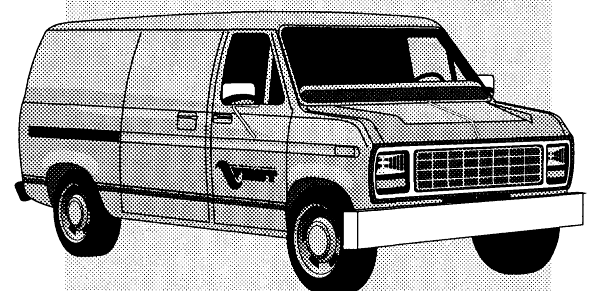
INTERIM REPORT

FACTORS AFFECTING MAINTENANCE OVERLAY RIDE QUALITY –1996 RIDEABILITY STATUS



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Supplementary Notes

Abstract

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Also during the 1996 construction season, the Virginia Department of Transportation began to pilot a special provision for pavement smoothness. This new provision is somewhat unique in that it replaces the California type Profilograph with a South Dakota style road profiler. Correspondingly, ride quality targets and pay adjustments, previously established in terms of the Profile Index (PI), are expressed in terms of the International Roughness Index (IRI).

This interim report presents a summary of the ride quality of Virginia's maintenance overlays as observed for the 1996 construction season. The information covers nearly 1,600 lane-kilometers (990 miles) of overlay in 61 counties of eight construction districts.

The findings suggest that the achievable smoothness of an overlay is highly influenced by functional classification. For example, the average smoothness of overlays on interstates was well below the specified target while most overlays on two-lane primary highways would have fallen just short. In general, current targets for ride quality (in terms of IRI) appear to be well within the capabilities of most of Virginia's paving contractors. Preliminary results of the pilot study indicate that the presence of a smoothness specification can have a distinctly positive influence on overlay ride quality.

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(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
The University of Virginia)

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INTRODUCTION

The Virginia Department of Transportation (VDOT) spent $72 million dollars in fiscal year 1996 on maintenance resurfacing.[1] In Virginia, most maintenance overlays are prescribed in response to pavement deterioration. In this sense, the overlay serves to restore or add to the pavement structure. Although transportation officials place top priority on a pavement's structural capacity, ride quality is the characteristic that is often most significant to the traveling public. Many also contend that ride quality is a product of overall construction quality, and therefore can be indicative of future maintenance requirements and potential service life.

Equipment for Measuring Ride Quality

Traditionally, larger-scaled ride quality testing has been conducted using devices that are classified as response type road roughness meters (RTRRMs). RTRRM estimates of rideability are based on the response of an instrumented vehicle (or trailer) traveling at a specified speed over a pavement surface. Unfortunately, the instrument-specific nature of a RTRRM makes its output subject to wide variability. Any change that would tend to affect the response of the vehicle to the surface (such as suspension, tire wear, or vehicle weight changes) will affect the estimate of roughness.

In the 1960s, the General Motors Research Laboratories developed an instrument that could collect ride quality information independently of the collecting vehicle's characteristics. The General Motors Profilometer was able to collect longitudinal road profiles while being operated at highway speeds.[2] Today, many transportation agencies (including VDOT) use the South Dakota Road Profiler (SDRP), a lower-cost adaptation of the GM Profilometer. The SDRP and the GM Profilometer belong to a classification of instruments known as accelerometer-established inertial road profiling systems. All inertial profiling systems use a combination of accelerometers, height sensors, and electronic distance measurement instruments to collect road profiles. In theory, these profiles are purely a geometric property of the pavement surface, and completely independent of the vehicle used to conduct the testing. In reality, the reaction of an automobile to the pavement surface has everything to do with what one would consider ride quality.

The International Roughness Index (IRI)

A vehicle's response to a road surface is a function of the combination of a vehicle's weight, the condition and configuration of its chassis and suspension, the size and inflation pressure of its tires, and a number of other factors (not to mention the influence of the road surface, itself). As vehicles (as well as their operators) come in all shapes and sizes, rarely do two users experience the identical ride over the same section of road. Therein lies the dilemma. If an agency wishes to measure ride quality equitably, how does it derive a standard vehicle response for use as an 'official' measure of rideability? Given this ideal instrument, how should its response be measured and reported? A variety of answers have been provided to these questions. The most common solution is to measure and analyze the road surface profile, rather than measuring the response of any single instrumented vehicle. A repeatable, objective assessment of ride quality is necessary in order to make an accurate measurement of the surface profile.

