2007 Ride Specification Paving Results

Prepared by:
Pavement Design and Evaluation Section
Materials Division
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VIRGINIA DEPARTMENT OF TRANSPORTATION

2007 RIDE SPECIFICATION PAVING RESULTS

BY

PAVEMENT DESIGN AND EVALUATION SECTION
CENTRAL OFFICE, MATERIALS DIVISION
JULY 2008

Comments should be directed to
Affan Habib, P.E., Pavement Program Engineer
Materials Division, Central Office
1401 E. Broad St, Richmond, VA 23219
Ph: (804) 328-3129, email: affan.habib@vdot.virginia.gov

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EXECUTIVE SUMMARY

As a response to the public's desire for smoother roads and FHWA's goals to reduce road roughness and decrease vehicle user costs, the Virginia Department of Transportation (VDOT) developed a ride quality specification for appropriate application to paving projects across the Commonwealth. This Ride Specification utilizes high-speed profilers to capture pavement roughness, with the intent to provide pay incentive to contractors to achieve smoothness in their paving operations or pay disincentive for failing to achieve desired ride or improvement. The ride (smoothness or roughness of the road) is measured by an index called International Roughness Index (IRI) and is expressed in terms of in/mile. The lower the IRI number, the better the ride and vice versa. Following ranges could be used as general categorization for pavement ride; Excellent: less than 60, Good: in between 60 and 100, Fair: in between 100 and 140, Poor: in between 140 and 200 and Very Poor: greater than 200.

VDOT has ride specifications for both asphalt and concrete pavements. In 2007, VDOT applied the Ride Specification to 67 maintenance projects across the state (involving asphalt concrete placement), totaling over 408 lane miles in length. VDOT did not have any hydraulic cement concrete project subject to ride specifications in 2007. Among the ride spec projects, an overwhelming majority number of projects (64) were maintenance and three were new construction projects. For the maintenance projects, the average after paving IRI was 62 in/mile, marking a 27% improvement in ride quality as obtained by comparing the after paving ride with that for before paving for the same project. The average ride for the two construction projects was 53 in/mile, while the third one was subjected to corrective action and no ride testing was performed following corrective action. The average IRI on statewide asphaltic in service interstate and primary routes in 2007 had been reported to be 95 in/mile by the Asset Management Division. In 2007, contractors earned a net bonus of $528,327 or approximately 2.87% of the $18.4 million paving cost for the projects (plant mix and construction combined) where the Ride Specifications were applied. This represents a total incentive payment amount of $776,107 and a total applied disincentive of $247,780. Additionally, administrative cost to implement ride spec on 408 lane miles of paving projects in 2007 is estimated to be around $93,800.

By applying ride spec in paving projects VDOT is expected to achieve many fold benefits. Following are some estimated benefits from having ride spec on 408 lane miles of pavement in 2007 paving year.

- Having ride spec is expected to make the roads about 10% smoother compared to roads paved without ride spec.

- With 10% improvement in ride, the resurfacing work can be expected to be deferred by 2 years.
- Deferral of resurfacing works by 2 years is associated with a potential savings of about $1,525/lane mile. For having ride spec on 408 lane miles in 2007, the direct saving to the agency is estimated to be around $622,000.
- Assuming 10% improvement in ride will result in 3% fuel efficiency, yearly fuel saving is estimated to be 2.4 million dollars.

In 2006, VDOT increased the incentive amount in its ride specifications for the maintenance projects. In order to assess the impact of the change, the rideability specification statistics from 2006 and 2007 paving seasons were compared to those from 2005 and 2004. Statistical comparison indicates that the specification change led to smoother and more consistent paving in 2006 and 2007 for which the increase was in effect.

This report provides the summary statistics for 2007 rideability projects and the apparent trends in ride data over the past years. The data was collected by the Lynchburg NDT Section and pay adjustments were computed by District Materials and Pavement Management personnel.

PURPOSE OF THIS REPORT

The purpose of this report is to provide VDOT management summary statistics of the statewide ride spec results for projects in 2007. The parameters included in the analysis are incentive/disincentive payment amount, before and after paving ride data and percent improvements. The information was assessed based on various districts and systems. Finally, the results have been compared with those of previous years to assess any trends. This report is also intended to provide an overall picture of the impact of the change in incentive in the ride spec made in 2005.

BACKGROUND

History

Beginning in 1996, VDOT implemented ride quality specifications that incorporated high-speed inertial profilers and the International Roughness Index (IRI) to provide incentives for the construction of smooth pavements. Since that time, based on years of analysis, VDOT has enhanced and modified the ride specification several times[1]. A detailed history of the development of VDOT's Ride Specification can be found in Appendix A: VDOT's History of Ride Specifications.

In 1996, the Federal Highway Administration (FHWA) initiated a national survey among the road users result of which identified that the road condition was the top priority for the traveling public followed by safety and reducing congestion[2]. FHWA also recognizes the fact that pavement smoothness provides the best quantifiable measure of the pavement condition[2]. FHWA mandates the states to provide FHWA IRI data on roads within the National Highway System on routine basis as part of Highway Performance Monitoring System (HPMS) program. Many studies have shown that roads built smoother last longer and stay smoother compared to roads built relatively rougher. It is therefore very important to make every effort to increase the smoothness of the road when it comes to new construction or resurfacing. VDOT's rideability specification is aimed to achieve public expectation to have smooth roads and is in line with FHWA's guidance and initiative to improve ride quality.

In its current form, the Ride Specification has two separate sets of IRI ranges used to calculate the incentives or disincentives to be applied on a project; one for Interstate routes and the other for U.S. and State Routes. For each system, separate pay adjustment rates had been established for maintenance and construction projects. Pay adjustments on maintenance projects are applied only on the surface asphalt layer, while that on construction projects are applied over all asphalt layers. Tables 1 and 2 show the current ride relative pay ranges for Interstate and Non-Interstate

projects, respectively. Using these pay ranges, pay adjustment is first calculated for each 0.01 mile of road. The 0.01 mile pay adjustments are aggregated over 0.1 mile increments to compute the pay adjustment for the 0.1 mile section. The pay adjustment for all 0.1 mile sections over the entire project are summed together to compute the final pay adjustment for the project in question.

For single lift asphalt concrete resurfacing applications (where the resurfacing is limited to 1.5 to 2 inches), depending on the initial condition of the pavement the contractor may not have the control necessary to achieve ride in the 100% pay range but still can achieve a substantial improvement in ride quality. In this situation, VDOT protects the contractor from penalty by applying a 30% improvement clause to the ride specification. This clause allows for full pay on any 0.10 mile section of the project where the after paving IRI is at least 30% smoother than the before paving IRI. However, this does not apply to multi-lift maintenance projects where contractor has more control to achieve desired ride.

INTERSTATE SYSTEM		
After Paving IRI (Inches Per Mile)	Maintenance Projects Pay Adjustment (Percent Surface Mix Unit Price)	Construction Projects Pay Adjustment (Percent Pavement Unit Price)
45.0 and Under	115	105
45.1-55.0	110	103
55.1-70.0	100	100
70.1-80.0	90	90
80.1-90.0	80	80
90.1-100.0	70	70
100.1-120.0	60 or Subject to Corrective Action	60 or Subject to Corrective Action
120.1-140.0	40 or Subject to Corrective Action	40 or Subject to Corrective Action
140.1-160.0	20 or Subject to Corrective Action	20 or Subject to Corrective Action
Over 160.1	0 or Subject to Corrective Action	0 or Subject to Corrective Action

Table 1: Pay Adjustment Ranges for Interstate Routes

NON-INTERSTATE SYSTEM		
After Paving IRI (Inches Per Mile)	Maintenance Projects Pay Adjustment (Percent Surface Mix Unit Price)	Construction Projects Pay Adjustment (Percent Pavement Unit Price)
55.0 and Under	115	105
55.1-65.0	110	103
65.1-80.0	100	100
80.1-90.0	90	90
90.1-100.0	80	80
100.1-110.0	70	70
110.1-130.0	60 or Subject to Corrective Action	60 or Subject to Corrective Action
130.1-150.0	40 or Subject to Corrective Action	40 or Subject to Corrective Action
150.1-170.0	20 or Subject to Corrective Action	20 or Subject to Corrective Action
Over 170.1	0 or Subject to Corrective Action	0 or Subject to Corrective Action

Table 2: Pay Adjustment Ranges for Non-Interstate Routes

Ride Spec Site Selection

Ride specifications should be applied to roadways with mix types, project characteristics and pavement conditions that provide a contractor with ample opportunity to meet the requirements. To aid VDOT personnel to determine to which projects the rideability specifications are to be applied, a set of guidelines has been developed. These guidelines are based on VDOT's experiences gathered over the years. A comprehensive list of guidelines for Ride Project selection can be found in Appendix B: Project Considerations.

QUALITY MANAGEMENT FOR RIDEABILITY TESTING

Equipment and Operators

The keys to collecting quality ride data are good equipment and experienced operators. VDOT owns and operates two (2) International Cybernetics Corporation, Inc. inertial profilers. Both profilers are equipped with lasers and accelerometers for longitudinal profiler data collection. Many studies over the last ten years have pointed out the variability between equipment manufactures. For that reason, VDOT has only used one equipment type for data collection.

VDOT equipment operators have many years of experience using inertial profilers. Driving experience is critical to measuring the longitudinal wheel path profiles and experience with the equipment allows for adaptation of testing procedures to project requirements. Operator experience in both these areas has reduced the variability in IRI results.

Equipment Verification and Consistency

VDOT's quality management program requires inertial profile equipment be verified and that consistent test procedures are followed at all sites. The verification procedures apply to the lasers, accelerometers and distance measuring instruments. These procedures are part of a three-tier process – daily, weekly and monthly verifications. These checks are designed to limit the risk of bad data collection to a short period of time, determine the repeatability and accuracy of equipment and to detect sensor drift over time. To insure the consistency of data collection between one site and another, Virginia Test Method (VTM) 106 was developed. For a description of the daily, weekly and monthly verifications as well as the details of VTM 106, see Appendix C: Quality Management Program Details.

RESULTS

This report outlines the results of the rideability specifications projects in 2007. The following parameters were considered and presented in detail.

- Number of test sites
- Results by district and system
- Cost of implementing rideability specifications including net incentive or disincentive applied
- Comparisons of roughness between Stone Matrix Asphalt (SMA) and Superpave mixes

Number of Sites and Lane Miles per District

Tables 3 and 4 show the number and total lane miles of Ride Spec sites in the 2007 Plant Mix and construction schedules by District and System respectively; IS are interstate routes; U.S. are United States routes; and SR are State Routes. For all of the following tables and figures, the districts will be referenced by District Number as shown in Tables 3 and 4. The 2007 Plant Mix schedules included both single and multi lift projects which had been analyzed together. The miles paved with ride specifications represent about 5% of the total plant mix schedule (about 7,100 lane miles) for the paving year of 2007.

