance curve.

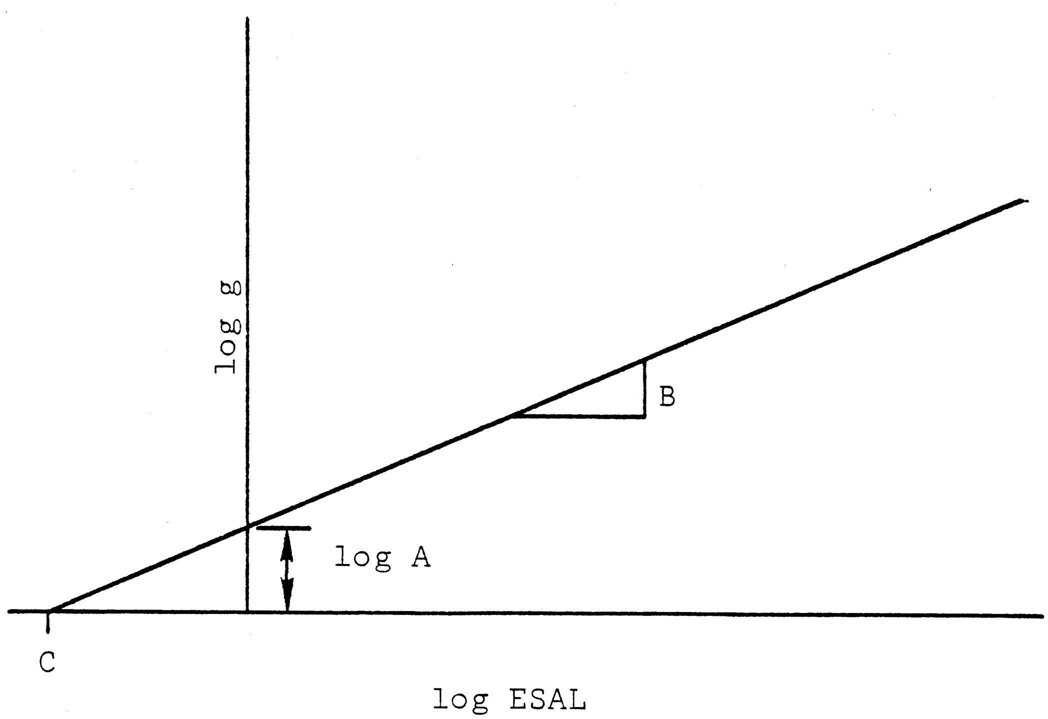


Figure 3. Distress function vs. traffic.

In lieu of waiting for a second round of pavement ratings to begin development of performance curves, a statistical approach utilizing a large number of similar pavements of various ages and traffic exposures has been adopted as an interim method. The pavements chosen comprise 294 miles (470 km) of the northbound lane of Interstate 81, all of which are very similar in design and life in similar environmentals and soil types. Data for these pavements are summarized in Table 5, where the pavements are grouped by the December 1981 average ages, average DMRs, and average cumulative ESALs.

A statistical analysis of the Table 5 DMR and ESAL data in logarithmic form resulted in the equation

$$g = 1.25\ ESAL^{1.68}, \qquad (3)$$

i.e., A = 1.25 and B = 1.68.

Table 5

Summary

NBL I-81 Grouped by Age
(December 1981)

Age, yr.	No. Miles	Avg. DMR	Avg. Cumulative ESAL, millions
0.5	22	100.0	0.08
1.5	25	98.6	0.70
2.5	42	98.7	0.94
3.5	13	97.2	1.44
4.5	80	93.8	2.00
5.5	28	92.2	2.51
6.5	6	89.3	2.68
7.5	14	93.5	3.21
8.5	2	87.0	3.54
9.5	12	85.4	4.13
10.5	16	91.6	4.15
11.5	3	86.3	4.99
12.5	-	-	-
13.5	10	73.4	4.79
14.5	-	-	-
15.5	21	83.6	4.51

$$DMR = 100 - 1.25\ ESAL^{1.68}$$

$$r^2 = 0.937$$

$$SE = 1.6$$

1 mi. = 1.6 km

When written in the form relating to Virginia distress ratings equation (3) becomes

$$DMR = 100 - 1.25\ ESAL^{1.68}. \quad (4)$$

The I-81 DMR data and equation (4) are shown graphically in Figure 4, where it is evident that the equation is a reasonable prediction of DMR with ESAL. The figure shows, for example, that the threshold DMR of 85, discussed earlier, will be reached by I-81 pavements at an average cumulative 18,000 lb. (8,170 kg) equivalent axle loading (ESAL) of 4.2 million. Further, one can be highly confident that at 4.2 million ESALs an I-81 pavement will have a DMR of between 82 and 88, 85 $\pm$ 2 SE.

The prediction of when a pavement can be expected to reach a terminal DMR value is possible when equation (2) is modified using a DMR of 85 as the terminal value and assuming a 5% compounded annual increase in daily ESALs. The resulting equation is

$$n = 47 \log \left[1 + \frac{138 \left(\frac{15}{A}\right)^{1/B}}{N_{18}}\right] \quad (5)$$

where n is the number of years required for the DMR to fall from 100 to 85, N_{18} is the daily ESAL for the pavement surface when it is new, and A and B are as defined earlier.