Today, the most widely used method for reporting ride quality is through the International Roughness Index (IRI). ASTM Standard E1170, "Practices for Simulating Vehicular Response to Longitudinal Profiles of a Vehicular Traveled Surface," describes the method for conducting a quarter-car simulation that produces an IRI. Using a fairly sophisticated algorithm, a model of a quarter vehicle traveling at a specified speed is applied to a profile, and its reaction is measured and reported. This reference vehicle is complete with all the basic parameters necessary to describe an actual automobile (or at least a critical portion of it). These parameters include: 1) the mass of the vehicle body, suspension, wheels and tires; 2) spring stiffness coefficients for the vehicle springs, shocks and/or struts; and 3) damping coefficients indicative of a conventional shock absorbing system. The simulated suspension motion is accumulated and divided by the distance traveled to yield the IRI.[3] Lower values represent a smoother ride; higher values indicate a rougher one.

VDOT's Smoothness Specifications

Section 315.07, Pavement Tolerances, of VDOT's Road and Bridge Specifications, addresses new pavement smoothness and provides a mechanism for measuring it. This mechanism incorporates another profiling device known as the California Profilograph (Figure 1). In simplest terms, the profilograph consists of a rigid 7.5 meter (25 feet) rolling frame with a profiling wheel located at its midpoint and attached to a strip chart. The system monitors and records the vertical displacement of the center wheel and provides a profile trace of the surface in question. It is typically hand-propelled and operated at speeds of three to five kilometers per hour.

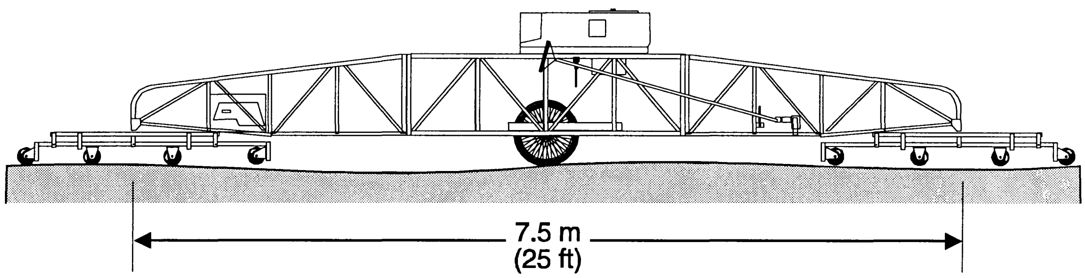

Figure 1. California Profilograph

For a number of reasons, the profilograph-based specification is most often applied only to new construction or major reconstruction projects. Transporting and assembling the device is quite involved. Also, conducting a profilograph test is time-consuming; and the machine can be dangerous to operate while under traffic. Depending upon the degree of automation applied, data reduction requirements for this assessment method can be significant and highly subjective.[4]

The profilograph is very much a project-level tool and has been applied very effectively when the situation has allowed. It is not practical, however, for large volumes of work, such that associated with the maintenance overlay program. To combat some of the shortcoming associated with the profilograph-based specification, VDOT chose the 1996 construction season to pilot a new special provision for rideability. This new provision includes two important deviations from the conventional specification. First, it replaces the profilograph with the South Dakota Road Profiler (SDRP). To complement the new equipment, it also incorporates the International Roughness Index (IRI). As is the case with the profilograph-based specification, this provision stipulates the degree of smoothness required in order for the contractor to receive a given percentage of payment. The specification includes disincentives, incentives, and limits on localized roughness. If exceeded, these trigger the need for corrective actions.

Table 1 lists the pay adjustments as they would apply using the 1996 construction season's version of the pilot specification. (It should be noted that the IRI intervals and the Pay Adjustments have been modified slightly for the 1997 season. Minor modifications are likely to continue for some years to come, provided that the specification is implemented.)

Table 1. Pay adjustment intervals

IRI After Completion (mm/km)	Pay Adjustment (% pavement unit price)
Under 950.0	106
950.1 - 1025.0	104
1025.1 - 1105.0	102
1105.1 - 1260.0	100
1260.1 - 1340.0	98
1340.1 - 1420.0	95
1420.1 - 1500.0	90
1500.1 - 1580.0	85
Over 1580.1	Subject to Corrective Action

(Note: IRI units may be converted to inches/mile by multiplying by 0.06336)

The advantages of applying the SDRP and the IRI are numerous. Projects are surveyed at highway speeds. Testing is conducted without the need to expose personnel directly to traffic. Repeatability with the profiler is comparable, if not superior, to the profilograph. Profiles collected with the inertial road profiler are objective and versatile. The IRI correlates well with subjective rideability and is consistent with units of roughness measurement applied statewide, nationally and around the world.[5-6]

Like many agencies, VDOT generally reports ride quality in terms of mean roughness index (MRI). ASTM Standard Terminology Relating to Traveled Surface Characteristics (E 867) defines MRI as "… the average of the International Roughness Index (IRI) values for the right and left wheel paths." The purist will quickly point out that an IRI is only valid for a given profile. When the two-wheel path IRIs are averaged, as is fairly common practice, there is no longer a direct relationship with a profile.