District Number	District	Number of Construction Rideability Projects	Number of Plant Mix Rideability Projects			
			IS	US	SR	Sub-total
1	Bristol	1				
2	Salem		5	5	1	11
3	Lynchburg			10		10
4	Richmond		3	5	5	13
5	Hampton Rds.		2			2
6	Fredericksburg		1	6	1	8
7	Culpeper	1	3	4		7
8	Staunton		5	3		8
9	No.Va.	1	3		2	5
Sub-total		3	22	33	9	64
Total		67				

Table 3: Rideability Projects in 2007 by District and System

District Number	District	Number of Lane Miles of Construction Rideability Projects	Number of Lane Miles of Plant Mix Rideability Projects			
			IS	US	SR	Sub-total
1	Bristol	10				
2	Salem		24	22	3	49
3	Lynchburg			69		69
4	Richmond		29	20	15	64
5	Hampton Rds.		5			5
6	Fredericksburg		10	32	5	47
7	Culpeper	6	32	26		58
8	Staunton		44	28		71
9	No.Va.	8	15		5	20
Sub-total		24	159	197	28	384
Total		408				

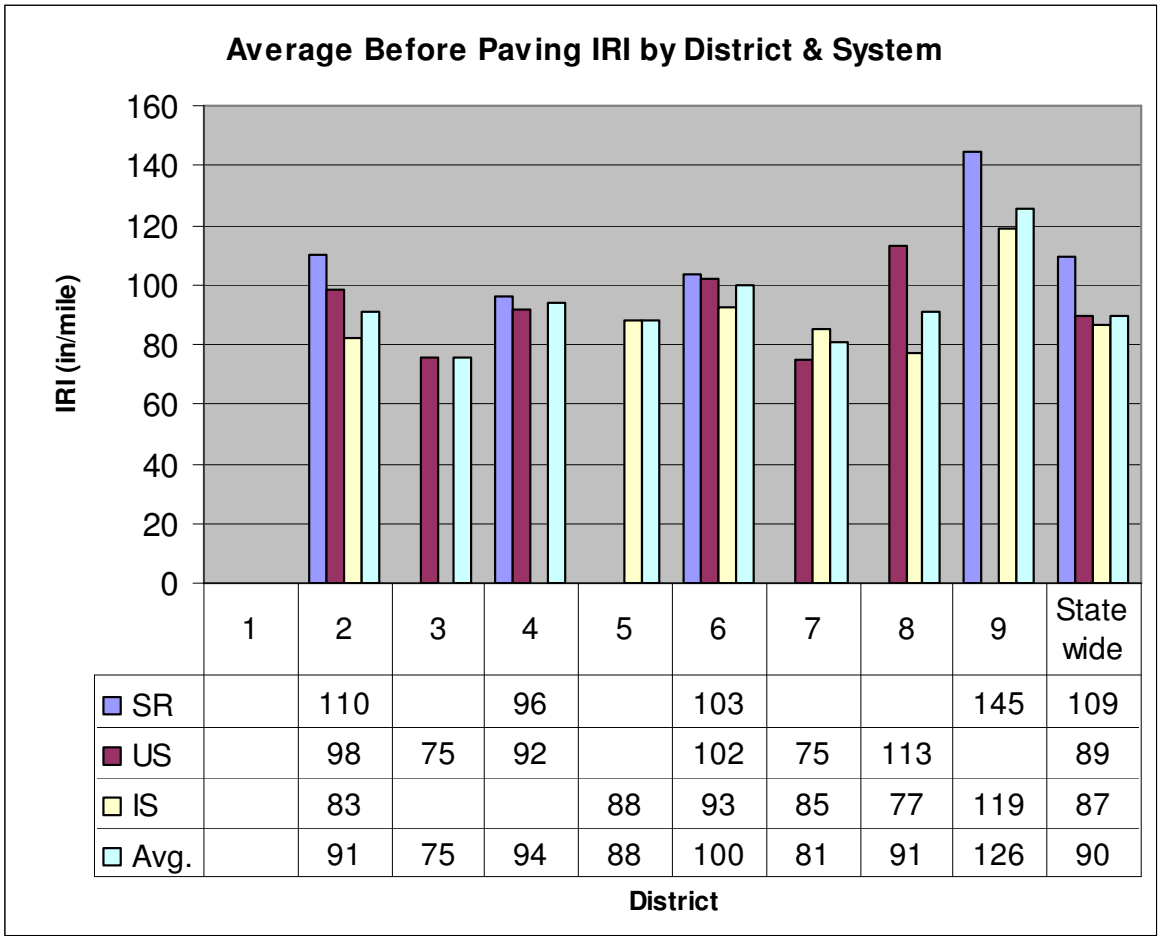
Table 4: Rideability Project Lane Miles in 2007 by District and System

Results by Districts and Systems

Before Paving Ride Results

Figure 1 provides before paving average IRI, grouped by district and system, respectively for the plant mix projects. Note that the projects involving multiple lifts do not require ride testing before paving for pay adjustment calculation and hence the before paving IRI were not recorded for those projects. Interstate routes had the lowest average IRI before paving, followed closely by U.S. routes and State routes were the roughest before maintenance or paving. This trend was expected; Interstate and U.S. routes generally have the highest traffic, requiring a higher level of

serviceability than State routes, which may be allowed to reach lower standards before maintenance can be scheduled.

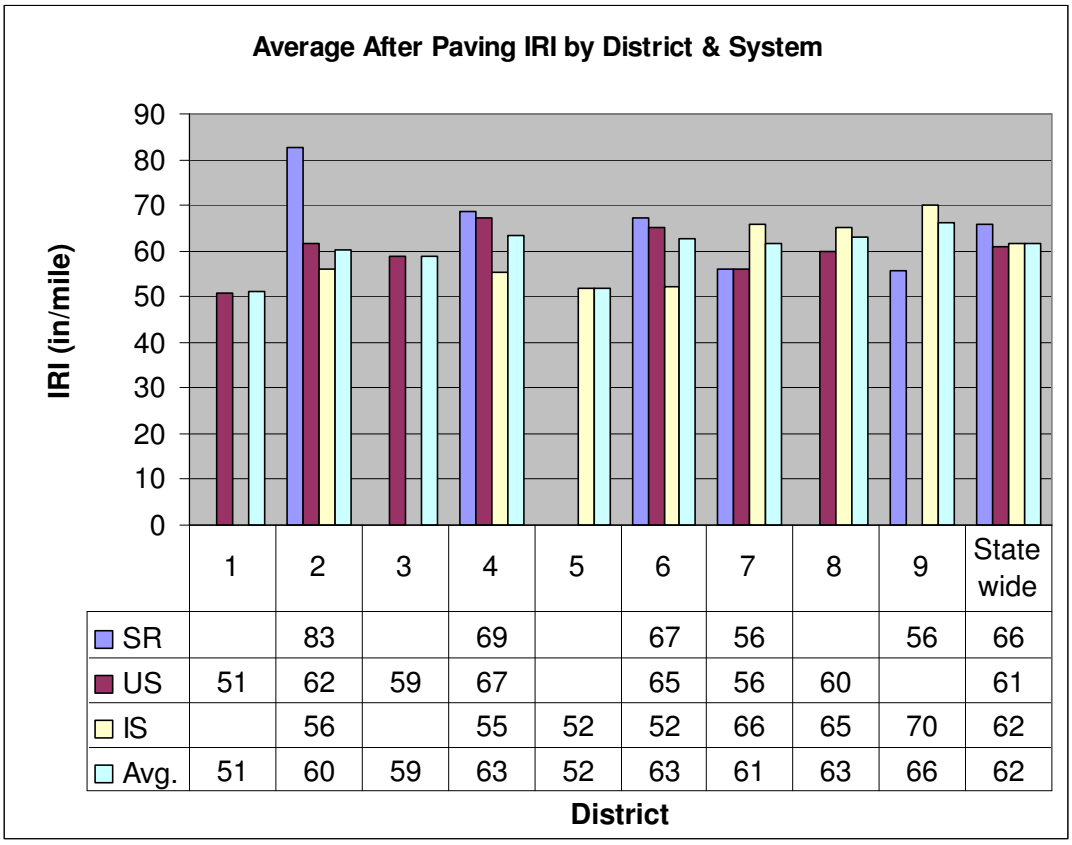


	1	2	3	4	5	6	7	8	9	State wide
SR		110		96		103			145	109
US		98	75	92		102	75	113		89
IS		83			88	93	85	77	119	87
Avg.		91	75	94	88	100	81	91	126	90

Figure 1: Average Before Paving IRI by District and System

After Paving Ride Results

Within 30 days of the completion of paving, profile testing was conducted on the finished surface course of the rideability sites. The after paving IRI show a similar trend as the before paving IRI; U.S. and Interstate routes have almost identical IRIs after paving and have significantly lower IRI than State routes. Figure 2 summarizes the results of the after paving IRI for each district and by system. Please note the average IRI values presented in this report represent the algebraic average of the individual 0.01 mile IRI for the respective categories.



	1	2	3	4	5	6	7	8	9	State wide
SR		83		69		67	56		56	66
US	51	62	59	67		65	56	60		61
IS		56		55	52	52	66	65	70	62
Avg.	51	60	59	63	52	63	61	63	66	62

