SMOOTHNESS ACCEPTANCE SPECIFICATIONS: MEASUREMENTS, IMPLEMENTATION & PAY ADJUSTMENT FACTORS FOR ASPHALT CONCRETE OVERLAYS

DRAFT FINAL REPORT

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**Abstract**

The West Virginia Department of Transportation has an ongoing concern with the quality of asphalt-concrete overlay construction. In the earlier research project RP#127, Shoukry at al. (1998) demonstrated the difficulty in developing an acceptable specification for construction smoothness. This project was initiated to augment the findings of the earlier project by performing an integrated approach for establishing a construction smoothness specification. The major tasks involved in the analyses are: i. Evaluation of the Inertial Profilometer and check its applicability in quality acceptance; ii. Evaluate ability to improve roughness in each lift of the overlay; iii. Analyze the data obtained to develop acceptable smoothness limits for asphalt overlay projects.

Due to operational problems, the KJ Law non-contact low speed profilometer was not evaluated during the project. All data were collected with Mays Ride Meter. The improvements with overlays were performed by measuring the roughness of the original pavement and each lift of the overlay for three projects in the 2003 construction season. It was observed that the contractor was able to achieve improvement in each and every lift. The maximum improvement (up to 65%) was observed after the placement of the first lift or the scratch course. The 3 projects analyzed started construction with initial rough conditions. The improvements after each lift were compared and were found to be similar. All the 3 projects had their final smoothness values in the range of 50 in/mi to 55 in/mi.

Data from 14 projects during the 1998, 2002 and 2003 construction seasons were accumulated for analyses purposes. A new acceptable smoothness range, 45 to 65 in/mile, was proposed for future projects involving asphalt overlay with thickness greater than 3”. Incentive/Disincentive policies were recommended within the new smoothness specification to achieve good quality and smooth pavements. Pay adjustment factors were included within the scope of the proposed Smoothness Specification. These factors were selected based on careful review of smoothness specification from other states. The pay adjustment factors have been identified as a very important parameter in controlling the quality of highway pavements.

**Key Words**

Smoothness specifications, Asphalt concrete Overlays, Roughness measurements, Quality control of smoothness.
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CHAPTER ONE

INTRODUCTION

1.1 Background

The demands of the highway users have come a long way from “just passable ride” in the early 20th century to a “comfortable, safe and smooth ride” in the 21st century. Undoubtedly, pavement smoothness has become a key factor in determining today’s highway user satisfaction. Apart from providing a smooth ride, users have identified that smooth pavements provide a very high level of comfort; ride quality, and efficient movement of vehicles. Other factors, such as effect on traffic flow, less vehicular damage, fuel economy, and safe driving conditions, are also associated with pavement smoothness. Due to the widespread focus of the public in pavement smoothness, all improvements, procedures, and specifications developed for smoothness of a roadway will directly lead to enhanced consumer satisfaction.

How is smoothness defined? In simple words smoothness can be defined as “absence of roughness”. Sometimes “evenness” or “trueness” is used to define pavement smoothness. In reality, the roughness of a pavement surface is being measured; not its smoothness. However, smoothness is frequently used due to its positive connotation. As defined by ASTM (2001) roughness is defined as: “The deviations of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage, for example, longitudinal profile, transverse profile, and cross slope.”

A smooth pavement reflects the workmanship and maintenance proficiencies of the contractor and owner agencies, i.e. State DOT’s. The initial smoothness acts as an indicator for the quality of pavement construction, since a great amount of commitment and concentrated effort is needed to effectively control all the factors that could possibly affect pavement smoothness. The AASHTO Pavement Design Guide (1993) relates smoothness to pavement serviceability. The performance equations in the guide indicate that pavements constructed with high serviceability (i.e. smoothness) will last longer than
otherwise equivalent, but initially rougher, pavements. Attending to minor recurrent problems effectively can further increase the life of pavements. This requires a great amount of maintenance activities by the State agencies to provide a safe and smooth riding surface at all times thus reducing the possibility of pavement failure leading to more economic and man hour losses.