A similar equation for the I-81 pavements, then is

$$n = 47 \log \left(1 + \frac{606}{N_{18}}\right). \quad (6)$$

If the results of equation (6) are plotted graphically as in Figure 5, some alarming conclusions could be drawn. For example, the graph shows that in 1975 I-81 sustained an average of approximately 1,000 daily ESALs and that pavements had an average life expectancy of about 9.5 years. By 1981, the average daily ESALs had reached about 1,200 and the pavement life expectancy had fallen to about 8 years. The graph further shows that by about 1987, if present trends in traffic and present resurfacing technologies continue, the I-81 pavements will average some 1,700 daily ESALs and have a life expectancy of only about 6 years. Clearly, if the projections are anywhere near accurate, some fundmental changes in maintenance replacement funding or in resurfacing strategies will be necessary.

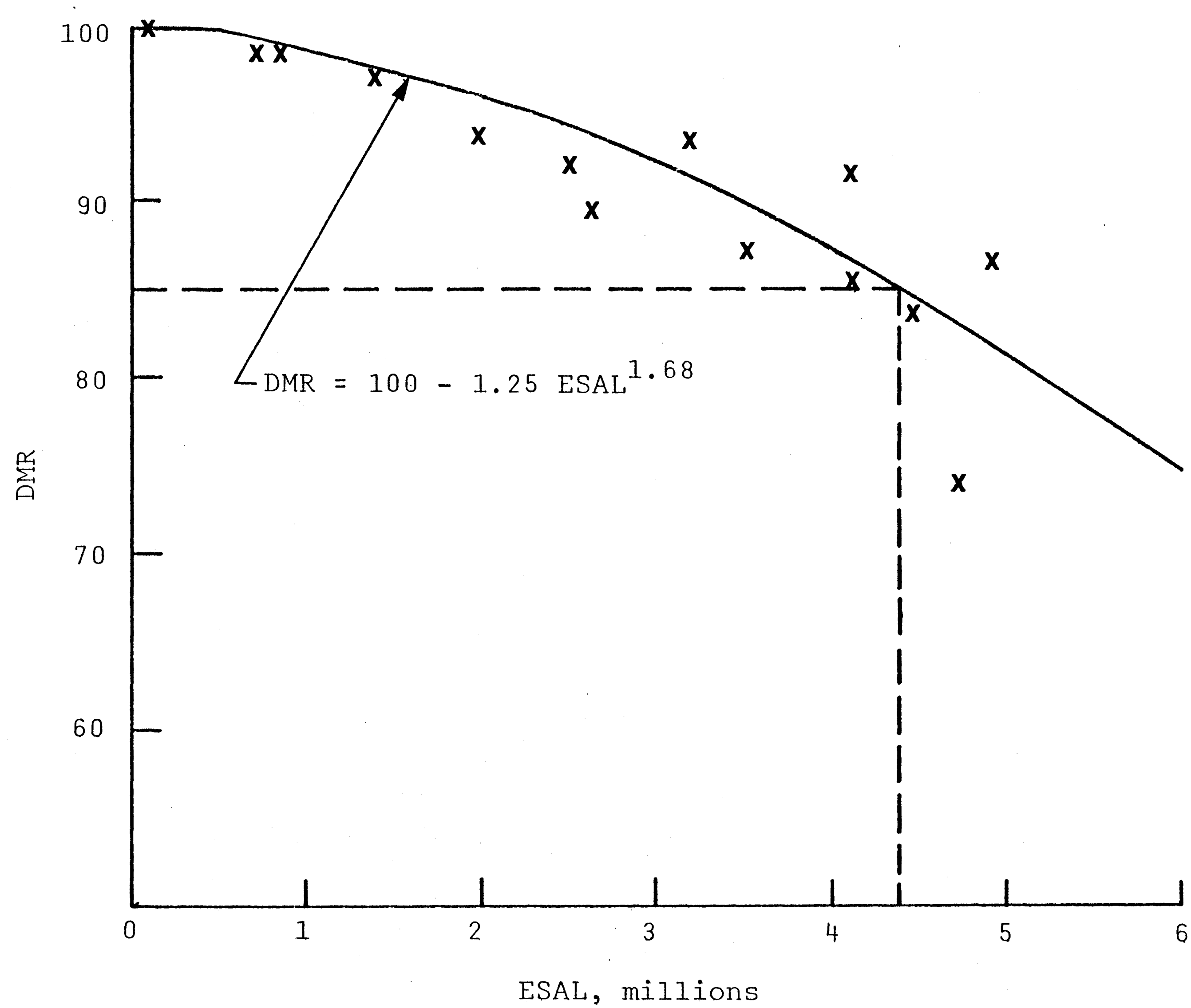


Figure 4. DMR vs. ESAL NBL I-81, 1981.