Figure 2: Average After Paving IRI by District and System

Discussion of Interstate Results

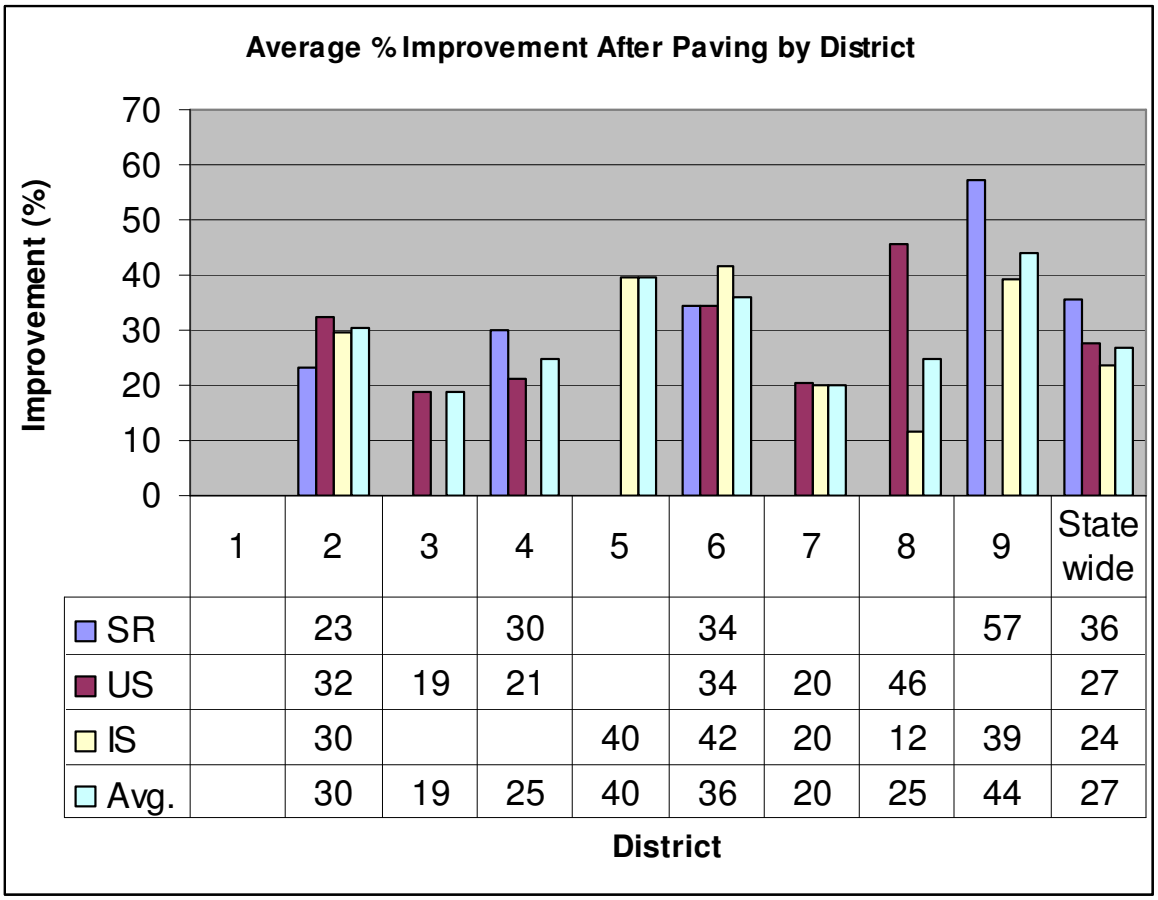
Table 5 shows the average IRI for the interstate routes separated by mix type. The data shows that after maintenance the average IRI for stone matrix asphalt (SMA) mixes, 56, was significantly lower than that of regular, Superpave mixes, 65. Since the first widespread use of SMA on the Interstate system, the IRI for SMA projects were higher than Superpave projects in the initial years, however the gap subsequently reduced and consistently smoother ride for SMA projects (as compared to those with Superpave projects) had been achieved for the last few years. The trend continued in 2007 as well. This clearly demonstrates that the contractors have overcome the initial difficulties with SMA mixes and placement and have progressively developed expertise with SMA mixes.

Route Type	Average After Paving IRI	Lane Miles Tested
Interstate (All)	62	159
Interstate (Superpave mixes)	65	89
Interstate (SMA mixes)	56	70

Table 5: Results for Interstate Rideability Projects in 2007 by Mix Type

Percent Improvement

The percent improvement in ride quality due to paving was calculated using the results of before and after paving IRI testing. It is to be noted, percent improvement applies to only single lift maintenance projects as before paving IRI testing is not required on multiple lift maintenance projects. Percent improvement is also not relevant to construction projects. The system with the highest before paving IRI (i.e., state routes) had the greatest percent improvement followed by U.S. and Interstate routes. This is due to the fact that SR routes were, on average, 25% rougher prior to paving than IS routes which facilitated the achievement of higher percent improvements. The statewide, average percent improvement was 27%, while four Districts reported improvement in excess of 30%. Figure 3 summarizes the results of the percent improvement for each district and by system. It is to be noted that percent improvement is relative to before paving IRI value and is not an automatic indicator of the final ride after paving.



	1	2	3	4	5	6	7	8	9	State wide
SR		23		30		34			57	36
US		32	19	21		34	20	46		27
IS		30			40	42	20	12	39	24
Avg.		30	19	25	40	36	20	25	44	27

Figure 3: Percent Improvement in Ride from Maintenance by District and System

Costs

The cost to implement the rideability specifications in paving projects include the following two separate components:

1. Pay Incentive/Disincentive for projects based on ride
2. Administrative cost including equipment and personnel time for testing and processing the ride spec with any travel expenses.

Incentives and disincentives, as reported by District Materials/Pavement Management personnel, were summarized over the statewide projects. The costs of VDOT personnel to test and process the rideability projects were estimated from past records and experience. These two cost components are discussed separately in the following two sections. Overall, the total cost to implement the rideability specifications in 2007 paving projects was estimated to be $622,187 or 3.39% of the total paving cost of the projects.

Incentives/Disincentives

Table 6 shows the amount paid in incentives/disincentives for rideability projects in 2007. Table 6 also shows that most of the incentives were paid for U.S. routes, which comprised the largest portion of ride candidates. A net incentive of $525,388 was awarded to the contractors for statewide Plant Mix ride projects in 2007. The net incentive on the two construction projects was $2,939 (one project in Nova was excluded). The grand total pay adjustment for the paving year 2007 is $528,327.

District	Pay adjustment for Plant Mix Projects ($)			Pay Adjustment for Construction Projects ($)	Total Pay Adjustment ($)	Estimated Paving Costs ($)	Percentage of Paving Cost (%)
	IS	US	SR				
Bristol				7,828	7,828	788,992	0.99
Salem	22,396	40,897	(5,616)		57,677	2,252,085	2.56
Lynchburg		171,067			171,067	2,511,204	6.81
Richmond	75,452	21,862	9,833		107,147	3,180,158	3.37
Hampton Rds.	21,458				21,458	336,236	6.38
Fredericksburg	54,318	34,384	$4,830		93,532	2,094,461	4.47
Culpeper	(24,665)	70,297		(4,889)	40,743	2,664,405	1.53
Staunton	(56,653)	77,358			20,705	3,557,634	0.58
No.Va.[Note 1]	(7,635)		15,805		8,170	993,089	0.82
Total	84,671	415,865	24,853	2,939	528,327	18,378,264	2.87

Table 6: Incentive/Disincentive for Rideability Projects in 2007
Note 1: One construction project in Nova was subject to corrective action and was excluded in the table

A total of $776,107 was applied as incentive payment and 247,780 was applied as disincentive payment making the net payment of $528,327. At each project, ride is analyzed separately for the

lanes. Statewide, incentive was assessed at 111 project lanes, while disincentive was assessed at only 32 project lanes. This implies better paving works being achieved at ride spec projects.

Administrative Costs

Statewide, there were 67 ride projects in 2007 and the average length of a ride specification site was 6.08 lane miles. Administrative costs include the cost to test and time spent to process ride spec software to calculate pay adjustment. Based on established charge rates for technicians/equipment and assuming an average of 6 hours to process the rideability data, the total employee costs were estimated. The total administrative costs to perform ride specification testing and processing was estimated at approximately $93,800. This corresponds to 0.51% of the total statewide paving costs for 2007 projects utilizing the ride specification. These costs are shown in Table 7.

Activity	Cost/Site ($)	Total Costs ($)
Testing (Before and After, 2 runs/lane)	1,190	78,540
Processing (requests, analysis, report)	210	13,860
Total Administrative Costs	1,400	93,800

Table 7: Administrative Costs for Rideability Projects in 2007

Comparison of 2007 Data with Previous Years

The pay adjustment data of 2007 were compared to those with 2006 and combined 2005 and 2004 data. All rideability specification sites paved in respective years (including construction projects) were considered. 2004 and 2005 data were combined into a single database and is referred to as 2005 data for simplicity. Table 8 demonstrates that the statewide incentive pay adjustment for 2006 paving year was far greater than that of any other year. A possible explanation for higher incentive payment in 2006 compared to 2007 was that very low IRI was obtained by the contractors in Staunton district which facilitated the utilization of the increased pay ranges to greater extent. As a matter of fact, Staunton district 2006 paving constituted about 12% of the total statewide lane miles paved, however, the incentive payment represents about 33% of the total statewide adjustment payment. This reveals that good paving works could be significantly benefited by the pay adjustment increase made in 2005.

Paving Year	Pay Adjustment ($)	Lane Miles Paved (Miles)	Pay Adjustment per Lane Mile ($/Lane Mi)
2007	528,327	408	1,294
2006	1,088,188	546	1,994
2005	(19,933)	950	(21)

Table 8: Pay Adjustment for Rideability Projects for Successive Years

IMPACT OF INCREASING BONUS IN RIDE SPECIFICATIONS

Starting in the 2006 paving season, the upper two incentive ranges in the ride specification were increased from 105 and 110 percent pay (2003 Ride Specification) to 110 and 115 percent pay (2005 Ride Specification) for maintenance (plant mix) projects. In order to determine the effect of this change, the average IRI, percent improvements and total incentives paid during the last two years were compared to 2005 and 2004 paving seasons.

For the purpose of an accurate comparison, all projects carried over from 2005 into the 2006 or 2007 schedules and construction projects were omitted from the analysis because the specification change was not applied to those projects. About 351 lane miles were paved using 2005 spec in 2007 and are considered for this impact analysis (others are excluded). Therefore, the statistics for 2007 presented in this section are somewhat different from those presented in the previous sections of this report. Also, note that data from the 2004 and 2005 paving seasons were analyzed together; so, for the purposes of this report, the 2004 and 2005 data will hence forth be referred to as the 2005 data, for simplicity's sake. The following figures (Figures 4, 5, 6 and 7) show the average IRI values before and after paving, the average percent improvement and the average standard deviation of after paving IRI by year and by route classification over the successive years. Figure 8 provides the pay adjustment per lane mile for these years.