To achieve a desired level of smoothness both accepted by the state agencies and achievable by the contractors, a smoothness specification is generally formulated by the state highway departments to ensure that they are receiving quality, long lasting, and safe pavement. Previous studies provided evidence that enforcement of an effective smoothness specification results in obtaining improved pavement smoothness (Ksaibati et al., 1998; Hancock and Hossain, 2000; Swanland, 2000). The specifications require that the smoothness of a newly constructed pavement fall within a specified tolerance limit ensuring that the resultant pavement has a uniform planar surface. These smoothness specifications are often written around the measuring equipment used by the state agencies. These specifications help the state and contractors to develop a consistent approach to smoothness during construction.

Due to the widespread benefits associated with smoothness, almost all states in US have adapted and written smoothness specifications. West Virginia DOH uses the Mays Ride Meter to measure the smoothness of all its pavements. The smoothness specification therefore is written according to the Mays number obtained from the Mays Ride Meter.

1.2 WVDOT Smoothness Acceptance Specifications

Section 401.7.1 “Surface Tolerance” of WVDOT Specifications reads as follows:

It is intent of these specifications that projects with a total new pavement thickness of 3 inches or more shall be constructed to provide a smooth riding surface. The smoothness of the riding surface will be determined by the Engineer using an Inertial Profilometer or Mays Ride Meter. The smoothness testing will generally be accomplished within 30 days after the project is complete. The pavement shall be divided into sampling LOT’s of one mile each. Each LOT will
be divided into 0.1-mile sublots. Statistics derived from measurements of each sublot will be used to determine the acceptability of the LOT. When the statistics indicate that 95 percent of the pavement in the LOT will be expected to exhibit smoothness in accordance with Table 401.7, the LOT shall be accepted. When a LOT is represented by statistics that indicate that less than 95 percent of the pavement would exhibit smoothness values other than that shown in Table 401.7, the unit price should be adjusted as in 401.13.12.

**Table 401.7 (WV Smoothness Specifications)**

<table>
<thead>
<tr>
<th>Total New Pavement Thickness</th>
<th>Smoothness Statistic</th>
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<tr>
<td>3 inches to 4 inches (75 to 100 mm)</td>
<td>81 inches per mile (1250 mm per km) or less</td>
</tr>
<tr>
<td>4 inches (100 mm) or greater</td>
<td>65 inches per mile (1000 mm per km) or less</td>
</tr>
</tbody>
</table>

When compaction is completed on the course, it shall present a uniform surface, true line and grade, conforming to the cross section shown on the plans. When tested with a 10 foot straightedge and template of the specified dimensions, the finished base course shall not show a deviation greater than 1/4 inch and the finished wearing course shall not show a deviation from the required surface greater than 3/16 inch…”

**Procedure that WVDOT Uses to Calculate the Lot Statistic:**

In a previous WVDOH research project, Shoukry et al. (1998) documented the following procedures for computing the lot statistics for quality evaluation:

1. The project is divided into LOTS, each 1 mile long.
2. Each LOT is divided into 10 sublots, each 0.1 mile long, and the smoothness of each sublot is evaluated. The average, M, and standard deviation, S, of the ten sublots are then calculated.
3. The ten sublot values are assumed to have a normal probability distribution whose probability density function is given by:

   \[ f(x, \mu, \sigma) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \]

   Where \( \mu \) and \( \sigma \) are the population mean and standard deviation respectively. The values of \( M \) and \( S \) are substituted for \( \mu \) and \( \sigma \).
4. The table of cumulative area under the standard normal distribution is used to calculate the percentage area under the above probability curve with smoothness
values below the specified limit, where the value of $x$ is substituted for as the smoothness specification limit for the project (81 or 65 inches per mile depending on the overlay thickness).