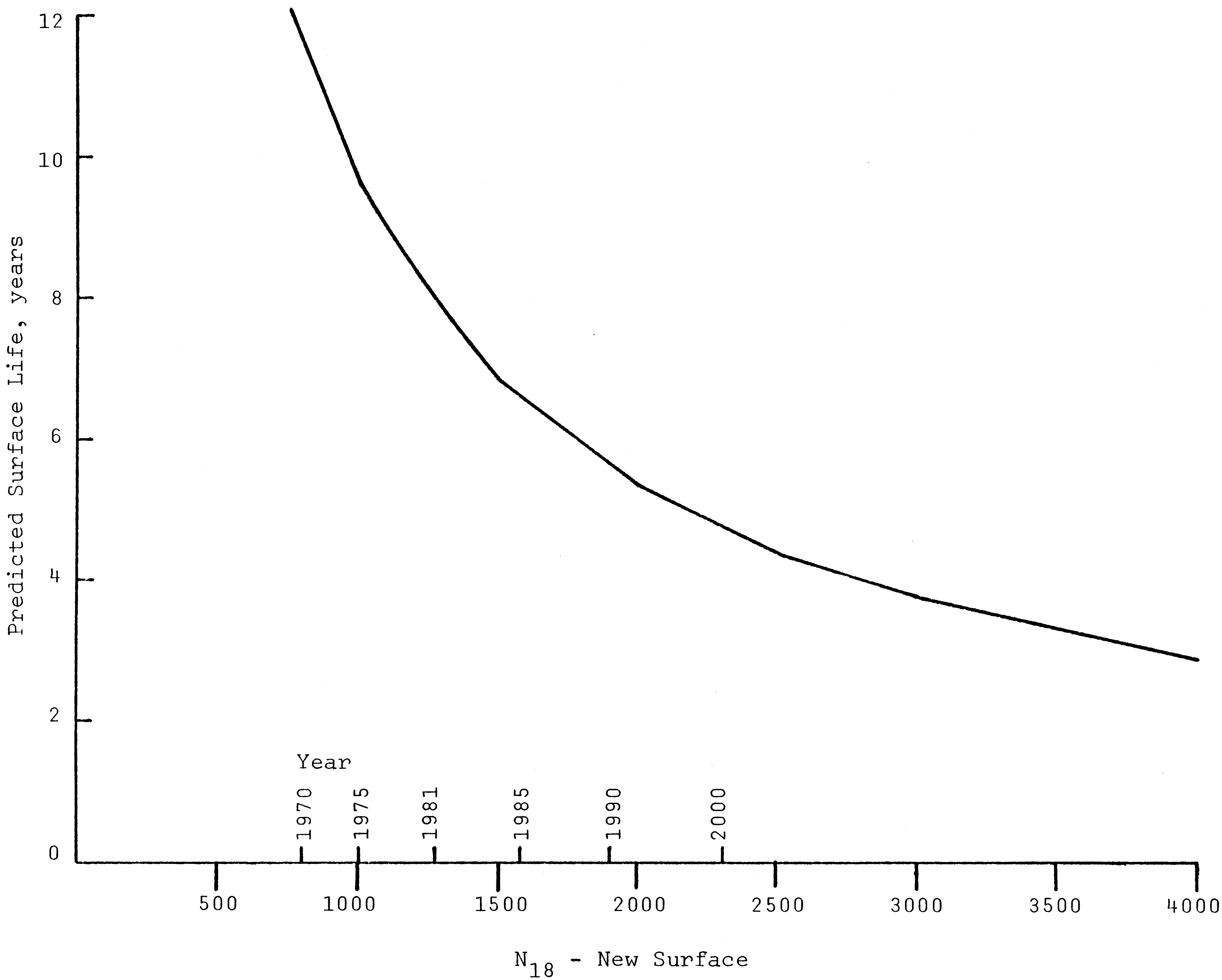


Figure 5. Predicted overlay life vs. daily ESAL NBL I-81.

A variation of equation (5) has been used to develop an algorithm used in the interstate pavement management computer package to develop projections for the whole system as listed on the printout in Appendix B. A summary of the projections given in the printout dated March 1, 1983, is given in Table 6.

Table 6

Projected Interstate Resurfacing Needs
1983 - 1990

Year	Projected Direction Miles
1983	185
1984	401
1985	361
1986	140
1987	355
1988	201
1989	73
1990	53

1 mi. = 1.6 km

Note that the projections do not indicate an even outlay of funds with time. Largely because of variations in project age, previous maintenance replacements, and traffic volumes, there are certain years in which inordinately heavy maintenance replacement efforts will be required. These projections show a distinct departure from the 10% annual historical objective for resurfacings, which would provide some 140 miles (224 km) of interstate resurfacing per year.

Limitations

With the above discussion of resurfacing projections in mind, it is worthwhile to note some of the limitations of the projection method. The limitations generally will exist until additional data are collected.

1. The projection equation used is strictly applicable to only I-81 pavements. Other interstate pavements have not been analyzed in depth, but due to variations in the properties of materials and the position of the materials in the pavement, they no doubt will have different deterioration curves. To avoid over projections due to these unknowns and to the presence of low traffic volumes, the computer package does not project more than 8 years into the future.

2. It is almost certain, but not quantifiable at this time, that for low levels of ESALs, weathering is the dominant destructive factor. Thus, a pavement subject to a low daily ESAL may last a significantly shorter time than the general projection equation would predict. Again, the 8-year limitation is applied as an interim measure.

3. The estimation of ESAL values from vehicle classification is based on historical data of average vehicle weights and must be updated periodically as vehicle weights increase.

4. The annual growth rate in the volume of commercial traffic is an estimate based on historical data. The growth rate between 1969 and 1979 was 5.4% compounded annually. Between 1971 and 1981 there were years where a decline in commercial traffic was reported. The annual compound growth rate for that 10-year period was 4.7%. The 5% rate chosen for the projection equation appeared to be a suitable compromise and is widely used in the highway industry. In practice, it may be advisable to adjust the rate each year based on experience over the prior 10 years.

Roughness Inventory

As discussed earlier, the ride quality of Virginia interstate pavements generally is quite good as compared to construction standards used by the state. For this reason, roughness would not be particularly useful in prioritizing projects except in the extreme cases of Mays meter results greater than, say, 100 in./mi. (160 cm/km). For such cases, it is suggested that the computer printout indicate that the pavement is considered deficient in ride quality.