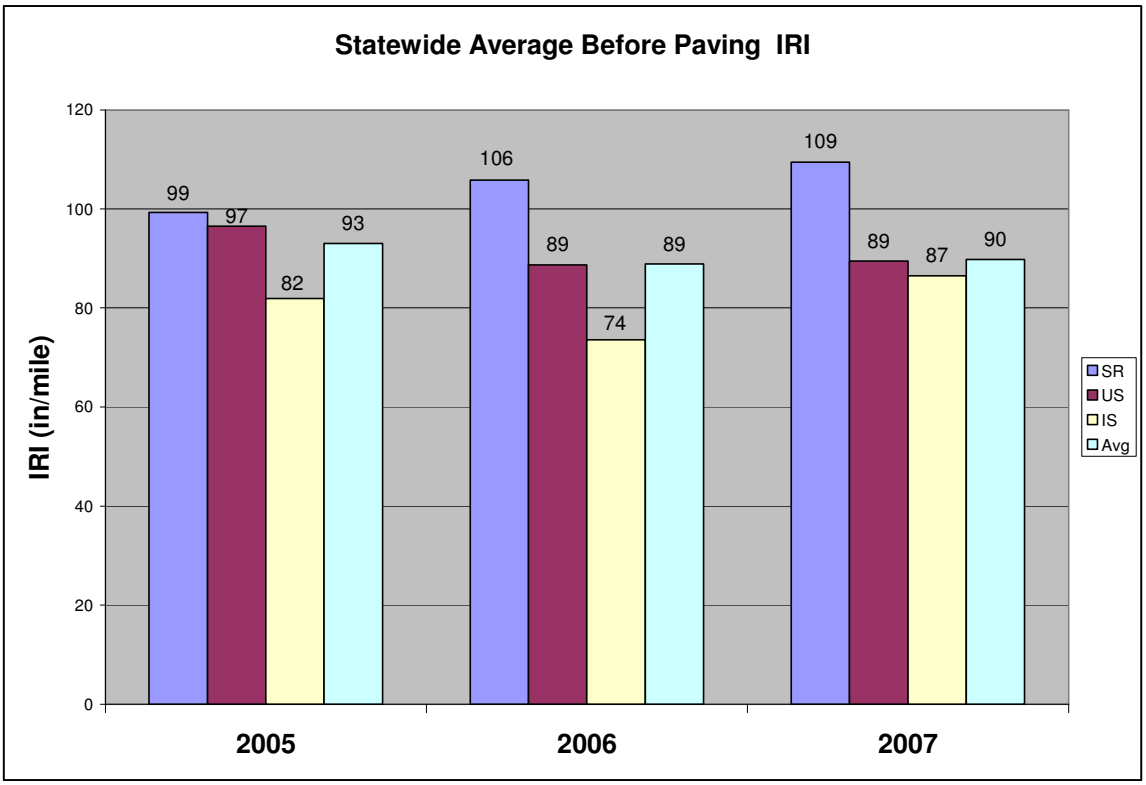


Figure 4: Statewide Before Paving Average IRI for Successive Years

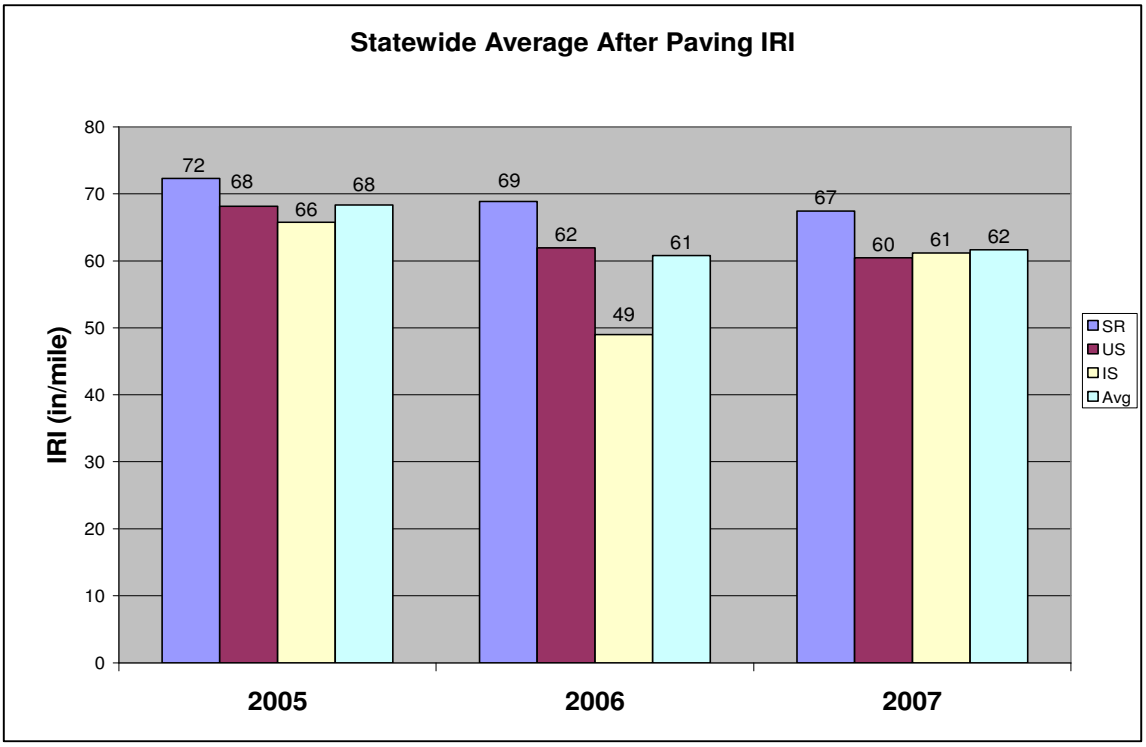


Figure 5: Statewide After Paving Average IRI for Successive Years

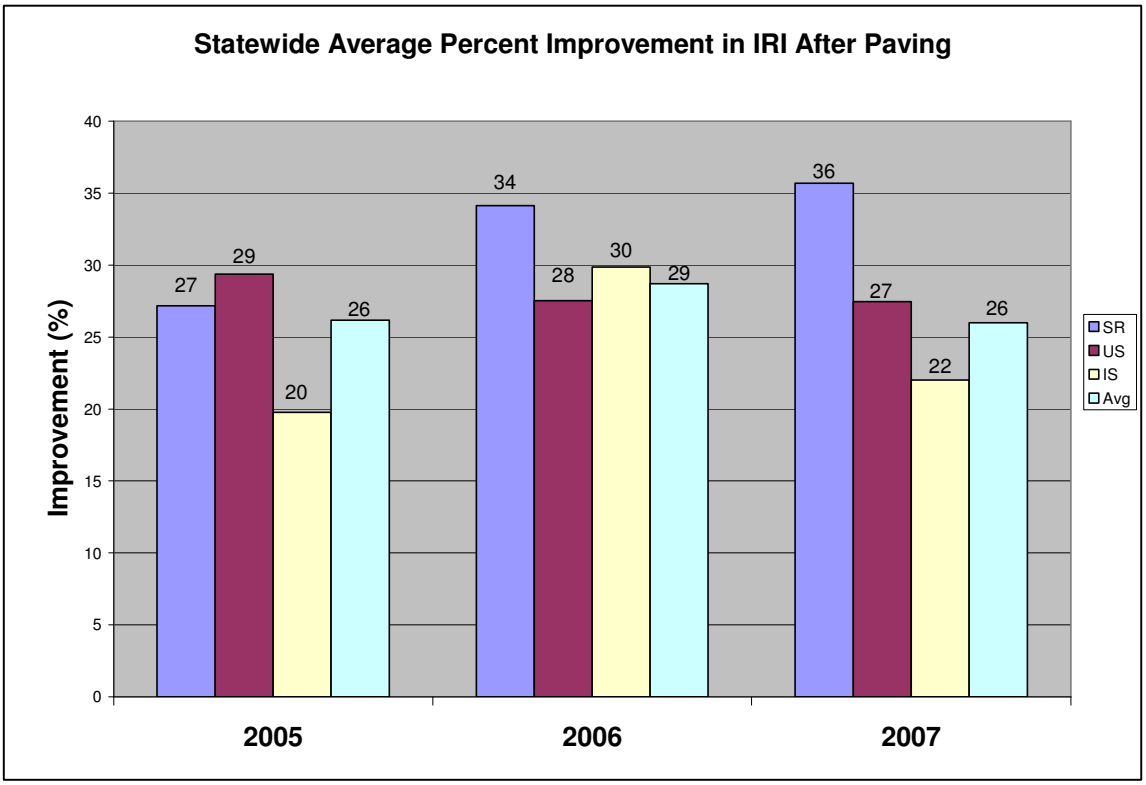


Figure 6: Statewide Average Percent Improvement for Successive Years

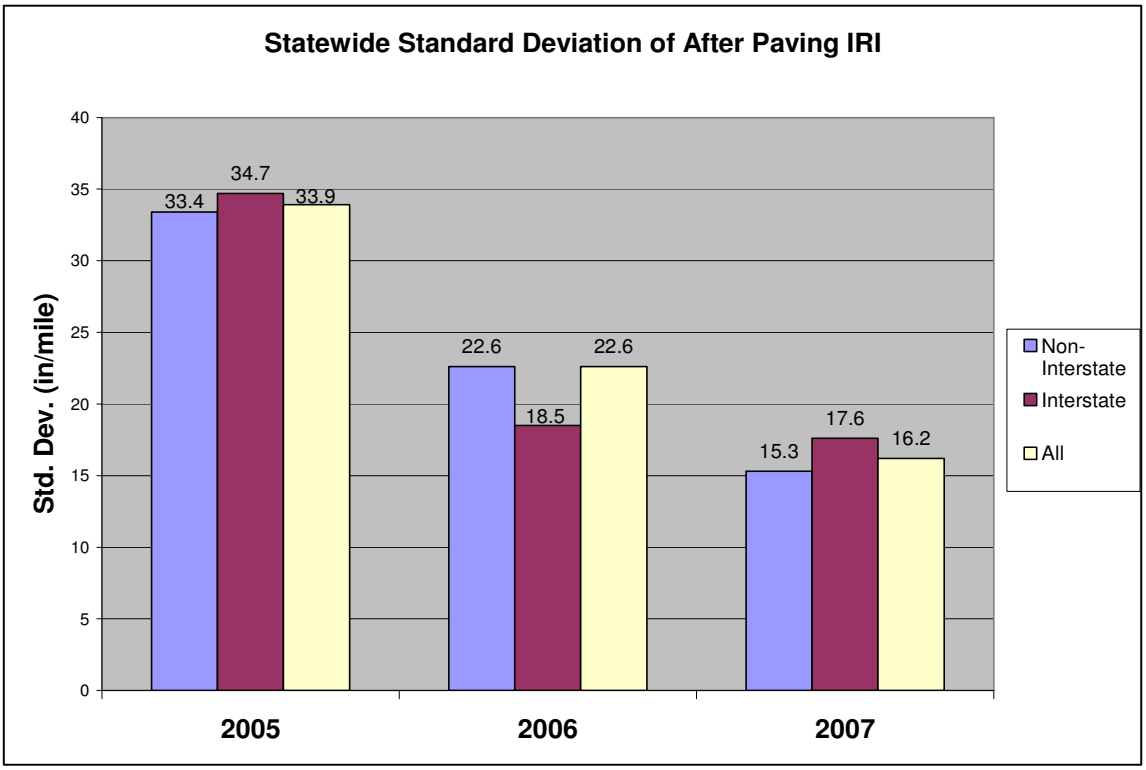


Figure 7: Statewide Standard Deviation in After Paving IRI for Successive Years

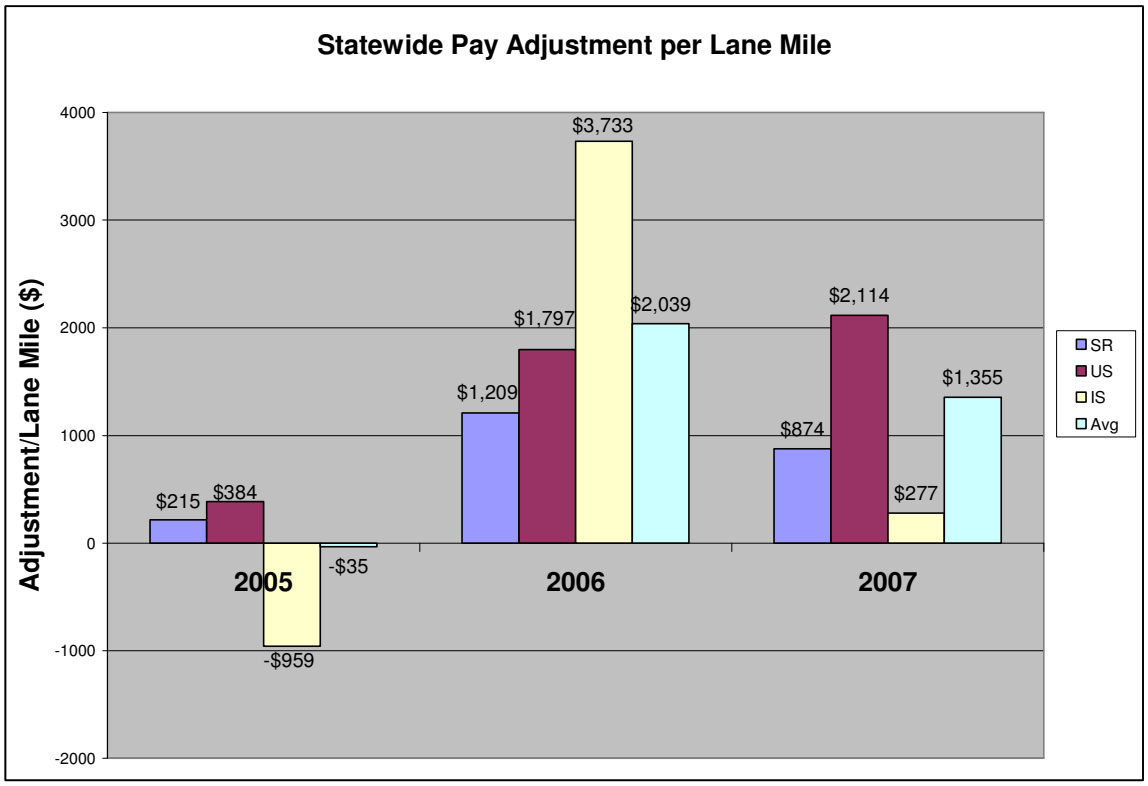


Figure 8: Statewide Pay Adjustment per Lane Mile for Successive Years

It is evident that after paving ride generally increased in 2006 and 2007 compared to that of 2005. Although 2007 average after paving ride shows slightly higher IRI values for all roadway types than those of 2006, 2007 ride data has significantly lower standard deviation indicating progressively reduced divergence in paving quality which is also very much desired. All these are indicative that by applying ride specifications, the ride quality is getting progressively better in Virginia.

A detailed statistical analysis of the data represented by Figures 7, 8, 9, and 10 led to the conclusion that the specification change had, on average, a significant and positive effect on the results of maintenance projects in 2006 and 2007. With 99% confidence, the following general conclusions can be made about the differences between the 2005 and 2007 paving results. In 2007:

- the average after paving IRI was lower by 6.0 IRI
- the standard deviation in the after paving IRI was almost half that of 2005 for all routes

With 99% confidence, the following general conclusions can be made about the differences between 2005 and 2006 paving results. In 2006:

- the average after paving IRI was lower by 7.0
- the standard deviation in the after paving IRI was lower than 2005

In 2006, the average after paving IRI for Interstate projects dropped to a very low of 49. Since 1999, the lowest average after paving IRI for Interstate projects was 60[1]. In 2007, the Interstate average returned to a more typical value of 62 in./mi. So, the very low IRI number obtained in 2006 paving year was not consistently reflected in the subsequent year, i.e., 2007. Upon closer review, the reason for the 2006 Interstate paving results became somewhat apparent. In 2006, the ride specification was only applied to 86 lane miles of Interstate paving. Also, the Interstate ride sites were limited to two (2) districts: Richmond and Staunton; of which, Staunton district accounted for over 80% of the total lane miles. In 2006, the contractors in Staunton were able to consistently achieve after paving IRI in the 30's and 40's, averaging 45 in/mile which is most likely a reflection of the very low average before paving IRI of the sites (71 in/mile). As a result of this unusual distribution of lane miles and the low average before paving IRI statewide Interstate results in 2006 were much lower than both 2005 and 2007 results.

Overall, the specification change appears to have a positive effect on after paving IRI. In 2006 and 2007, both the average values and the standard deviations in after paving IRI decreased by substantial amounts. The results of paving operations statewide not only became smoother but

they are also were more closely banded around those seasons' averages, indicating better, more consistent paving work may have resulted from the change. For the complete statistical analysis, refer to Appendix D: Details of Statistical Analysis. However, a further comprehensive statistical analysis involving all affecting factors is necessary to ascertain the impact of the spec change to its fullest extent.

DISCUSSION

In general, the ride for pavement sections subject to rideability specifications appear to improve progressively. However, this improvement did not come without cost. Over the 2004 and 2005 paving seasons, the ride specification resulted in a net penalty of $19,933; a disincentive of $21 per lane mile or 0.06% of the $33.4 million paving cost of those years' ride projects. In 2006, the ride specification resulted in $1,088,188 of bonuses; an incentive of $1,994 per lane mile or 5.25% of the $20.7 million paving cost of ride projects in that year. In 2007, the specification resulted in a net bonus of $528,327; an incentive of $1,294 per lane mile or 2.87% of the $18.4 million paving cost of ride projects in that year. Therefore, amount of pay adjustments in 2006 and 2007 has significantly increased compared to the previous two years. The increase in payment adjustment could be attributable to better quality paving (as evident by progressively lower IRI values and lower standard deviation), increase in incentive pay ranges of the specifications made in 2005 and increasingly higher asphalt price. However, it can be ascertained that the long term benefits of smoother pavement justifies the cost (incentive plus administrative) very well. The benefit of having smoother roads could be attributed to direct savings to the agency from deferred resurfacing works by about 2 years and substantial savings in terms of fuel efficiency (especially for the trucks), less congestion due to deferred resurfacing, less vehicle maintenance cost (from smoother roads) etc. In order to get a detailed picture of the benefits of smoother roads, please refer to the VTRC research report "Impact of a Smoothness Incentive/Disincentive on Hot-Mix Asphalt Maintenance Resurfacing Costs" (VTRC 06-R28)[3]. Using the information from the referenced report and with some reasonable assumptions, the following benefits could be assumed to have obtained by applying ride specifications over 424 lane miles of pavements in 2007:

1. Having ride spec is expected to make the roads about 10% smoother compared to roads paved without ride spec[3].
2. With 10% improvement in ride, the resurfacing work can be expected to be deferred by 2 years.

3. Deferral of resurfacing works by 2 years is associated with a potential savings of about $1,525/lane mile. For having ride spec on 408 lane miles in 2007, the direct saving to the agency is estimated to be around $622,000.