1.3 Problems Associated with the Current Lot Statistic:

1. The use of LOT statistics emphasizes the variance of the smoothness measurements rather than their means. This is based on the assumption that the distribution of the smoothness of 10 sublots will have a normal probability distribution.

2. The smoothness values of the subsequent sublots are not checked for statistical independence.

3. Fixing the LOT length to be 1 mile has no relative meaning for acceptance criteria.

4. WVDOT smoothness specifications, according to Section 401.7 (March 1997), mandates the use of statistics to compute the acceptability of a LOT whose smoothness is 100 percent defined by measurements obtained for 10 sublots each of which is 0.1 mile long.

Using the statistical procedures may result in rejecting a LOT if it includes smooth sublots (0.1 mile long) together with relatively rougher ones (i.e. greater than or equal to 65 inches per mile). The statistical approach is sensitive to the repeatability of the readings from the smoothness-measuring instrument. Since the smoothness along the LOT is fully defined, there is zero probability that any distance along this LOT may be rougher or smoother than the smoothness values already measured. The problem of accepting the smoothness of the one lane-mile LOT becomes deterministic.

1.4 Project Overview

This project was initiated to augment the findings of RP #127 (Shoukry et al., 1998) by performing an accurate and systematic analysis and to develop a new smoothness specification, which takes into account the following:
1. Evaluation of the KJ Law Low Speed Non Contact Profilometer and Mays Ride Meter to determine their suitability for measuring smoothness with respect to specifications compliance.

2. Quantify the improvement that can be achieved with each lift of the overlay.

3. Smoothness values of the entire length of the project by measuring every 0.1-mile section.

4. New overlay projects would be selected having thickness greater than 3”, and the data obtained would be compared with the past years projects.

5. Study the effect of pay adjustment factors and its effectiveness if included in the smoothness specification.
CHAPTER TWO

ROUGHNESS MEASURING EQUIPMENT

Accurate and reliable roughness measurements are one of the foremost issues concerning the development of a smoothness specification. One of the tasks of this project was to evaluate the usability of the two measuring instruments owned by the WVDOH, namely, the Mays Ride Meter and the KJ Law Light Weight Low Speed Inertial Profilometer.

2.1 Mays Ride Meter

The Mays Ride Meter is a robust and inexpensive device, which measures the response of the host vehicle to pavement roughness. The Mays Ride Meter belongs to a class of roughness evaluation instruments which measure the response of the vehicle to the pavement roughness. The measurements from this device are sensitive to vehicle and operational parameters. This means that the instrument needs periodic calibration against a reference device. The operating characteristics, calibration procedures and maintenance schedules were presented in the earlier report (Shoukry et al., 1998).

2.2 KJ Law Light Weight Non-Contact Low Speed Inertial Profilometer

This device uses the principle of inertial profilometry to measure the profile of the pavement surface. The profile measurements are then used to compute various roughness indexes. Basic components of inertial profilometer are as follows:

1. Device to measure the distance between the vehicle and the road surface.
2. An inertial referencing device to compensate for the vertical movement of the vehicle body.
3. A distance measuring device (odometer) to locate the profile points along the pavement.
4. An on-board processor for recording and analyzing the data.
Presented below is an evaluation of the KJ Law Low Speed Profilometer owned by WVDOH. The evaluation consists of the following:

1. Physical Examination
2. Principle of Operation
3. Operating Characteristics
4. Repeatability of Measurements

2.2.1 Physical Examination

This includes the examination of the Vehicle, On-Board Computer and Peripherals, Profiling System Components, Software used to generate the profile and various indices such as International Roughness Index (IRI), Profile Index (PI), Mays Number (MAYS), etc.