VDOT makes one minor departure from the suggestions of ASTM E 867, which specifies the reporting of IRI (and MRI) in SI units. The Standards call for metric units in terms of millimeters per meter, or the numerical equivalent meters per kilometer. Virginia, in an effort to avoid a preponderance of decimal places, has chosen to report IRI in millimeters per kilometer. As such, the SI-savvy reader will notice an extra factor of one thousand being applied to VDOT's numbers, and should make the appropriate conversion as necessary or desired.

PURPOSE AND SCOPE

In early 1996, the Research Council began a study to evaluate the achievable smoothness of maintenance overlays. The primary objective of that project is a formal analysis of the factors affecting overlay ride quality. It also involves an observation of the draft special provision performance, and the development of recommendations for improvements.

As part of this study, the research team began a significant multi-year data collection effort. Working from the Bid Proposal and Contract for Maintenance Resurfacing (Form C-6A or "Resurfacing Schedule") provided for each District, the team developed a plan to survey as many of the new overlays as possible. Beginning in the spring and continuing into the winter, an extensive series of ride quality assessments were conducted statewide. To enable an evaluation of ride quality improvements attributable to maintenance overlays, these assessments were performed for both new overlays and pavement awaiting overlays.

This interim report has been prepared in order to establish and present the ride quality of Virginia's maintenance overlays as observed for the 1996 construction season. The information presented covers nearly 1,600 lane-kilometers (990 miles) of overlay in 61 counties within eight of the nine state construction districts. In addition to a discussion of the relative overlay rideability by geographic grouping, a summary of smoothness achieved by functional classification is also included. The report briefly describes the improvement in rideability resulting from newly placed overlay, and provides a cursory look at the perceived effect of the pilot provision.

METHODS

Data Collection

In the spring of 1996, researchers began to assemble the database. First, the research team isolated the maintenance resurfacing schedules for each county. As they entered this information into the database, the team used certain guidelines to cull projects that would not have provided practical samples. For example, projects with less than 800 meters (0.5 mile) of continuous paving were not selected for testing. Also, projects in which the contractor was required to negotiate surface utilities (i.e., manhole covers) were not surveyed, and their scheduling records were deleted. Projects that included more than one traffic signal light, or low speed limits (i.e., less than 56 kph) were also dropped from the testing database.

Since data collection efforts began fairly early in the construction season, it was relatively easy to conduct the surveys ahead of the overlay work. Unfortunately, timing trips to collect rideability data on just-completed overlays was and will continue to be more of a challenge. An informal polling of Central office and District Maintenance and Material officials indicated that the best sources for status reports on resurfacing work are the residencies. Correspondingly, early in the summer, the research team issued a widespread electronic mailing to Resident Engineers requesting assistance. Since that time, the research team has been working cooperatively with a variety of district and residency officials to survey new overlays in a timely fashion.

Reporting

Performing a project-level survey with the SDRP involves mapping multiple longitudinal road profiles over a designated section of roadway. For ride quality, the profiles of greatest interest are typically those of the left and right wheel paths. Obtaining a set of accurate profiles is important, but does not constitute a completed roughness evaluation. It is also necessary to extract the required reports using these profiles.

As per the 1996 version of the draft specification, three reports are required for each finished lane of pavement. These include 1) a summary of the job-long ride quality of the project; 2) a record of the MRI values at 160 meter (0.1 mile) intervals; and 3) a breakdown of the project MRI numbers into16 meter (0.01 mile) intervals. The reporting requirements evolved largely through the adaptation of the profilograph-based specification to the inertial profiling system.

A test run involves collecting a continuous profile set for each lane of each pavement section; it is accomplished with a single pass of the profiling vehicle. A profile set consists of one profile each for the left and right wheelpaths, and a third for the lane center. For a new overlay, a complete roughness evaluation requires at least two runs per lane. It also requires the preparation of a job-long summary for each run, in order that the test run yielding the lowest average MRI can be identified. The remainders of the reports are then generated using the information from the "smoothest" run. The corresponding 160-meter report is generated in order to apply the incentive/disincentive portion of the specification, and to determine the total amount due a contractor for the given surface. The 16-meter report is necessary in order to determine any correction requirements.