4. Assuming 10% improvement in ride will result in 3% fuel efficiency, yearly fuel saving is estimated to be 2.4 million dollars (Appendix E: Detailed Benefit Computation).

CONCLUSIONS AND RECOMMENDATIONS

In 2007, all nine districts had paving projects subject to ride spec with varying size. Majority of these projects were either interstate or US routes while a small portion was on state routes. The distribution is obvious due to the fact that state routes are expected to have more obstruction (signals, intersections, utility manholes etc) to apply ride spec compared to interstate and US routes. From the data it is apparent that overall ride quality for Virginia's rideability projects has improved in 2007.

In 2006, the average improvement in ride quality increased to over 29% after paving was completed, but the net pay adjustment figure rose dramatically (to over $1 million) as a result of the change in the incentives.

In 2007, a similar low after maintenance IRI was achieved. This represents about 27% improvement in ride quality. The net pay adjustment of the ride program dropped to about half a million dollars but this is still a significant increase when compared to the costs of the program in 2005.

However, the additional service life and reduced agency costs from smoother roads more than offset the costs of the rideability specification. A recent report published by the VTRC suggests that the improvements in ride quality could be reasonably assumed to increase pavement life by two years[3]. An extension in service life from 10 years to 12 years would provide a savings for VDOT due to the deferred rehabilitation costs; savings that are comparable if not in excess of the initial added cost of implementing the ride specification. Furthermore, increased smoothness reduces vehicle operating costs, noise pollution, greenhouse gas emissions and provides other tangible and intangible benefits to both the traveling public and third parties[3]. While limitations exist in applying the IRI-based ride specification, such as intersections, short project lengths and low-speed routes, it is recommended that VDOT continue to apply the ride specification to paving projects statewide in order to continue to realize the benefits of smooth pavements.

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REFERENCES

1. Reid, R. and Clark, T.M. *2003 Ride Specification Testing Results – Maintenance Schedules,* May, 2004.

2. US Department of Transportation, Federal Highway Administration, "Public Roads", September/October 200. Vol. 64-No. 2.

3. McGhee, K.K. and Gillespie, J.S. *Impact of a Smoothness Incentive/Disincentive on Hot-Mix Asphalt Maintenance Resurfacing Costs.* VTRC 06-R28. Virginia Transportation Research Council, Charlottesville, 2006.

4. U.S. Department of Transportation, National Highway Traffic Safety Administration, "Traffic Safety Facts 2005". Publication No. DOT HS 810 631. Washington, D.C., 2006

5. Habib, A., Wells, M., and Pettigrew, L. *High Speed Profiler Calibration and Maintenance: VDOT's Strategy and Practice.* In proceedings, Transportation Research Board Annual Meeting, Washington D.C., January, 2008.

APPENDIX A: VDOT'S HISTORY OF RIDE SPECIFICATIONS

VDOT's History with Ride Specifications

In 1995, VDOT's primary method for regulating smoothness of highway surfaces used a specification that was built around the California-type profilograph. The profilograph can be described as a long (25 ft) rigid frame assembly with several wheels at each end and a measurement wheel at the center. As the instrument moves along a surface, the center wheel travels up and down with variations in the surface. The amount of up and down movement is accumulated and reported as roughness. In some situations, a vehicle can tow the profilograph. More commonly, however, the instrument is pushed along the pavement by hand.

VDOT's engineers had very good reasons for being reluctant to use the existing smoothness special provision on a widespread basis. The first of those reasons was that administering the specification would involve manually propelling the profilograph for two passes over each of the lanes of a project, if all went perfectly. With limitations on budget and a desire to reduce workforce, implementing the smoothness special provision would have been difficult, if not impossible.

A second and perhaps more compelling reason for VDOT's aversion to the traditional specification was one of safety. According to statistics published by the Federal Highway Administration's Work Zone Safety Program, 1074 people were killed in 2005 in work-zone-related accidents[4]. Although most of these fatalities were individuals operating or traveling in motor vehicles, 161 (15%) were non-motorists. It is safe to assume that a large portion (if not the majority) of non-motorists injured in a work zone are either construction workers or inspectors. The fact that the existing Virginia special provision for smoothness involved performing manual tests within several feet of high-speed traffic made it very unattractive in consideration of statistics like these.

A New Smoothness Provision

Virginia's solution was a new specification, one with which testing could be conducted at highway speeds and without the need to expose workers directly to traffic. The new provision replaced the California Profilograph with an inertial road profiler. Inertial profilers measure longitudinal profiles in accordance with the American Society for Testing and Materials (ASTM) standard E950. These systems combine accelerometers, height sensors, and electronic distance measuring equipment on a vehicle to collect two profiles with each pass, one representing the left and the other the right wheel-path. The conceptual difference between the inertial profiler and more traditional road roughness equipment is simple but important. Instead of measuring

roughness as a response to the surface profile (e.g., Mays Meter), the inertial profiler directly measures the profile.