A. Vehicle

- Steel roll bar and cage assembly
- Four rim mounted tubeless smooth-tread tires
- Two bench seats
- Removable canvas top
- Side view mirrors on both driver and passenger sides
- Safety flasher

B. On-Board Computer and Peripherals

- Dash Mounted on/off switch
- IBM compatible PC
- 133 MHz Intel Pentium processor
- 2 GB hard disk, 16 MB RAM
- 11” SVGA LCD flat screen monitor
- Standard PC Keyboard
- Dot Matrix printer
C. Profiling System Components

- Precision Accelerometer
- Non Contact displacement sensor that measures the vertical distance from vehicle to pavement surface
- Automatic photocell pickup sensor for starting/stopping profile
- Precision Calibration kits with both metric and US 1-2-3 blocks, and base plates
- Hand held pendant to start and/or stop profile data acquisition
- The vehicle speed pickup is used to measure the traveled distance.

D. Software

- Compatible with English and Metric Units
- Real-time trace display on LCD screen of profile
- User friendly menu displays

2.2.2 Principle of Operation

The principles of inertial profilometry were developed over 40 years ago and are well documented in the literature. While the concept of inertial profilometry is relatively simple, the implementation is very complex. The following describes the basic principle. Mechanical, electronic, and data processing issues, which make measurements of pavement profiles beyond the scope of the literature review. A precision accelerometer measures the vertical acceleration of the vehicle. Double integration of the signal produces the vehicle vertical motion and hence establishes an inertial reference plane. A non-contacting displacement sensor accurately determines the vehicle-to-road displacement. The distance measurement from the vehicle to the pavement is combined with the inertial reference plane to compute elevation points for the pavement surface. The distance location of each evaluation point is determined by the distance measuring instrument.
2.2.3 Operating Characteristics

The operating characteristics are summarized as:

- Calibration procedures have to be performed before taking any profile measurements. This involves calibrating the displacement sensors, accelerometers, and distance-measuring units of the Profilometer. An on-screen menu guides the user through the entire calibration procedure.
- Profile recordings are started using either the photocell or the pendant, and they can be stopped by the photocell, pendant or by presetting the distance.
- Pavement profile data points are taken every 1” (25mm) and averaged over a running 12” (300mm) interval. Profile data points are stored every 6” (150mm).
- The Profilometer takes measurements at a speed of 18 mph and exerts a pressure of 6-7 psi on the pavement.
- The Profilometer produces the measured profile for any longitudinal interval selected for calculation.
- The profiles can be displayed on the LCD monitor in the form of a strip chart for the entire path or for selected intervals. Profiles can also be stored on a floppy disk or optionally printed using the on-board printer.
- The on-board computer calculates and stores profile and several roughness indexes such as:
  a. International Roughness Index (IRI)
  b. Profilograph Index (PI)
  c. ASTM Ride Number (RN)
  d. MAYS Number (MAYS)
  e. Variable Length Straightedge Deviation (SD)

2.2.4 Repeatability of Measurements

The ability of the Profilometer to produce repeatable values was checked by performing a sample measurement on a test section near Elkins, WV. Roughness was
measured during two times of the day, once during afternoon and the other during evening. Three runs were performed for each roughness measurement. The calibration steps were followed for both times to maintain a consistent methodology. The calibration results yielded an error of 0.002%, which was well within the allowable range. The test settings were as follows:

1. Distance (Section Length): 470 ft.
2. Sampling Interval: 1 inch.
3. Start Method: Pendant
4. Stop Method: Pendant
5. Speed: 19mph
6. Reference Points: Reflector Cones

The readings of the two tests are listed in Table 2.1.