FINDINGS AND DISCUSSION

By late fall 1996 and early winter 1997, the technical research staff had assembled ride quality data from a significant portion of the previous season's maintenance overlay schedule. Work to compile related information on surface history, traffic data, producer/supplier data, and other characteristics of the various tested projects is well underway. This discussion, however, will be limited to what may be concluded from the road roughness reports. *A county-by-county list of each project included, as well as the lane-by-lane summary of MRI is available upon request.* For brevity's sake, this report limits discussion to observations that can be made at the district and functional classification levels.

Statistics on Sample Pool

The following two tables include some general statistics regarding the overlay schedule sites that have been incorporated into the database. The site statistics may refer to a single lane, but more often cover two or more lanes of paving. In terms of detailed rideability data, a record is stored for each lane of each site. In that sense, the lane statistics may be thought of as sub-site statistics. For the purposes of this report, these sub-sites will be referred to as data records.

Table 2 and Figure 2 describe the database from a district-by-district perspective. Table 3 and Figure 3 provide the same information according to functional classification. *A breakdown by residency is available upon request.* The researchers surveyed a total of 193 sites. These corresponded to nearly 1594 lane-kilometers of overlay, with a statewide average of 4.3 kilometers (2.7 miles) per site and an average site width of just over 8 meters (27 feet). The reported width varied significantly, with most sites including multiple lanes and many also extending to the shoulders.

Table 2. General statistics, by district

District	No. of Sites	Avg. Site Length (km)	Avg. Site Width (m)	Avg. Age of Orig. Surf. (yrs)
Bristol	9	5.6	8.7	7.7
Culpeper	32	4.0	7.7	8.0
Fredericksburg	36	4.0	7.6	9.3
Lynchburg	30	4.2	7.5	8.6
Richmond	27	3.4	8.0	9.9
Salem	8	4.7	9.3	11.7
Staunton	24	4.6	8.8	10.1
Suffolk	27	4.5	7.1	9.6

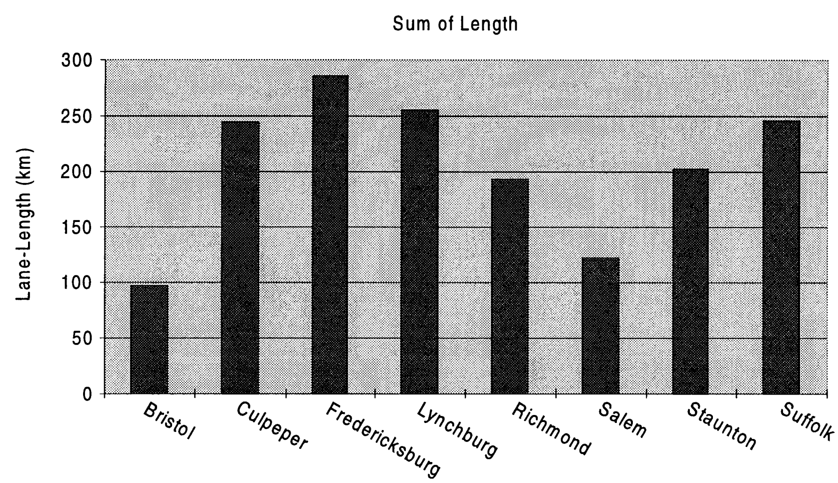

Figure 2. Tested lane length, by district

It should be noted that records were maintained on a schedule site as long as some information was available on ride quality. In many cases, the research team was not able to obtain both original surface and overlay rideability numbers for a given site. In fact, to obtain both original surface and overlay rideability numbers for a given site. In fact, for the 391 available records on rideability, 32 included data only on the original surface. In 118 records, data only cover the ride quality of the overlay. Fortunately, for 241 sub-sites (62 percent), data is available both for the original surface and the overlay.