The new provision was constructed around the International Roughness Index (IRI). The IRI, which is calculated using ASTM's Standard E1926, is produced through a simulation that applies a "virtual" quarter-vehicle to an elevation profile such as that collected with the inertial profiler. The suspension motion resulting from this simulation is accumulated and divided by the distance traveled to yield the IRI. Smaller values (less roughness) imply a smoother ride and higher values are indicative of a rougher one.

In the new special provision, an average IRI value is generated and reported for every 0.1-mile of the project. These values are then used to determine a pay adjustment for that 0.1-mile section. There is a target IRI range where full contract price is paid as well as several IRI ranges above and below this target where either disincentives (for rougher pavements) or incentives (for smoother pavements) are applied. This target IRI is not the same for all projects; interstate routes are held to higher standards then either U.S. or state routes. In addition to the IRI values generated for each pay lot, IRI's are generated at 10 subintervals and these values are reviewed to identify localized roughness or bumps/dips. A threshold for allowable roughness (maximum IRI) exists for both the pay lot and the subintervals. Roughness above these thresholds is subject to correction.

Application and Evolution of Early Provision

Although high-profile construction projects are important, they represent only a fraction of the hot mix asphalt concrete (HMAC) pavement placed during a typical construction season. In Virginia, the annual maintenance resurfacing program is responsible for a much larger portion of new surfaces. The real potential for a smoothness special provision of the type proposed would be realized only through its application to this program.

With this in mind, the 1996 resurfacing schedule was amended to include an application of the experimental smoothness specification to 41 lane miles of new surface. In its original form, the provision offered a single schedule of pay adjustments, regardless of highway system or other important characteristics of a project. To achieve 100% of the material bid price, a contractor needed to achieve a final surface IRI of 70 to 80 in/mi over the 0.1-mile lot. The maximum allowable IRI of any 0.01-mile interval was 120 in/mi.

In 1997, the pilot was expanded to 380 lane miles in six of Virginia's nine construction districts. Although not substantial, the special provision used in the second season of the pilot did incorporate a couple of minor changes. The maximum incentives and disincentives were softened

(reduced) and the pay steps were broadened slightly. The target smoothness range necessary to achieve 100 percent payment remained unchanged, but the maximum IRI eligible for payment was increased to 110 in/mi. Perhaps the most significant of the changes was acknowledgment of the influence of original surface ride quality. For all practical purposes, the added language required that a before-overlay roughness survey be conducted. It specified that a project was not eligible for an incentive if the final surface was rougher after completion of the work; regardless of the average ride quality achieved. Conversely, if a contractor was able to effect at least a 25 percent improvement (over the original surface) in ride quality, he or she would not be subject to a disincentive, regardless of the degree of roughness remaining in the final surface.

By late summer, 1997, the specification revisions governing the 1998 construction season were complete. The 1998 version provided separate pay adjustment tables for interstate and non-interstate projects. According to these new pay schedules, contractors working within the special provision on an interstate highway were required to reduce the pavement roughness by an additional 10 in/mi with the new surface. The targets for non-interstate overlays remained unchanged. The updated pay adjustments were consistent with those applied to the interstate system projects, with the appropriate increase in allowable roughness.

Beginning in 2000, the Ride Spec committee revised the language in the 1998 special provision and modified the following areas:

Section Length to Base Payment- Length was revised to 0.01 mile for payment. This length better reflected the "seat-of-the-pants" ride quality felt by the traveling public and allowed VDOT to penalize or require corrections on isolated locations.

Pay Tables and IRI Ranges- Bonus and penalty percentages were increased to encourage contractors to improve on paving processes, and to discourage the paving of rougher pavements, knowing those pavements have a shorter service life. In addition, the number of pay ranges were reduced and combined to more accurately reflect variability.

Percentage of Improvement- Realizing ride quality could be improved by a larger percentage and still protect contractors from being penalized for a poor initial condition, the Ride Spec committee increased the % improvement clause from 25% to 30%.

Testing Period- Testing window was expanded from 60 to 180 days prior to paving and from 14 days to 30 days after completion of the final surface course after determining the change in IRI was minimal over that time period.

In 2002, the most significant change made from the 2000 special provision was the addition of pay percentages for sections requiring corrective action. This gave VDOT the option to apply the penalty or require the contractor to correct those sections. These pay ranges are displayed below:

Interstate Routes IRI Range	Non-Interstate Routes IRI Range	Pay Adjustment
100.1 – 120	110.1 – 130	60% or Corrective Action
120.1 – 140	130.1 – 150	40% or Corrective Action
140.1 – 160	150.1 – 170	20% or Corrective Action
> 160.1	> 170.1	0% or Corrective Action

In 2003, the percent improvement clause was revisited. The percent improvement clause was changed to apply to each 0.10-mile section rather than the entire project. This meant that a project might exceed 30 percent improvement but still have 0.1-mile sections subject to corrective action or penalty. This was added to the special provision to enable VDOT to correct bumps or objectionable short sections, which were previously exempted from penalty or correction due to the project's overall improvement (greater than 30%).

The most recent changes to the Ride Specification were made in 2005, increasing maximum incentives from 5% and 10% to 10% and 15% on single lift maintenance projects. Prior to this change, contractors felt that in many cases the extra cost to achieve a good ride was not offset by the bonus.

APPENDIX B: PROJECT CONSIDERATIONS

Project Considerations

In order for the Materials Division's Non-Destructive Testing Section to perform ride quality testing and to give the contractor opportunity to provide a smooth surface, the characteristics of the project must be considered. Below is a list of rejection criteria. If a project meets one of these criteria, it should **NOT BE** considered for rideability specifications:

- Projects with a total pavement overlay length less than 0.5 miles
- Projects where the total lane width has not been paved
- Projects with excessive grade changes within limits (>6%)
- Projects with a design speed less than 45 mph
- Projects where the testing equipment is not able to maintain a speed between 25 and 60 mph
- Projects with Signalized Intersections where the distance between any two adjacent intersections or where the distance between an intersection and the project limits is less than 0.5 miles
- Projects with Stop Sign Controlled Intersection where the distance between any two adjacent intersections or where the distance between an intersection and the project limits is less than 0.5 miles
- Projects containing Railroad Crossings where the distance between the railroad crossing and the project limits is less than 0.5 miles
- Projects with Permanent Obstructions in the lane such as manhole, valve and vault covers.
- Projects where the overlay was constrained due to existing curb and gutter limitations at edge of lane (less than 4 feet between edge stripe to curb and gutter)
- Projects with lane widths less than 9 feet
- Projects with excessive surface distress (rutting, shoving, corrugation, etc.) where surface removal was not intended and only one AC lift will be placed
- Projects that are a surface treatment
- Projects with pavement transitions at construction tie-ins not leaving 0.5 miles to test

In addition, the following pavements should not be tested:

- Pavement Shoulders
- Truck climbing lanes less than 0.5 miles in length
- Acceleration, Deceleration Lanes or ramp pavements

If a project contains any of the rejecting criteria outlined above and the District wants the ride specs applied, then the requesting individual must provide copied notes indicating specific areas (by station) for application to apply the ride specifications.

APPENDIX C: QUALITY MANAGEMENT PROGRAM DETAILS

Verification of Equipment[5]

VDOT conducts three tiers of checks on its profilers – daily, weekly and monthly verification. Following are the routine checks performed on the profilers:

1) Block Test: This check is performed on the height sensors. The accuracy of the sensors is tested against special blocks that have been milled and measured with a micrometer.

2) Bounce Test: This test is performed twice a year in order to check overall system stability.

3) Weekly Calibration: Every week, the profilers make two runs each of a calibration site. The repeatability of the two runs is checked against target criteria. If the repeatability fails, the profiler must repeat the test until it is able to pass.

4) Monthly Calibration: Every month, the profilers make five runs on a calibration site. The repeatability and accuracy of the profilers are tested against ground truth and set standards.

Virginia Test Method 106

To ensure the consistent collection of data from one site to another, Virginia Test Method (VTM) 106 was developed. The major highlights of this VTM are:

- Optical triggering;
- Minimum of two runs per lane; and
- Acceptance criteria for data in the field.

Optical triggering is used to initiate testing on the control site. This allows data for all runs to be referenced to an exact, fixed location. This is crucial in VDOT's data analysis process because the lowest IRI value for each 0.01-mi. increment is used in payment determination. Statistically, the more runs collected on a lane the variability is reduced. However, from a production standpoint, fewer passes result in more sites being tested. Based on analysis of historic VDOT ride quality data, it was determined that two passes are acceptable. Finally, the VTM outlines the method to accept data results in the field. If the average IRI for two runs is within 5% or 3 in/mi, whichever is greater, then the data is approved. If the average is outside of this tolerance, then the data are discarded and two additional runs are made. If the average is once again outside of

this tolerance, then based on VDOT experience, the inertial profiler system has an error and must be repaired.

By combining reliable equipment, experienced operators, verification processes, and documented testing procedures, VDOT has a sound quality management program for the Ride program.

APPENDIX D: DETAILS OF STATISTICAL ANALYSIS

2007 vs 2005 Results

Statistical Parameters

	All Routes		
Year	BeforeStDev	VarBefore	BeforeAvg
2005	26	658	93
2007	28	785	90
Year	AfterStDev	VarAfter	AfterAvg
2005	34	1147	68
2007	16	264	62
Year	StDevOfPercentImprove	VarOfPercentImprove	AvgOfPercentImprove
2005	21	431	26
2007	23	527	27

	Sample Size	
Year	Before	After
2005	8118	9308
2007	3660	3341

	Non-Interstate Routes		
Year	BeforeStDev	VarBefore	BeforeAvg
2005	25	625	97
2007	28	810	92
Year	AfterStDev	VarAfter	AfterAvg
2005	33	1118	69
2007	15	233	62
Year	StDevOfPercentImprove	VarOfPercentImprove	AvgOfPercentImprove
2005	17	296	29
2007	23	514	28

	Non-Interstate Sample Size	
Year	Before	After
2005	5883	6678
2007	2073	2200

	Interstate Routes		
Year	BeforeStDev	VarBefore	BeforeAvg
2005	24	555	82
2007	27	729	87
Year	AfterStDev	VarAfter	AfterAvg
2005	35	1203	66
2007	18	311	62
Year	StDevOfPercentImprove	VarOfPercentImprove	AvgOfPercentImprove
2005	26	697	20
2007	23	534	24