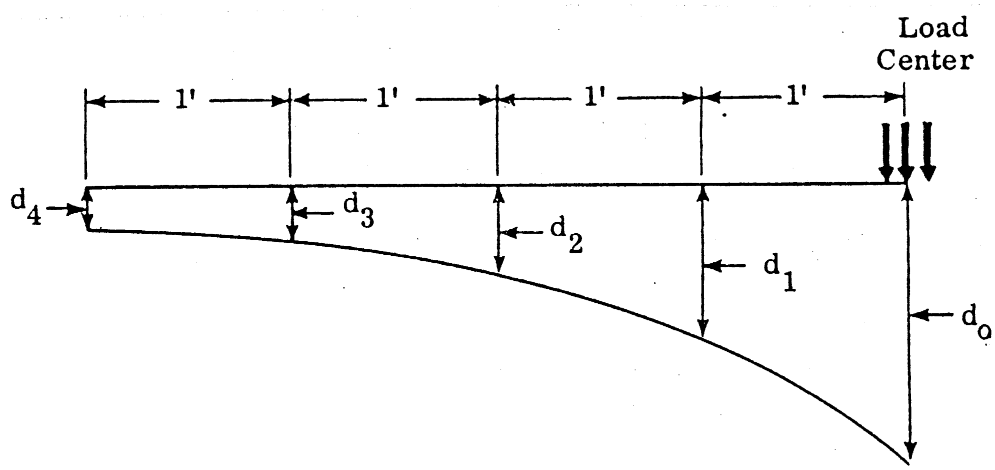
Probably due to variations in "as constructed" roughness, the author could identify no statistically significant relationship between roughness and either ESALs or age. Therefore, at least one more series of roughness tests will be necessary for the detection of any trends. This second series would make it possible to look at the response of the system and individual pavements to additional time and traffic. It may then be desirable to use roughness values more directly in the analysis of the system or in the projection of long-range needs.

As an additional comment on pavement ride quality, it should be pointed out that the Department's experience shows that the primary highway system is not nearly as uniform as the interstate. Thus, it is anticipated that roughness tests would be of more value to pavement management on primary highways than on the interstate.

Deflection Inventory

Analysis Procedure

Deflections measure the response of a pavement to vehicular axle loads and thus provide an indication of pavement strength. Pavement deflections provide the basis for Virginia flexible pavement design and rehabilitation design methodologies.[9,18] Therefore, methods have been developed to assess the structural capacity of in-service pavements through the analysis of deflection test results. Analysis methods make use of the deflection data indicated in Figure 6, where both the deflection at the point of loading and the pavement response at points 1, 2, 3, and 4 ft. (0.3, 0.6, 0.9, and 1.2 m) from the load are measured with the dynaflect. In the analysis, pavement stiffness, or spreadability, (S) is the ratio of the average deflection to the deflection at the wheel load. Vaswani showed that the thickness index (D) of a pavement could be estimated from the maximum deflection (d_o) and the spreadability through a graphical method.[13]



$$\text{Spreadability} = \frac{d_o + d_1 + d_2 + d_3 + d_4}{5\ d_o} \times 100$$

Figure 6. Dynaflect deflection basin.

As an extension of the Vaswani approach, the author, during the course of the present study, has developed a numerical method as indicated in equation (7).

$$D = (5.73 - 0.25\ S) \log d_o - 0.17\ S + 3.0. \qquad (7)$$

Equation (7) has statistical parameters D > 3.0, a coefficient of determination of 0.975, and standard error of estimate of 0.62 as determined from 30 randomly selected pavement analyses.

Once the in situ pavement strength (D) has been determined as given in equation (7), other methods provide a measure of estimating any required strengthening of the pavement to accommodate prevailing traffic.[9] The equation giving the necessary increase in thickness index to enable a pavement to perform satisfactorily for about 8 years is

$$T = 2 \log ESAL + 4.5 - D, \qquad (8)$$

where T is the required increase in thickness index, ESAL is the prevailing daily 18-kip (8,170 kg) equivalent axle loads on the pavement, and D is the in situ thickness index. In keeping with the Virginia pavement design methodology, T may be made up entirely of asphaltic concrete or of other materials used in such a manner as to yield an equivalent structural strength.

Results

Equations (7) and (8) have been applied to the 5% random interstate sample as given in columns 14 and 15 of Appendix B. Note that many interstate pavements would require substantial strengthening to accommodate present traffic. This is particularly true on I-81 where most pavements already have exceeded their 20-year design life and are carrying several times the original design traffic. On mile 200-201, for example, the in situ thickness index is 5.0 and an increase in thickness index of 5.9 units is indicated.

A distribution of suggested next overlay thicknesses for the major interstate routes, based on the 5% random sample, is given in Table 7.

Table 7

Distribution of Required Overlay Thickness Based on 5% Interstate Sample

Route	Percentage Needing Thickness Given: Less Than 0.75 in.	More Than 1.5 in.	More Than 3.0 in.
64	53	22	1
66	34	41	6
77	66	9	0
81	13	77	48
85	100	0	0
95	15	76	45
All	27	59	29

1 in. = 1.6 cm

Note that, according to the above analysis, approximately 27% of interstate pavements are structurally capable of sustaining the prevailing traffic for the next 8 years with an overlay less than 0.75 in. (1.9 cm) thick. In these cases an open-graded mix (S-8) may be indicated. Some 59% of interstate pavements need overlays in excess of 1.5 in. (3.8 cm), while 29% need more than 3 in. (7.5 cm). As the table shows, the preponderance of heavy overlays are needed in the heavy traffic corridors of I-81 and I-95, where nearly one-half of the pavements have indicated needed overlay thicknesses of greater than 3.0 in. (7.5 cm).