Table 3. General statistics by functional classification

Functional Class.	No. of Sites	Avg. Proj. Length (km)	Avg. Proj. Width (m)	Avg. Age of Orig. Surf. (yrs)
Interstate	26	5.1	8.7	9.4
Divided Primary	96	4.3	7.8	9.0
2-Lane Primary	71	3.6	7.8	9.8

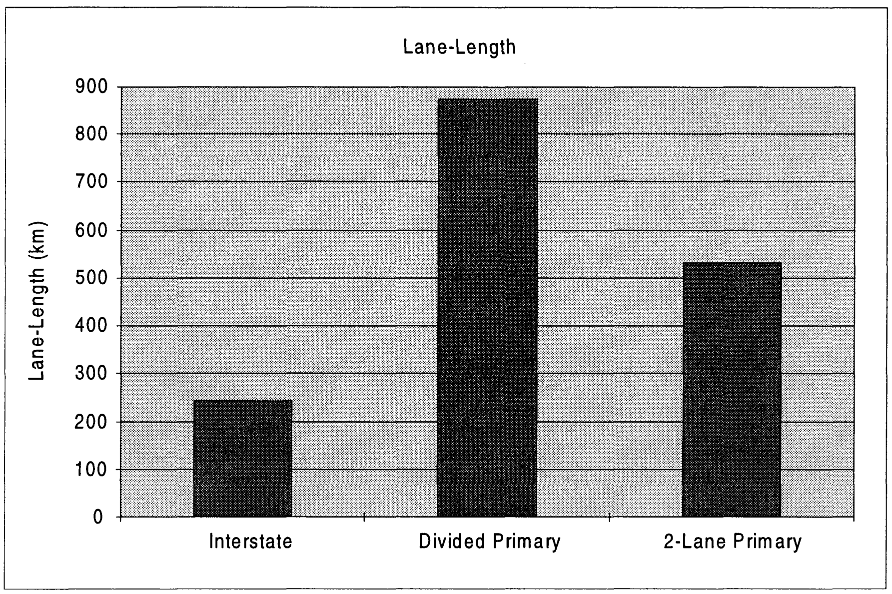

Figure 3. Tested lane length, by functional classification

Original Surface Ride Quality

The best way to observe the character of the statewide rideability is by observing the average and range associated with the database. A high-low-close/average chart is an efficient way to view this type of information. Figure 4 depicts the average smoothness (in terms of MRI), as well as the range of smoothest to roughest surfaces that were overlaid in each of the sampled construction districts. On average, pavements that were scheduled for overlays in 1996 exhibited an original MRI of 1600 millimeters per kilometer (between 100 and 105 in/mi). As Figure 4 shows, that 1600 mm/km average is coupled with a range of about the same magnitude within some districts. The average standard deviation is 330 mm/km (21 in/mi). Statewide, the smoothest pavement overlaid exhibited a MRI, prior to overlay, of 920 mm/km (58 in/mi). The roughest measured MRI was 3060 mm/km (194 in/mi).

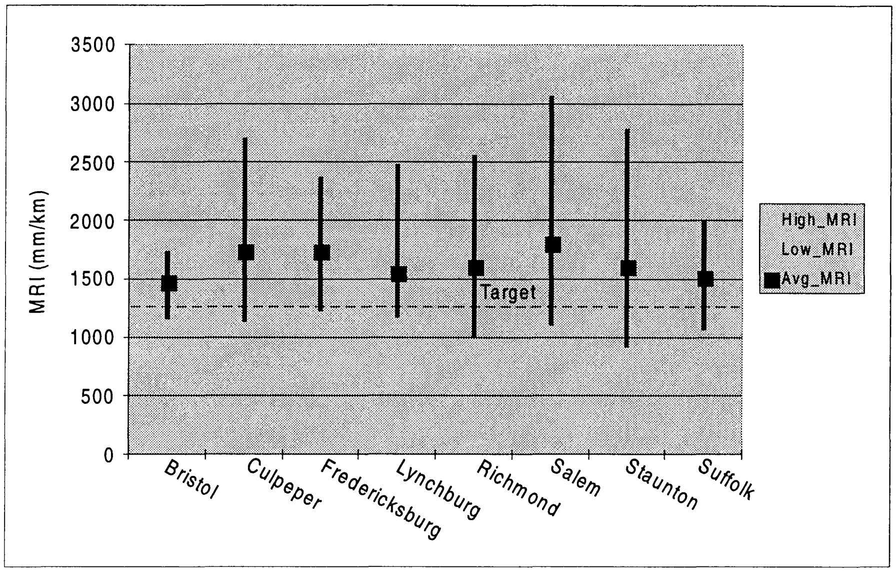

Figure 4. Original surface ride quality, by district

Categorization by functional classification produced results that were consistent with intuition. Figure 5 shows that the interstate sites have an overall smoother average ride, and exhibit lower overall variation (standard deviation of just under 190 mm/km) than the other functional classifications. The divided primaries have higher MRI values than the interstates; the two-lane primaries have the highest MRI values. Statewide,