	Interstate Sample Size	
Year	Before	After
2005	2235	2630
2007	1460	1268

Z-Tests

Z-Test All Routes			
Null hypothesis	(2005 Data - 2007 Data) = 0		
Hypothesis	(2005 Data - 2007 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
If Z > Zα	Reject null		
If Z < Zα	Cannot reject null		
Do	Z Before		
0	9.31		
1	6.38		
2	3.46	Z < 2.33	At 99% confidence, 2005 before maintenance IRI value
2.5	2.00		was greater than 2007 by 2.0
Do	Z After		
0.0	51.83		
3.0	28.59		
5.0	13.10		
6.0	5.36	Z > 2.33	99% confident 2005 after IRI values are greater by 6.0
6.5	1.48		
Null hypothesis	(2007 Data - 2005 Data) = 0		
Hypothesis	(2007 Data - 2005 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z % Improve		
0.0	3.69		
0.5	-0.52		At 99% confidence there is no significant difference
1.0	-4.73		between 2007 and 2005
1.5	-8.94		

Z-Test Non-Interstate Routes			
Null hypothesis	(2005 Data - 2007 Data) = 0		
Hypothesis	(2005 Data - 2007 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
If Z > Zα	Reject null		
If Z < Zα	Cannot reject null		
Do	Z Before		
0	7.89		
2	5.05		
3.5	2.92	Z > 2.33	99% confident 2005 before IRI values are greater by 3.5
4.0	2.22		
Do	Z After		
0.0	14.88		
3.0	9.14		
5.0	5.32		
6.5	2.45	Z > 2.33	99% confident 2005 after IRI values are greater by 6.5
7.0	1.49		
Null hypothesis	(2005 Data - 2007 Data) = 0		
Hypothesis	(2005 Data - 2007 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z % Improve		
0.0	2.54		
0.5	-1.93		No statistical difference in percent improvement between 2005 and 2007
1.0	-6.41		
1.5	-10.89		

Z-Test Interstate Routes			
Null hypothesis	(2007 Data - 2005 Data) = 0		
Hypothesis	(2007 Data - 2005 Data) < 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
If Z > Zα	Reject null		
If Z < Zα	Cannot reject null		
Do	Z Before		
0.0	5.28		
2.5	2.39	Z > 2.33	99% confident 2007 IRI is greater than 2005 by 2.5
3.0	1.81		
Null hypothesis	(2005 Data - 2007 Data) = 0		
Hypothesis	(2005 Data - 2007 Data) < 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z After		
0.0	4.77		
1.0	3.58		
2.0	2.38	Z > 2.33	99% confident that 2005 after IRI is greater than 2007 after IRI by 2.0
2.5	1.79		
Null hypothesis	(2007 Data - 2005 Data) = 0		
Hypothesis	(2007 Data - 2005 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z % Improve		
0.0	29.59		
2.0	14.24		
3.5	2.73	Z > 2.33	99% confident 2007 percent improvement is greater than 2005 by 3.5
4.0	-1.10		

F-Tests

F-Test All Routes			
Null hypothesis	StDev(2007 IRI) / StDev(2005 IRI) = 1		
Hypothesis	StDev(2007 IRI) / StDev(2005 IRI) > 1		
Confidence		Before	After
	95%	Fα = 1.029	Fα = 1.029
	99%	Fα = 1.042	Fα = 1.042
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F Before			
1.09		F > 1.042	99% confident 2007 has greater before IRI standard deviation
Null hypothesis	StDev(2005 IRI) / StDev(2007 IRI) = 1		
Hypothesis	StDev(2005 IRI) / StDev(2007 IRI) > 1		
Confidence		Before	After
	95%	Fα = 1.029	Fα = 1.029
	99%	Fα = 1.042	Fα = 1.042
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F After			
2.09		F > 1.042	99% confident 2005 after IRI has a greater standard deviation than 2007

F-Test Non-Interstate			
Null hypothesis	StDev(2007 Data) / StDev(2005 Data) = 1		
Hypothesis	StDev(2007 Data) / StDev(2005 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.034	Fα = 1.034
	99%	Fα = 1.041	Fα = 1.041
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F Before 1.14		F > 1.034	At 99% confidence the standard deviation in 2007 is greater than in 2005
Null hypothesis	StDev(2005 Data) / StDev(2007 Data) = 1		
Hypothesis	StDev(2005 Data) / StDev(2007 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.034	Fα = 1.034
	99%	Fα = 1.041	Fα = 1.041
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F After 2.19		F > 1.034	99% confident 2005 after IRI has greater standard deviation than 2007

F-Test Interstate Routes			
Null hypothesis	StDev(2007 Data) / StDev(2005 Data) = 1		
Hypothesis	StDev(2007 Data) / StDev(2005 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.075	Fα = 1.075
	99%	Fα = 1.108	Fα = 1.108
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F Before			
1.15		F > 1.108	99% confident 2007 Interstate before IRI have greater standard deviation
Null hypothesis	StDev(2005 Data) / StDev(2007 Data) = 1		
Hypothesis	StDev(2005 Data) / StDev(2007 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.075	Fα = 1.075
	99%	Fα = 1.108	Fα = 1.108
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F After			
1.97		F > 1.108	99% confident 2005 interstate after IRI has a greater standard deviation than 2007 after paving

2007 vs 2006 Results

Statistical Parameters

	All Routes		
Year	BeforeStDev	VarBefore	BeforeAvg
2006	25	625	89
2007	28	785	90
Year	AfterStDev	VarAfter	AfterAvg
2006	23	510	61
2007	16	264	62
Year	StDevOfPercentImprove	VarOfPercentImprove	AvgOfPercentImprove
2006	18	331	29
2007	23	527	27

	Sample Size	
Year	Before	After
2006	5260	5556
2007	3660	3341

	Non-Interstate Routes		
Year	BeforeStDev	VarBefore	BeforeAvg
2006	25	629	91
2007	28	810	92
Year	AfterStDev	VarAfter	AfterAvg
2006	23	512	63
2007	15	233	62
Year	StDevOfPercentImprove	VarOfPercentImprove	AvgOfPercentImprove
2006	17	296	30
2007	23	514	28

	Non-Interstate Sample Size	
Year	Before	After
2006	4564	4685
2007	2073	2200

	Interstate Routes		
Year	BeforeStDev	VarBefore	BeforeAvg
2006	17	288	74
2007	27	729	87
Year	AfterStDev	VarAfter	AfterAvg
2006	18	341	49
2007	18	311	62
Year	StDevOfPercentImprove	VarOfPercentImprove	AvgOfPercentImprove
2006	20	417	30
2007	23	534	24

	Interstate Sample Size	
Year	Before	After
2006	696	871
2007	1460	1268

Z-Tests

Z-Test All Routes			
Null hypothesis	(2007 Data - 2006 Data) = 0		
Hypothesis	(2007 Data - 2006 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
If Z > Zα	Reject null		
If Z < Zα	Cannot reject null		
Do	Z Before		
0	2.73		At 99% confidence, there is no statistical difference
0.5	1.25		between 2007 and 2006 before maintenance IRI
Null hypothesis	(2007 Data - 2006 Data) = 0		
Hypothesis	(2007 Data - 2006 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z After		
0.0	8.98		
0.5	4.00	Z > 2.33	99% confident 2007 after IRI values are greater by 0.5
1.0	-0.98		
1.5	-5.95		
Null hypothesis	(2006 Data - 2007 Data) = 0		
Hypothesis	(2006 Data - 2007 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z % Improve		
0.0	18.33		
1.5	5.21	Z > 2.33	99% confident 2006 percent improvement is greater by
2.0	0.84		1.5 percentage points

Z-Test Non-Interstate Routes			
Null hypothesis	(2007 Data - 2006 Data) = 0		
Hypothesis	(2007 Data - 2006 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
If Z > Zα	Reject null		
If Z < Zα	Cannot reject null		
Do	Z Before		
0	0.92		At 99% and 95% confidence there is no statistical difference between 2007 and 2006 IRI before maintenance
0.5	0.23		
1.0	-0.46		
Null hypothesis	(2006 Data - 2007 Data) = 0		
Hypothesis	(2006 Data - 2007 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z After		
0.0	2.85		
0.5	1.77		At 99% and 95% confidence there is no statistical difference between 2007 and 2006 IRI before maintenance
1.0	0.70		
1.5	-0.38		
Do	Z % Improve		
0.0	16.69		
0.5	12.22		
1.0	7.74	Z > 2.33	99% confident 2006 percent improvement greater by 1.0
1.5	3.26		

Z-Test Interstate Routes			
Null hypothesis	(2007 Data - 2006 Data) = 0		
Hypothesis	(2007 Data - 2006 Data) < 0		
Confidence	95%	Zα = -1.645	
	99%	Zα = -2.33	
If Z > Zα	Reject null		
If Z < Zα	Cannot reject null		
Do	Z Before		
0.0	13.51		
6.0	7.23		
9.0	4.09		
10.5	2.52	Z > 2.33	99% confident 2007 before IRI values are greater than
11.0	2.00		2006 by 10.5
Do	Z After		
0.0	15.95		
8.0	5.92		
10.5	2.79	Z > 2.33	99% confident 2007 after IRI values are greater than
11.0	2.16		2006 by 10.5
Null hypothesis	(2006 Data - 2007 Data) = 0		
Hypothesis	(2006 Data - 2007 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z % Improve		
0.0	52.54		
3.0	27.28		
5.5	6.22	Z > 2.33	99% confident 2006 percent improvement greater than
6.0	2.01		2007 by 5.5

F-Tests

F-Test All Routes			
Null hypothesis	StDev(2007 IRI) / StDev(2006 IRI) = 1		
Hypothesis	StDev(2007 IRI) / StDev(2006 IRI) > 1		
Confidence		Before	After
	95%	Fα = 1.029	Fα = 1.029
	99%	Fα = 1.042	Fα = 1.042
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F Before			
1.12		F > 1.042	99% confident 2007 has greater before IRI standard deviation
Null hypothesis	StDev(2006 IRI) / StDev(2007 IRI) = 1		
Hypothesis	StDev(2006 IRI) / StDev(2007 IRI) > 1		
Confidence		Before	After
	95%	Fα = 1.029	Fα = 1.029
	99%	Fα = 1.042	Fα = 1.042
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F After			
1.39		F > 1.042	99% confident 2006 after IRI has greater standard deviation than 2007

F-Test Non-Interstate			
Null hypothesis	StDev(2007 Data) / StDev(2006 Data) = 1		
Hypothesis	StDev(2006 Data) / StDev(2007 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.034	Fα = 1.034
	99%	Fα = 1.041	Fα = 1.041
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F Before			
1.13		F > 1.034	99% confident 2007 before IRI has greater standard deviation than 2006
Null hypothesis	StDev(2006 Data) / StDev(2007 Data) = 1		
Hypothesis	StDev(2007 Data) / StDev(2006 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.034	Fα = 1.034
	99%	Fα = 1.041	Fα = 1.041
F After			
1.48		F > 1.034	99% confident 2006 after IRI has greater standard deviation than 2007