Deflection data for all interstate flexible pavements are in the interstate pavement management automated data file. However, the analyses discussed above have not been applied to that file to permit ready access to overlay needs data for each segment of interstate pavement. It is recommended that such an analysis be performed and the results provided as part of future printouts of the file.

Limitation

The analysis discussed above is based largely on emperical relationships and may be subject to considerable error relating to changes in subgrade moisture content, pavement temperature variations, and inaccuracies in the estimation of 18-kip (8,170 kg) axle loadings. It does, however, represent the state of the art in rehabilitation analysis with deflection data and should provide useful guidelines for both field and central office engineers.

Clearly, the engineer may make any of several decisions based on such an analysis. For examples he may —

1. do nothing and let further deterioration occur,
2. provide the indicated overlay,
3. provide the overlay he can afford, or
4. reconstruct or rehabilitate the pavement.

Any or all options may be dictated by the availability of funds and by geometrics or other requirements.

IMPLEMENTATION OF THE SYSTEM

Efforts to implement the condition inventory system have been pursued through the Maintenance and the Information Systems divisions concurrent with the development of the system. The effort is primarily under the direction of the pavement management steering committee, which establishes recommended actions and procedures.

Data Handling

Among the major obstacles to ready implementation have been the difficulty in integrating various automated data files and the relatively low priority given pavement management data handling early in the program.

The interstate pavement management printout is heavily dependent upon the "surface mix section direction report" which was found to contain many out-of-date entries resulting from a breakdown in the flow of resurfacing data from the field to the Information Systems Division. While full updating will be carried out when the 1983-84 interstate ratings are conducted, the failure to provide current data has been corrected by the institution of a new requirement providing that the surface mix information (Form DP-20) accompany the final package documenting payment for work done. Similar inaccuracies in primary system data files were detected early enough to make arrangements for their correction at the time of the first primary ratings in 1982.

The relatively low priority initially given pavement management by the Information Systems Division resulted from a consultant's review of the Department's data processing needs.(19) In that study, pavement management was assigned a priority 11 in a field of 12 options. Such a priority dictated that Information

Systems commit manpower to pavement management only on an occasional basis. While such effort accomplished a great deal, timely implementation of pavement management on all systems clearly indicated the need for a higher priority. Recognizing this need, departmental management assigned the pavement management effort a number 2 priority during 1983.

Much of the effort required in implementing the system is one-time only in establishing integrated and corrected data files. Once this effort has been completed for all systems, only continuous update of the various files will be necessary.

As mentioned earlier, pavement condition ratings were conducted on the primary system in the fall of 1982. The first complete computer printout of these ratings was due in October 1983. Again, a manpower shortage and the low early priority have resulted in long delays in providing usable data.

Delays in data handling are being addressed through a move to input pavement management information through district office remote terminals. Personnel in the Lynchburg District have been trained in this procedure and will assist in providing training to other districts. While this move will assist in reducing delays, the system will not be fully efficient until pavement management data can be processed on-line rather than through the current batch operation.

Funding

The pavement management steering committee recognized early the need for designated funding of pavement management. While the Maintenance Division has been able to fund efforts, other than research, to date, there is no official budgeting of the activity. It is the belief of the author and the PMS steering committee that field personnel will be more receptive to the pavement management efforts required of them if funds are budgeted such that costs clearly will not detract from allocated maintenance dollars.

System Monitoring

As shown earlier in this report, the pavement condition evaluation method employed can, when the evaluators are properly trained, provide pavement ratings wherein differences between raters is minimized. However, one can monitor and ensure reliable results only through a system of ratings concurrent with those of field teams and conducted by a statewide monitoring team. Such a system should be instituted under the direction of the state pavement management engineer. As mentioned earlier, a very small percentage of the network, properly sampled, is adequate for monitoring purposes. Such monitoring could also provide sufficient data for systemwide condition analyses for use in projecting needed funds etc.

CONCLUSIONS

The studies reported herein appear to support the following conclusions.

1. The condition inventory method used is capable of differentiating among candidate projects for the establishment of maintenance replacement priorities.

2. A 5% random sample is adequate for monitoring purposes and can provide a systemwide indication of overall pavement conditions.

3. The ride quality of Virginia interstate pavements is generally so high that roughness tests are of little value in pavement evaluation or in prioritization except in the most extreme cases. Interstate roughness values compare favorably with the standards for new construction wherein a Mays meter roughness of 75 in./mi. (120 cm/km) is considered good.

4. The deflection inventory shows that a significant portion of the interstate system is below par in structural capability. This suggests that heavier than normal overlays or complete rehabilitation will be required on many miles of roadway over the next few years.

5. Equations developed to predict pavement condition show an excellent correlation between condition and cumulative 18,000 lb. (8,170 kg) equivalent axle loads on I-81. Similar equations will need to be developed for other interstate routes and for primary roads as later pavement condition data are collected.

6. Projection equations show that if the inordinate increase in 18,000 lb. (8,170 kg) equivalent axle loadings over the past several years continues, the life of an overlay on I-81 will be reduced to less than 5 years by the year 2000. The reductions will be less dramatic on other highways. This finding suggests that maintenance replacement funding levels will need to be increased or new maintenance replacement technology will be required.

7. The rating system and analysis methods developed in the course of this study will provide management with an objective approach to pavement management, including documentation for maintenance replacement funding requirements.

RECOMMENDATIONS

Based on the studies reported herein, the following recommendations are offered for consideration by the management of the Department.

Recommendations for Implementation

1. The Department should continue with implementation of the pavement management system utilizing the condition rating and analysis methods presented in this report.