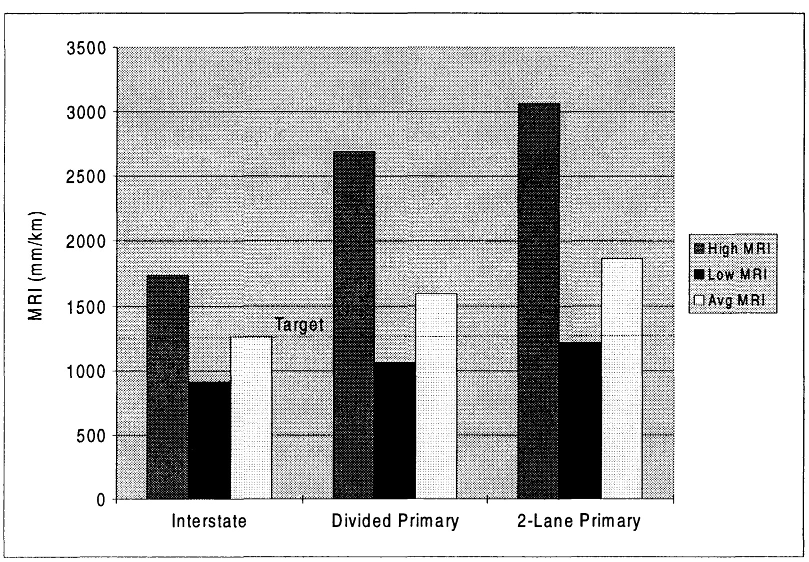

Figure 5. Original surface ride quality, by functional classification

the average interstate pavement section that was scheduled for resurfacing in 1996 had an original MRI of just below the target of 1260 mm/km (80 in/mi). Incidentally, the draft smoothness specification would have paid 100 percent on average to contractors with interstate jobs, as long as they did not adversely affect the ride quality of the original pavement through the application of the new overlay.

For the primary system projects, the divided primary pavements averaged about 1580 mm/km (100 in/mi). The two-lane primary projects ran closer to 1890 mm/km (120 in/mi).

New Overlay Ride Quality

Figure 6 provides the high-low-close analysis for the newly applied overlays. It appears that the target MRI of 1260 mm/km (80 in./mi.) was almost perfectly in line with what most contractors are achieving. In every district except one, the average overlay MRI was right on or just below the target figure. Notice, also, that the variability of the MRI (within the districts and from site to site) has decreased substantially in the overlays, as compared to the original surfaces. The average range of MRI values for all districts has dropped from 1350 mm/km (86 in/mi) for the original surfaces to 718 mm/km (40 in/mi) for the new overlays.

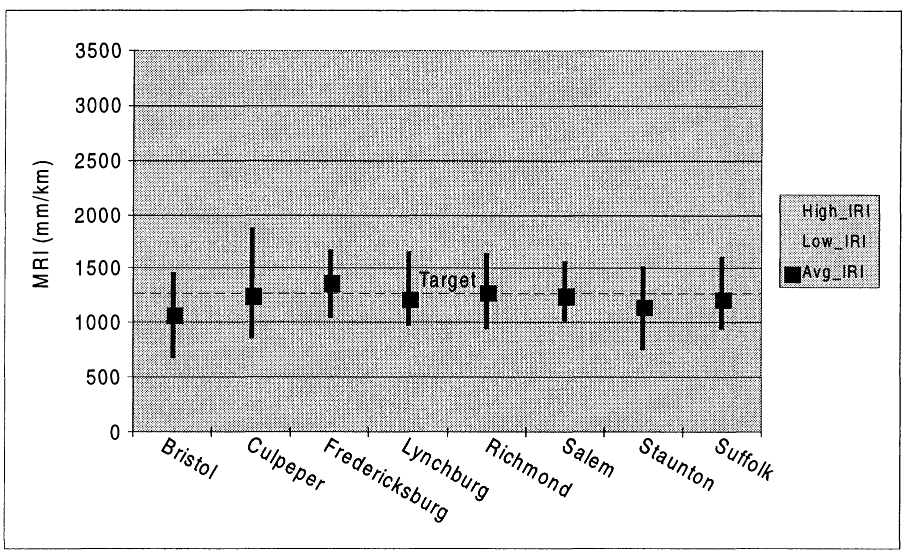

Figure 6. Overlay ride quality, by district

When the data are separated into the respective functional classifications (Figure 7), it can be seen that the current specification targets are better suited to one class of pavements - the divided primaries. Last season, on average, a new overlay on a divided primary in Virginia registered a MRI of 1230 mm/km (77.8 in./mi.). The interstate and two-lane primary overlays exhibited lower and higher values, respectively. Thus, as the specification is written, the contractors with interstate paving jobs would have received incentives, and the divided primary contractors would have been paid near-bid price. Assuming a contractor would have accepted a two-lane primary job with a rideability provision, a modest pay reduction would likely have been imposed.