<table>
<thead>
<tr>
<th></th>
<th>Run</th>
<th>Distance</th>
<th>IRI</th>
<th>PI</th>
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<tr>
<td><strong>Test # 1</strong></td>
<td>1</td>
<td>472</td>
<td>69.36</td>
<td>21.42</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>470</td>
<td>71.50</td>
<td>23.52</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>474</td>
<td>69.46</td>
<td>20.44</td>
</tr>
<tr>
<td></td>
<td><strong>Average</strong></td>
<td><strong>472</strong></td>
<td><strong>70.10</strong></td>
<td><strong>21.79</strong></td>
</tr>
<tr>
<td><strong>Test # 2</strong></td>
<td>1</td>
<td>472.5</td>
<td>66.83</td>
<td>22.19</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>471.5</td>
<td>62.03</td>
<td>18.82</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>470</td>
<td>67.97</td>
<td>23.83</td>
</tr>
<tr>
<td></td>
<td><strong>Average</strong></td>
<td><strong>471.33</strong></td>
<td><strong>65.61</strong></td>
<td><strong>21.61</strong></td>
</tr>
</tbody>
</table>

The readings show differences in both the IRI (International Roughness Index) values and the PI (Profilograph Index) values. The difference in values could be due to the start/stop method used for the tests. The Pendant method requires the user to start and stop the measurements, which cause differences in readings since the user cannot start and stop the measurements at the same point. There is also a variability resulting from the operator’s inability to measure the same exact wheel path every time.

Other methods of operation are possible in the form of photocell and distance, but the user was not successful in making the photocell work. The photocell operation should be reviewed again.
2.3 Problems Encountered with the Low Speed Profilometer

The science and engineering associated inertial profilometry is superior to response type roughness measuring systems. Conceptually, inertial profilometers should produce more accurate and repeatable data than response type systems. However, the potential superiority of the inertial profilometer is offset by the increased sophistication and subsequent loss of reliability. During the construction seasons monitored over the course of this project, the profilometer was not operational. Hence the Mays Ride Meter provided the only data available for analysis.

2.4 Mays Ride Meter Calibration

The calibration of the Mays Ride Meter was performed according to the guidelines set forth earlier (Shoukry et al., 1998). The calibration was performed against the SHRP reference Inertial Profilometer. Regression equations are generated after each periodic calibration. These equations are used to compute the “true roughness” of the sections measured during that period. The calibration equations for the Mays Ride Meter measured during the 2002-2003 construction seasons are listed in Table 2.2.

<table>
<thead>
<tr>
<th>Calibration Periods</th>
<th>Calibration Equation</th>
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<tbody>
<tr>
<td>April 2002</td>
<td>$Y = 1.0584x + 17.173$</td>
</tr>
<tr>
<td>June 2002</td>
<td>$Y = 1.0566x + 17.334$</td>
</tr>
<tr>
<td>July 2002</td>
<td>$Y = 1.0144x + 10.556$</td>
</tr>
<tr>
<td>March 2003</td>
<td>$Y = 1.0168x - 5.5251$</td>
</tr>
<tr>
<td>June 2003</td>
<td>$Y = 0.9864x - 3.3364$</td>
</tr>
<tr>
<td>July 2003</td>
<td>$Y = 0.9977x - 9.3772$</td>
</tr>
<tr>
<td>November 2003</td>
<td>$Y = 1.0270x - 0.2773$</td>
</tr>
</tbody>
</table>

$Y = \text{Calibrated (True) Roughness}$

$X = \text{Measured Mays number}$
As observed in Table 2.2 the calibration equations were significantly different between the years 2002 and 2003. The difference is due to the replacement of the vertical rod connecting the vehicle axle and the transducer at the end of the 2002 construction season as well as the aging of the mechanical components. The calibration charts along with the measurements are documented in Appendix-A and summarized in Table 2.3.