2. The updating and integration of automated data files should continue at a high priority.

3. A statewide monitoring system to ensure that all district rating teams rate in a similar manner should be established under the direction of the state pavement management engineer.

4. The 5% sampling rate established for rating of the secondary system is adequate and should be carried out.

5. Future computer printouts of interstate pavement management data should show the estimated required thickness of the next overlay.

6. Efforts to provide pavement management input from field computer terminals should be continued with increased emphasis.

7. Designated pavement management funding should be identified in budgets of the Department.

Recommendations for Research

1. Studies should be undertaken to establish an automated method of determining pavement performance curves from a minimum number of condition ratings for a given pavement.

2. An efficient method of evaluating pavement ride quality should be identified, evaluated, and implemented.

3. Research Council studies to identify optimum maintenance replacement strategies should be continued and expedited.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the enormous contributions of many people on the district condition rating teams for their efforts in data collection and reporting. The Maintenance and Information Systems divisions, especially Messrs. A. D. Newman and C. S. Taylor, are acknowledged for key roles in the organization and processing of data. Special thanks go to the pavement management steering committee chaired by Messrs. P. F. Cecchini and W. R. Davidson for general guidance to the research and development effort. Finally, Messrs. R. W. Gunn and G. V. Leake are acknowledged for their untiring efforts in the collection and analysis of roughness and deflection data.

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APPENDIX A

Instructions and Attendance Roster, Interstate Pavement Condition Rating Training Sessions

INSTRUCTIONS

INTERSTATE FLEXIBLE PAVEMENT MAINTENANCE RATING

1. Rate pavements between mile markers using one rating sheet for each mile for each direction of travel. Drive the shoulder slowly over each mile to be rated and stop at approximately each mile marker to complete the rating sheet. Note approximate locations of change in surface mix.

2. Distress types are identified in "Bituminous Surface Maintenance," Training Manual MT-5-70. Definitions are provided on the next page.

3. Placing emphasis on the traffic lane, make an overall evaluation of the pavement section by —

   (a) estimating the frequency of occurrence of each major distress type and indicating it on the rating work sheet in column (2),

   (b) estimating the severity of each distress type and indicating it on the rating work sheet in column (3),

   (c) for the combination of frequency and severity, selecting a rating factor for each distress type and recording it on rating work sheet in column (4),

   (d) multiplying column (4) by column (5) and writing the results in column (6), and

   (e) obtaining the sum recording it in column (6).

4. Compute the distress maintenance rating (DMR) by subtracting the sum of column (6) from 100 as given on the work sheet.

5. Send one copy of each work sheet to

   K. H. McGhee
   P. O. Box 3817, University Station
   Charlottesville, Virginia 22903-0817

FLEXIBLE PAVEMENT MAINTENANCE RATING

Definitions

Frequency of Occurrence	Percentage of Length Affected
None	0
Rarely Observed	Less than 10%
Occasionally Observed	10% - 40%
Frequently Observed	More than 40%

Severity

Longitudinal Cracking (1-6)*
or Alligator Cracking (1-8)

Not severe - Cracks not readily apparent.

Severe - Well-defined cracks.

Very severe - Well-defined cracks with spalling.

Rutting (1-38)

Not severe - Not readily apparent.

Severe - Apparent to naked eye.

Very severe - Capable of serious ponding.

Pushing (1-34)

Not severe - Not readily apparent.

Severe - Apparent but not rough.

Very severe - Apparent and rough.

Ravelling (1-32)

Not severe - Not readily apparent.

Severe - Apparent.

Very severe - Apparent and rough.

Patching

Rated only on basis of frequency of occurrence.

*Numbers in parentheses refer to page numbers in Training Guide MT-5-70.

INTERSTATE FLEXIBLE
PAVEMENT MAINTENANCE RATING

Work Sheet

Date ____________________

District ____________________ County ____________________ Route ____________________

From Mile Marker: ____________________ EBL/NBL (circle one)

To Mile Marker: ____________________ WBL/SBL

Approximate Location of Mix Changes and County Lines : ____________________

(1)	(2)	(3)	(4)	(5)	(6)
Distress Type	Frequency (Circle One)	Severity (Circle One)	Rating Factor (0 to 9)		
Longitudinal Cracking or Alligator Cracking	N R O F	NS S VS	______	x 2.4 =	______
Rutting	N R O F	NS S VS	______	x 1.0 =	______
Pushing	N R O F	NS S VS	______	x 1.0 =	______
Ravelling	N R O F	NS S VS	______	x 0.9 =	______
Patching	N R O F	NS	______	x 2.3 =	______
				Sum =	______

DMR = 100 - sum of column 6 = 100 - ____ =

	Rating Factor		
Frequency of Distress	Not Severe (NS)	Severe (S)	Very Severe (VS)
None (N)	0	0	0
Rare (R) less than 10%	1	2	3
Occasional (O) 10% - 40%	2	4	6
Frequent (F) over 40%	3	6	9

Remarks on General Condition of Pavement:

For Research Council Use

Traffic Count: ____________ DMR x C_T: ____________
Ride Rating: ____________ PSI: ____________
Car: ____________ M. R.: ____________