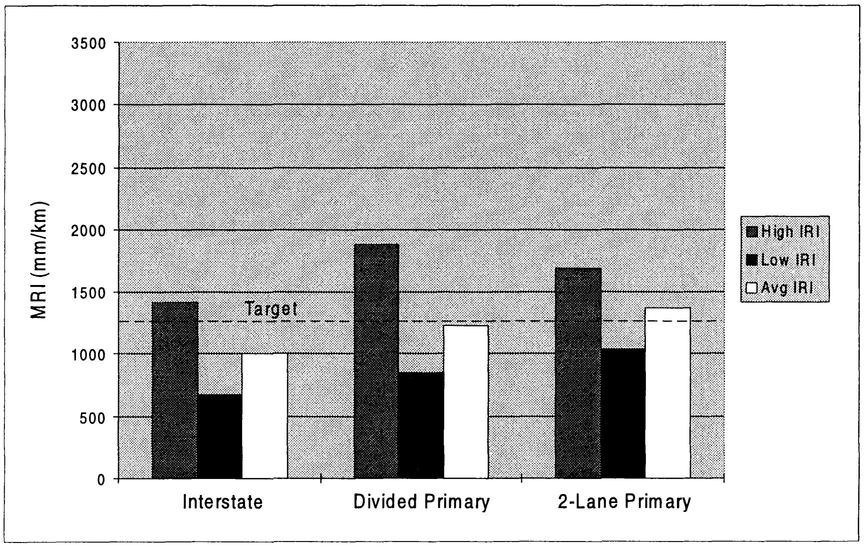

Figure 7. Overlay ride quality by functional classification

Change in Ride Quality

Statewide, the average improvement in ride quality due to the maintenance overlays was 390 mm/km (25 in./mi.), a 24 percent improvement over the original surface. Figure 8 illustrates how these improvements were distributed by district.

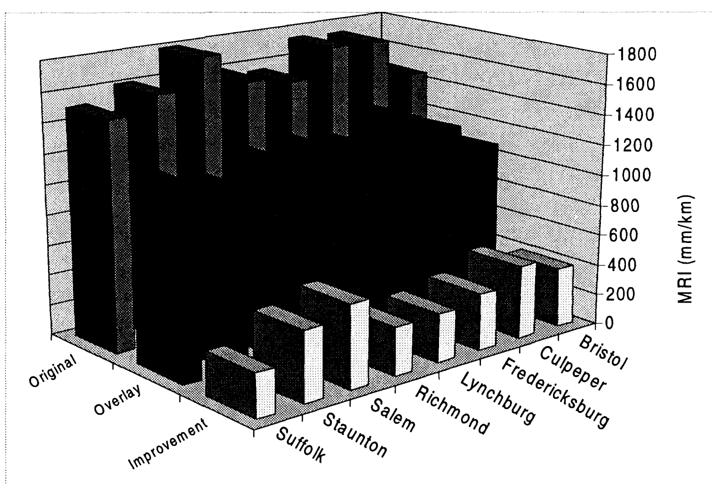

Figure 8. Improvement in ride quality, by district

Although the smooth original surfaces in Bristol likely contributed to their having the smoothest overlays, the most improved pavements were found in the Salem, Staunton, and Culpeper Districts. Figure 9 illustrates how ride quality improvement is related to functional classification.