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<tbody>
<tr>
<td>1</td>
<td>Ruth Road South</td>
<td>18.67 26.67 48.67 50.00 44.00 71.67 29.33</td>
<td>N/A 35.21</td>
<td>2002 2003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Ruth Road North</td>
<td>17.33 24.00 21.00 39.00 21.00 62.67 31.67</td>
<td>29.12 26.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Childress Road South</td>
<td>20.67 19.33 33.67 37.00 43.00 36.00 36.00</td>
<td>32.82 33.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Childress Road North</td>
<td>18.00 24.00 24.00 30.33 30.33 60.33 29.67</td>
<td>30.24 36.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Rabel Farm South</td>
<td>22.00 19.67 33.33 49.33 63.00 27.67 26.33</td>
<td>39.32 33.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Rabel Farm North</td>
<td>22.00 27.33 31.33 48.00 57.00 54.67 42.33</td>
<td>35.76 40.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Alum Creek/Friendly Drive North</td>
<td>66.67 60.33 74.67 94.00 90.33 90.00 83.33</td>
<td>99.60 88.93</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Alum Creek/Friendly Drive South</td>
<td>56.00 53.33 55.67 73.33 67.33 72.67 61.33</td>
<td>90.52 73.83</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Julian Mini-Mart West</td>
<td>120.67 117.00 128.67 142.00 153.00 153.67 133.00</td>
<td>115.14 140.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Julian Mini-Mart East</td>
<td>98.00 110.33 119.33 142.33 131.67 135.33 113.33</td>
<td>142.49 139.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Pennzoil Station West</td>
<td>68.67 55.00 78.67 90.67 91.33 97.33 75.33</td>
<td>105.24 94.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Pennzoil Station East</td>
<td>78.67 77.67 85.67 92.33 98.67 113.33 97.33</td>
<td>91.70 90.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The SHRP Inertial Profilometer used as the reference equipment for both 2002 and 2003 calibrations. The respective year values were used to generate the regression equations shown in Table 2.2.

It was also observed during this analysis that the Mays Ride Meter has high variability. The average standard error as computed for the Mays Ride Meter was 15 in/mi. The SHRP Inertial Profilometer had an average standard error of 3 in/mi.

Figure 2.1 reflects the Mays Ride Meter data for the calibration sections at different periods of time. It can be clearly seen that the values have a large variability for every section measured from April 2002 to November 2003. This variability would be reflected on all the Mays Ride Meter measurements. Due to the large variability of the Mays Ride Meter data, frequent calibration is necessary. In order to check the effectiveness of the Mays Ride Meter, calibration should be performed every 15 days during the construction season as compared to 45 days recommended by Shoukry et al.
The calibrated smoothness values are assumed to be the “true values”, and are used to develop the smoothness specifications described later in this report. Table 2.3 shows the frequency of calibration is a variable that should be defined by in a test method defined by DOH.

Figure 2.1 Variations in Mays Ride Meter Calibration Results.
CHAPTER THREE

DATABASE CREATION AND SMOOTHNESS SPECIFICATIONS

3.1 Introduction

This project involved the development of a new smoothness specification for asphalt overlays in the state of West Virginia. The Mays number was used to evaluate the smoothness of the sections included in this project. This chapter explains the project selection phase, data analysis, smoothness specifications including pay adjustments suggestions. Due to the lack of sufficient data, the specifications recommended in this report should be used as an experimental phase for implementation.

Smoothness measurements were made during the construction seasons for the years 2002 and 2003. There were 4 projects selected in 2002 and 3 projects in 2003. The project details are shown in Table 3.1. This gave an opportunity to compare the means of smoothness values achieved by 3 contractors, who were involved in the construction of 7 different projects spread across the entire state of West Virginia.