Attendance Roster

PAVEMENT RATING SEMINAR
July 30-31, 1981

Name	District/Division
K. H. McGhee	Research
Earl E. Wright	Materials Div., Fredericksburg
J. W. Barnes, Jr.	Inspector B, Warsaw
R. L. Lucas	Inspector B, Saluda
W. H. Whitlow	Materials Div., Salem
M. E. Gearhart	Materials Div., Salem
J. M. Nelson	Culpeper Dist., Louisa Res.
E. D. Henderson	Materials Div., Lynchburg
J. A. Copp	Maint. Supv., Staunton Dist.
C. E. Tudor	Maint. Supv., Richmond
M. J. Easter	Materials Div., Richmond
W. T. Reynolds	Asst. Res. Engr., Richmond
J. W. Brewer	Res. Maint. Supv., Williamsburg
K. C. Babb	Res. Maint. Supv., Norfolk
J. W. Bunch	Materials Div., Suffolk
B. R. Wilkerson	Construction, Staunton
C. W. Wilkerson	Materials, Staunton
J. P. Bassett	Materials, Elko
R. W. Sutton	Materials, Lynchburg
V. T. Reynolds	Materials, Lynchburg
C. M. Clarke	Suffolk
P. F. Cecchini	Staunton
R. W. Gunn	Research
G. V. Leake	VHTRC
R. H. Kelley	Inspector B, Warrenton
S. L. Martin	Materials Div., Culpeper
W. R. Davidson	Maintenance Div.
R. A. Hawkes	Technician Supervisor, Bristol

APPENDIX B

Results of 5 Percent

Random Sampling

of Interstate Pavements

Legend for Tables of Results of Sampling

Column (1) - Interstate Route No.
Column (2) - Direction, 1 - northbound
2 - southbound
3 - eastbound
4 - westbound

Column (3) - District, A - Northern Virginia
1 - Bristol
2 - Salem
4 - Richmond
5 - Suffolk
6 - Fredericksburg
7 - Culpeper
8 - Staunton

Column (4) - Beginning mile marker
Column (5) - End mile marker
Column (6) - Distress maintenance rating by research personnel
Column (7) - Distress maintenance rating by field personnel
Column (8) - Mays roughness index (in./mi.)
Column (9) - Roughness serviceability rating
Column (10) - 1981 estimated daily ESAL-18
Column (11) - Projected year of next overlay
Column (12) - Maximum dynaflect deflection
Column (13) - Spreadability
Column (14) - Estimated thickness index of existing pavement
Column (15) - Recommended thickness (in.) of next resurfacing or increase in thickness index if other rehabilitation methods are used.

Results of Sampling

(1) Rte.	(2) Dir.	(3) Dist.	(4) MM	(5) MM	(6) DMR_R	(7) DMR_F	(8) RR_{55}	(9) SR	(10) 1981 Daily ESAL-18	(11) Next Overlay	(12) d_o	(13) S	(14) D	(15) T
64	3	8	10	11	97	100	127	3.21	129	1988	0.011	50	7.8	1.2
64	3	8	20	21	91	94	73	3.93	259	1983	0.011	58	10.3	*
64	3	8	44	45	97	99	86	3.74	192	1985	0.007	69	16.1	*
64	3	8	92	93	91	82	64	4.07	423	1983	0.008	52	9.4	0.4
64	3	7	157	158	97	91	72	3.94	416	1989	0.022	66	9.6	0.5
64	3	7	162	163	90	94	-	-	385	1983	0.032	58	6.2	3.6
64	3	5	237	238	88	99	104	3.49	536	1987	0.014	58	9.4	0.8
64	4	8	6	7	96	97	81	3.81	150	1986	0.013	48	6.7	2.4
64	4	8	34	35	97	98	78	3.85	147	1987	0.008	52	9.4	*
64	4	8	50	51	98	99	73	3.93	160	1985	0.014	61	10.3	*
64	4	8	96	97	89	92	73	3.93	373	1983	0.012	69	13.4	*
64	4	8	97	98	87	92	59	4.15	373	1983	0.013	67	12.4	*
64	4	7	146	147	83	89	-	-	300	1983	0.008	71	14.0	*
64	4	4	165	166	100	100	69	3.99	385	1989	0.024	74	11.1	*
64	4	5	236	237	92	100	80	3.92	536	1987	0.015	58	9.1	1.1
66	3	8	10	11	97	99	65	4.05	227	1985	0.011	52	8.4	1.0
66	3	7	26	27	89	94	93	3.64	421	1983	0.012	62	11.2	*
66	3	7	37	38	100	99	71	3.96	252	1988	0.025	68	9.5	*
66	4	8	1	2	93	98	57	4.18	238	1983	0.012	46	6.3	3.0
66	4	7	24	25	96	97	85	3.75	421	1983	0.016	55	8.1	1.7
66	4	7	46	47	94	97	63	4.08	502	1985	0.012	53	8.4	1.7
77	1	2	3	4	97	96	68	4.00	476	1984	0.013	56	9.1	0.9
77	1	1	29	30	97	97	69	3.99	685	1987	0.008	57	11.2	*
77	1	1	47	48	97	99	68	4.00	420	1987	0.009	61	12.1	*
77	1	1	60	61	87	95	74	3.91	398	1983	0.007	51	9.5	0.3
77	2	2	9	10	97	94	64	4.07	597	1985	0.019	57	8.0	2.2
77	2	1	27	28	96	100	81	3.81	685	1987	0.010	60	11.3	*
77	2	1	45	46	97	98	78	3.85	423	1987	0.007	57	11.7	*
77	2	1	53	54	96	98	83	3.78	396	1983	0.008	62	12.9	*
81	1	1	5	6	95	91	80	3.82	1,050	1985	0.016	60	9.4	1.3
81	1	1	6	7	96	97	80	3.82	952	1985	0.014	61	10.3	0.3
81	1	1	29	30	100	100	87	3.72	950	1990	0.016	62	10.0	0.8
81	1	1	59	60	100	100	72	3.94	1,016	1990	-	-	-	-
81	1	1	86	87	94	87	81	3.81	1,500	1983	0.017	63	10.0	0.9
81	1	2	100	101	94	93	85	3.75	1,297	1983	0.014	59	9.7	1.1

*Pavement is structurally adequate, a thin resurfacing should be considered.