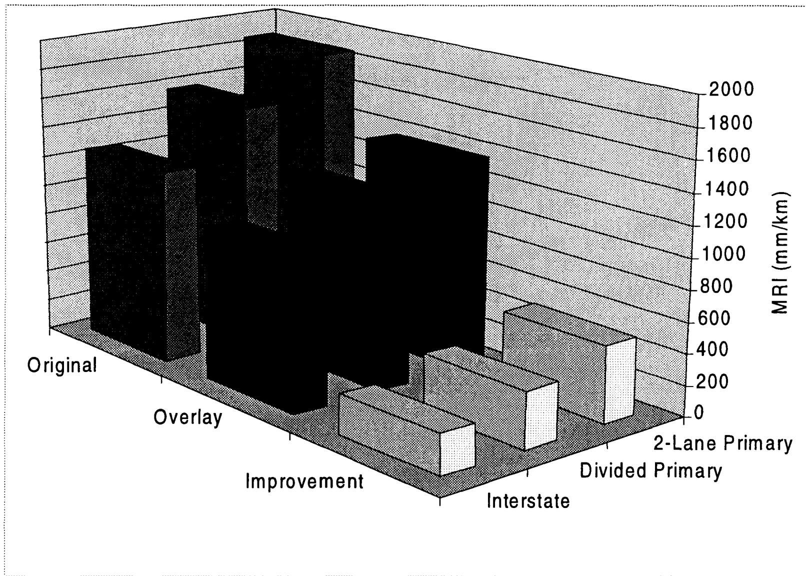

Figure 9. Improvement in ride quality, by functional classification

Not surprisingly, those pavements that had the most room for improvement experienced the largest reduction in roughness. The interstate, divided primary, and two-lane primary highways experienced a 21, a 23, and a 27 percent improvement, respectively.

Influence of the Smoothness Specification

Among the 193 sites surveyed last season, only five (three interstate and two four-lane primary) were selected to be subjected to the pilot specification for smoothness through the enforcement of the special provision. Statistically speaking, a sample size of five sites is negligible. These sites were important, however, since they represent actual application of the provision. The two divided primary sites (just over 25 lane-kilometers of overlay) experienced a rideability improvement of 23 percent. The three interstate projects (a total of almost 56 lane-kilometers of overlay) had improved smoothness of 27 percent. By comparison, the remainder of the population of projects (less the rideability sites) had average improvements of 20 percent for divided primary, and 19 percent for interstate projects. This represents a 3 percent and 8 percent increase, respectively, over those projects conducted without a provision for smoothness. In every instance where the specification was applied, the contractor was able to collect bonuses. In most cases, the contractor collected a substantial portion of the maximum achievable incentive.

It is also important to mention one additional project that was subjected to the provision. Because it was not included as part of the regular overlay schedule, this project was not formally covered by this study. The project, a showcase of sorts, involved almost 10 kilometers (4 lanes in each direction for a total of 77 lane-kilometers) of Interstate 295 east of Richmond. The provision for smoothness was identical to those incorporated into the study. However, this road repair posed a unique challenge, as it involved a multi-layer overlay of very distressed continuously reinforced concrete pavement. The overlay also incorporated a stone matrix asphalt (SMA) surface course, a relatively specialized mix that has seen limited application to date in Virginia. By all accounts, the project was a success. The average ride quality, in terms of MRI, was in the vicinity of 750 mm/km, well below the target. Accordingly, the contractor earned significant incentives totaling $84,000.

It is difficult to know with certainty whether or not these observed increases in improvement were influenced by the presence of a smoothness specification. Human nature suggests that this is very likely. A conclusive answer to that question will be left to future research.

CONCLUSIONS

- There are natural groupings in achieved smoothness. The most obvious of these is associated with highway functional classification. Future smoothness specification work may require establishing independent MRI targets, depending upon whether a given project is interstate, major rural primary, or a lesser-classified roadway.

- Current targets are well within the capabilities of Virginia's contractors. The targets are very lenient for interstate projects, and they are achieved on average for divided primary highway programs even without a smoothness provision in the contract. Further, it is likely that they could be achieved with some effort on many two-lane primary highway projects.

- Although the sample pool was admittedly very small, early indications are that the rideability provision has a great deal of potential for improving overlay quality.

RECOMMENDATIONS

The most important recommendation that this interim report could make, "to expand the pilot," has already been implemented. During the 1997 construction season, approximately 615 km of maintenance resurfacing in six of the nine districts (a 900 percent increase over 1996) was accomplished using the inertial road profiler-based provision for smoothness.

Research should continue in order to study the influence of functional classification and other factors on the achievable ride quality of Virginia's overlays. It appears that different targets for different functional classifications would be appropriate. It may also prove reasonable to allow exceptions in accordance with mix type and thickness, original surface smoothness or distresses, and other issues currently under investigation.

Further into the future, a "variability" approach for the smoothness provision may be worth considering. The current specification language evaluates and pays according to the average ride quality at 160-meter (0.1-mile) intervals. The mechanism for addressing extreme localized roughness (bumps) is also important, but receives less of an emphasis. It is possible that smoothness provisions could be made more effective by taking aim at ride variability, considering it along with average ride quality. The goals and hypotheses involved are much like those of the initial effort: consistency of good ride quality is every bit as (or more) important in assessing good construction quality as a desirable overall MRI.

ACKNOWLEDGEMENTS

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