F-Test Interstate Routes			
Null hypothesis	StDev(2007 Data) / StDev(2006 Data) = 1		
Hypothesis	StDev(2007 Data) / StDev(2006 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.075	Fα = 1.075
	99%	Fα = 1.108	Fα = 1.108
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F Before			
1.59		F > 1.108	99% confident 2007 Interstate before IRI have greater standard deviation than 2006
Null hypothesis	StDev(2006 Data) / StDev(2007 Data) = 1		
Hypothesis	StDev(2006 Data) / StDev(2007 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.075	Fα = 1.075
	99%	Fα = 1.108	Fα = 1.108
F After			
1.05		F < 1.108	2006 and 2007 Interstate after IRI have no statistical difference at 99% confidence

2006 vs 2005 Results

Statistical Parameters

	All Routes		
Year	BeforeStDev	VarBefore	BeforeAvg
2005	26	658	93
2006	25	625	89
Year	AfterStDev	VarAfter	AfterAvg
2005	34	1147	68
2006	23	510	61
Year	StDevOfPercentImprove	VarOfPercentImprove	AvgOfPercentImprove
2005	21	431	26
2006	18	331	29
	Sample Size		
Year	Before	After	
2005	8118	9308	
2006	5260	5556	
	Non-Interstate Routes		
Year	BeforeStDev	VarBefore	BeforeAvg
2005	25	625	97
2006	25	629	91
Year	AfterStDev	VarAfter	AfterAvg
2005	33	1118	69
2006	23	512	63
Year	StDevOfPercentImprove	VarOfPercentImprove	AvgOfPercentImprove
2005	17	296	29
2006	18	315	28
	Non-Interstate Sample Size		
Year	Before	After	
2005	5883	6678	
2006	4564	4685	
	Interstate Routes		
Year	BeforeStDev	VarBefore	BeforeAvg
2005	24	555	82
2006	17	288	74
Year	AfterStDev	VarAfter	AfterAvg
2005	35	1203	66
2006	18	341	49
Year	StDevOfPercentImprove	VarOfPercentImprove	AvgOfPercentImprove
2005	26	697	20
2006	20	417	30

Interstate Sample Size		
Year	Before	After
2005	2235	2630
2006	696	871

Z-Tests

Z-Test All Routes			
Null hypothesis	(2005 Data - 2006 Data) = 0		
Hypothesis	(2005 Data - 2006 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
If Z > Zα	Reject null		
If Z < Zα	Cannot reject null		
Do	Z Before		
0	12.88		
1	9.74		
2	6.61		
3	3.47	Z > 2.33	At 99% confidence, 2005 before maintenance IRI value was greater than 2006 by 3
3.5	1.90		
Do	Z After		
0.0	52.18		
5.0	17.82		
7.0	4.08	Z > 2.33	99% confident 2005 after IRI values are greater by 7.0
7.5	0.64		
Null hypothesis	(2006 Data - 2005 Data) = 0		
Hypothesis	(2006 Data - 2005 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z % Improve		
0.0	24.72		
1.0	14.96		
2.0	5.21	Z > 2.33	99% confident 2006 percent improvement greater by 2
2.5	0.33		

Z-Test Non-Interstate Routes			
Null hypothesis	(2005 Data - 2006 Data) = 0		
Hypothesis	(2005 Data - 2006 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
If Z > Zα	Reject null		
If Z < Zα	Cannot reject null		
Do	Z Before		
0	12.61		
4	4.51		
5.0	2.48	Z > 2.33	99% confident 2005 before IRI values are greater than
5.5	1.47		2006 by 5.0
Do	Z After		
0.0	12.28		
3.0	6.57		
4.0	4.67		
5.0	2.77	Z > 2.33	99% confident 2005 after IRI values are greater than
5.5	1.82		2006 by 5.0
Null hypothesis	(2005 Data - 2006 Data) = 0		
Hypothesis	(2005 Data - 2006 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z % Improve		
0.0	2.43		
0.5	-2.89		
1.0	-8.21		99% confident there is no statistical difference between
1.5	-13.53		2005 and 2006 percent improvement

Z-Test Interstate Routes			
Null hypothesis	(2005 Data - 2006 Data) = 0		
Hypothesis	(2005 Data - 2006 Data) < 0		
Confidence	95%	Zα = -1.645	
	99%	Zα = -2.33	
If Z > Zα	Reject null		
If Z < Zα	Cannot reject null		
Do	Z Before		
0.0	10.25		
3.0	6.57		
5.0	4.11		
6.0	2.88	Z > 2.33	99% confident 2005 before IRI values are greater than
6.5	2.27		2006 by 6.0
Do	Z After		
0.0	18.15		
5.0	12.72		
10.0	7.29		
14.5	2.41	Z > 2.33	99% confident 2005 after IRI values are greater than
15.0	1.87		2006 by 14.5
Null hypothesis	(2006 Data - 2005 Data) = 0		
Hypothesis	(2006 Data - 2005 Data) > 0		
Confidence	95%	Zα = 1.645	
	99%	Zα = 2.33	
Do	Z % Improve		
0.0	82.87		
5.0	41.82		
9.5	4.89	Z > 2.33	99% confident 2006 percent improvement greater than
10.0	0.78		2005 by 9.5

F-Tests

F-Test All Routes			
Null hypothesis	StDev(2005 IRI) / StDev(2006 IRI) = 1		
Hypothesis	StDev(2005 IRI) / StDev(2006 IRI) > 1		
Confidence		Before	After
	95%	Fα = 1.029	Fα = 1.029
	99%	Fα = 1.042	Fα = 1.042
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F Before 1.03		F < 1.042	At 99% confidence there is no difference in 2006 and 2005 before maintenance IRI standard deviation
F After 1.50		F > 1.042	99% confident 2005 after IRI has a greater standard deviation than 2006

F-Test Non-Interstate			
Null hypothesis	StDev(2005 Data) / StDev(2006 Data) = 1		
Hypothesis	StDev(2005 Data) / StDev(2006 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.034	Fα = 1.034
	99%	Fα = 1.041	Fα = 1.041
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F Before 1.00		F > 1.034	At 99 and 95% confidence the standard deviations in 2005 and 2006 are not statistically different
F After 1.48		F > 1.034	99% confident 2005 after IRI has greater standard deviation than 2006

F-Test Interstate Routes			
Null hypothesis	StDev(2005 Data) / StDev(2006 Data) = 1		
Hypothesis	StDev(2005 Data) / StDev(2006 Data) > 1		
Confidence		Before	After
	95%	Fα = 1.075	Fα = 1.075
	99%	Fα = 1.108	Fα = 1.108
If F > Fα	Reject null		
If F < Fα	Cannot reject null		
F Before 1.39		F > 1.108	99% confident 2005 Interstate before IRI have greater standard deviation
F After 1.88		F > 1.108	99% confident 2005 Interstate after IRI has greater standard deviation than 2006

Summary of Conclusions

2007 vs. 2005

After a statistical comparison of the 2007 and 2005 Ride Specification paving projects, the following conclusions can be drawn at 99% confidence:

For all routes:

- 2005 before paving IRI value was greater by 2.0
- 2005 after paving IRI values are greater by 6.0
- No statistical difference between 2005 and 2007 percent improvement
- 2007 has greater standard deviation in before paving IRI
- 2005 has twice the standard deviation in after paving IRI

For non-interstate routes:

- 2005 before paving IRI values are greater by 3.5
- 2005 after paving IRI values are greater by 6.5
- No statistical difference between 2005 and 2007 percent improvement
- 2007 has greater standard deviation in before paving IRI
- 2005 has greater standard deviation in after paving IRI

For interstate routes:

- 2007 before paving IRI value was greater by 2.5
- 2005 after paving IRI values are greater by 2.0
- 2007 percent improvement greater by 3.5 percentage points
- 2007 has greater standard deviation in before paving IRI
- 2005 has greater standard deviation in after paving IRI

2007 vs. 2006

After a statistical comparison of the 2007 and 2006 Ride Specification paving projects, the following conclusions can be drawn at 99% confidence:

For all routes:

- No statistical difference between before paving IRI
- 2007 after paving IRI are greater by 0.5
- 2006 percent improvement is greater by 1.5 percentage points
- 2007 has greater standard deviation in before paving IRI
- 2006 has greater standard deviation in after paving IRI

For non-interstate routes

- No statistical difference between 2007 and 2006 before paving IRI
- No statistical difference between 2007 and 2006 after paving IRI
- 99% confident 2006 percent improvement greater by 1.0
- 2007 has greater standard deviation in before paving IRI
- 2006 has greater standard deviation in after paving IRI

For interstate routes

- 2007 before paving IRI values are greater by 10.5
- 2007 after paving IRI values are greater by 10.5
- 2006 percent improvement greater by 5.5
- 2007 has greater standard deviation in before paving IRI
- No statistical difference between 2007 and 2006 standard deviations in after paving IRI

2006 vs. 2005

After a statistical comparison of the 2006 and 2005 Ride Specification paving projects, the following conclusions can be drawn at 99% confidence:

For all routes:

- 2005 before paving IRI value was greater by 3
- 2005 after paving IRI values are greater by 7
- 2006 percent improvement greater by 2
- No statistical difference in the standard deviation of 2006 and 2007 before paving IRI
- 2005 has greater standard deviation in after paving IRI

For non-interstate routes:

- 2005 before paving IRI values are greater by 5.0
- 2005 after paving IRI values are greater by 5.0
- No statistical difference in the percent improvement in IRI between 2005 and 2006
- No statistical difference in the standard deviation of 2006 and 2005 before paving IRI
- 2005 has greater standard deviation in after paving IRI

For interstate routes:

- 2005 before paving IRI values are greater by 6.0
- 2005 after paving IRI values are greater by 14.5
- 2006 percent improvement greater by 9.5
- 2005 has greater standard deviation in before paving IRI
- 2005 has greater standard deviation in after paving IRI

APPENDIX E: DETAILED BENEFIT COMPUTATION

VTRC report 06-R28 reported that smoother roads result in better fuel economy for truckers.

The report estimated a benefit of $1,295/lane mile for deferring the resurfacing by 2 years due to smoother road (from applying ride spec).
A $52.25/ton for asphalt was used in the computation.
Using the average asphalt price for the year 2007 ($61.50/ton), this is equivalent to $1,525/lane mile of saving in 2007.

The report noted benefit from several other studies that 10% increase in smoothness could results in the following fuel economy:

- 1.3% better fuel economy (FDOT study)
- 4.5% better fuel economy (West track study)
- 10% better fuel economy (NCAT study)

For the purposes of this analysis, it is assumed 10% lower IRI is associated with 3% increase in truck fuel economy which is very conservative as is evident from the above figures.

The report noted for each 1% increase in fuel economy 2,360 gallons of diesel fuel could be saved per million truck miles.

3% increase in truck fuel economy could, therefore, be computed to be equivalent to a savings of 7,080 gallons of diesel per million truck miles.

$4.50 is assumed to be price for per gallons of diesel.

Assuming 500 truck/day travel each section of the 408 miles of Ride Sites,

- Savings = (500 trucks/day) * (365 day/year) * (408 mi) * (7,080 gal/10^6 mi)
- Savings = 527,176 gallons or $2,372,296 per year