Results of Sampling

(1) Rte.	(2) Dir.	(3) Dist.	(4) MM	(5) MM	(6) DMR_R	(7) DMR_F	(8) RR_{55}	(9) SR	(10) 1981 Daily ESAL-18	(11) Next Overlay	(12) d_o	(13) S	(14) D	(15) T
81	1	2	119	120	94	93	69	3.99	1,443	1983	0.019	57	8.0	2.9
81	1	2	128	129	95	92	87	3.72	1,470	1983	0.015	48	6.3	4.6
81	1	2	141	142	97	97	79	3.84	1,690	1985	0.017	48	5.9	5.2
81	1	2	166	167	80	95	70	3.97	1,107	1983	0.012	54	8.7	2.0
81	1	8	188	189	70	69	68	4.00	1,300	1983	0.020	56	7.5	3.3
81	1	8	216	217	75	90	73	3.93	1,459	1983	0.027	48	4.7	6.2
81	1	8	222	223	95	97	65	4.05	1,380	1984	0.007	52	9.8	1.1
81	1	8	255	256	97	98	79	3.84	1,033	1987	0.009	52	9.0	1.8
81	1	8	270	271	95	99	69	3.99	1,058	1987	0.020	50	6.0	4.8
81	1	8	285	286	85	82	84	3.76	1,064	1983	0.020	52	6.5	4.1
81	1	8	316	317	77	81	84	3.76	1,343	1983	0.011	46	6.5	4.3
81	1	8	322	323	94	99	67	4.02	1,208	1983	0.018	45	5.0	5.7
81	2	1	2	3	92	83	77	3.87	930	1984	0.016	62	10.0	0.6
81	2	1	21	22	86	83	61	4.11	912	1984	0.018	58	8.4	2.1
81	2	1	31	32	98	100	64	4.07	961	1987	0.016	49	6.4	4.3
81	2	1	73	74	90	90	75	3.90	1,648	1984	0.018	58	8.4	2.7
81	2	2	87	88	94	91	85	3.75	1,222	1983	0.015	65	11.1	*
81	2	2	115	116	97	98	60	4.13	1,264	1985	0.023	54	6.5	4.4
81	2	2	145	146	97	95	59	4.15	1,219	1986	0.007	54	10.6	0.3
81	2	2	162	163	84	93	-	-	1,107	-	-	-	-	-
81	2	8	200	201	92	88	85	3.75	1,359	1984	0.022	47	5.0	5.9
81	2	8	203	204	95	94	69	3.99	1,359	1984	0.023	56	7.0	3.9
81	2	8	223	224	92	98	67	4.02	1,369	1984	0.011	48	7.1	3.8
81	2	8	258	259	93	98	75	3.90	1,026	1987	0.016	50	6.7	4.1
81	2	8	264	265	93	97	82	3.79	1,030	1987	0.014	50	7.1	3.7
81	2	8	277	278	97	98	83	3.78	1,106	1983	0.026	57	6.8	3.9
81	2	8	290	291	88	84	89	3.69	1,064	1983	0.022	47	5.0	5.6
81	2	8	318	319	95	99	76	3.88	1,208	1985	0.016	50	6.7	4.1
85	1	4	4	5	95	99	80	3.82	780	1985	0.008	75	17.6	*
85	1	4	33	34	95	97	60	4.13	590	1984	0.012	68	13.1	*
85	2	4	18	19	90	94	65	4.05	669	1984	0.015	73	13.4	*
85	2	4	38	39	97	97	72	3.94	607	1984	0.016	74	13.4	*
95	1	5	23	24	95	95	-	-	924	1987	0.017	46	5.4	5.3
95	1	4	44	45	90	98	42	4.43	1,000	1983	0.023	54	6.5	4.1
95	1	4	81	82	91	-	-	-	2,285	**	-	-	-	**

**Composite pavement, analysis method not applicable.

Results of Sampling

(1) Rte.	(2) Dir.	(3) Dist.	(4) MM	(5) MM	(6) DMR_R	(7) DMR_F	(8) RR_{55}	(9) SR	(10) 1981 Daily ESAL-18	(11) Next Overlay	(12) d_o	(13) S	(14) D	(15) T
95	1	6	118	119	80	91	139	3.07	2,063	**	-	-	-	**
95	1	6	133	134	93	98	108	3.44	2,100	**	-	-	-	**
95	1	6	144	145	97	95	89	3.69	1,924	**	-	-	-	**
95	1	A	167	168	77	80	83	3.78	2,972	**	-	-	-	**
95	2	5	27	28	93	100	95	3.61	924	1989	0.015	62	10.3	0.5
95	2	6	114	115	100	-	-	-	2,063	**	-	-	-	**
95	2	6	135	136	92	95	69	3.99	2,046	**	-	-	-	**
95	2	7	154	155	100	-	-	-	1,892	**	-	-	-	**
95	2	A	168	169	88	85	63	4.08	2,972	**	-	-	-	**
264	3	5	1	2	98	-	79	3.84	362	1984	0.020	57	7.8	1.9
381	1	1	1	2	100	100	-	-	-	-	-	-	-	-
581	1	2	5	6	97	95	68	4.00	890	1983	0.012	49	7.2	3.3

**Composite pavement, analysis method not applicable.