Table 3.1 Project Details for 2002-2003

<table>
<thead>
<tr>
<th>Year</th>
<th>Project No.</th>
<th>County</th>
<th>Route</th>
<th>Road Name</th>
<th>Contractor</th>
<th>Project No.</th>
<th>Length (Miles)</th>
<th>Start date/Finish date</th>
<th>Overlay Thick (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>1</td>
<td>KAN</td>
<td>US-119</td>
<td>Charleston (Cor G)</td>
<td>West Virginia Paving</td>
<td>S332-119-3.43</td>
<td>5.44</td>
<td>04/28/03-06/24/03</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>BRA</td>
<td>I-79</td>
<td>Frametown</td>
<td>West Virginia Paving</td>
<td>S304-79/-51.61</td>
<td>2.57</td>
<td>07/02/03-08/20/03</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>BRA</td>
<td>I-79</td>
<td>Servia Rd</td>
<td>West Virginia Paving</td>
<td>S304-79/-42.22</td>
<td>5.25</td>
<td>07/02/03-08/20/03</td>
<td>4.25</td>
</tr>
<tr>
<td>2002</td>
<td>4</td>
<td>MGL</td>
<td>I-68</td>
<td>Sabraton- Pierpont</td>
<td>Carl Kelly Paving</td>
<td>S331-68/-4.3100</td>
<td>2.9</td>
<td>05/28/02-10/18/02</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>MGL</td>
<td>I-79</td>
<td>Star City-Penn State</td>
<td>Carl Kelly Paving</td>
<td>S331-79/-158.3100</td>
<td>2.26</td>
<td>05/30/02-08/08/02</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>BRA</td>
<td>I-79</td>
<td>Frametown- Sutton Rd</td>
<td>West Virginia Paving</td>
<td>S304-79/-54.21 00</td>
<td>3.61</td>
<td>05/28/02-08/08/02</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>BRA</td>
<td>I-79</td>
<td>Flatwoods- Burnsville</td>
<td>J.F Allen Company</td>
<td>S304-79/-71.39 00</td>
<td>4.16</td>
<td>05/28/02-09/18/02</td>
<td>3.5</td>
</tr>
</tbody>
</table>
The projects listed in Table 3.1 contain 4 projects of overlays thickness of 4 inches or greater and 3 projects of overlay thickness less than 4 inches. To augment this data set, smoothness data of past projects with overlay thickness greater than 3 inches, were requested from WVDOT. Data from seven projects were received, all constructed in 1998, as shown in Table 3.2. All data were then organized in a computer database for analysis. In total 94.2 line miles of data were accumulated.

<table>
<thead>
<tr>
<th>year</th>
<th>Site No.</th>
<th>County</th>
<th>Route</th>
<th>St, Rd Name</th>
<th>Project No</th>
<th>Length (mi)</th>
<th>Overlay Thick (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>1</td>
<td>KAN</td>
<td>NH-0791(88)</td>
<td>Prj 68</td>
<td>S320-79-7.58</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>NIC</td>
<td></td>
<td>Prj 59</td>
<td>U334-19-24.59</td>
<td>5.1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>HAR</td>
<td>NH-50</td>
<td>Prj 46</td>
<td>S317-50-15.46</td>
<td>4.3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>DOD</td>
<td>NH-50</td>
<td>Prj 73</td>
<td>S309-50-3.78</td>
<td>2.9</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>MON</td>
<td>NH-793</td>
<td>Prj 145</td>
<td>S331-79-145.68</td>
<td>5.9</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>GRN</td>
<td>NH-644</td>
<td>Prj 35</td>
<td>S313-64-168.35</td>
<td>2.9</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>MON</td>
<td>I-79</td>
<td>Prj 44</td>
<td>S304-79/63.44</td>
<td>2.3</td>
<td>4</td>
</tr>
</tbody>
</table>

### 3.2 Data Collection

The Mays Ride Meter was run at a speed of 50 mph on the entire length of the project and was used to collect smoothness data from all the newly constructed projects used for this study. The Mays Ride Meter calibration and maintenance schedules were performed in accordance to the recommended guidelines presented in the previous report by (Shoukry et al. 1998). After the field-testing was performed, each project was divided into 0.1-mile sections or sublots, and their respective smoothness values were calculated manually using the strip charts (response charts) from the Mays Ride Meter. Sublots at the beginning and end of the project and those with bridges were neglected in this study. The total length of all sections included in the study was 190 lane miles. Data were collected immediately prior to construction and after each construction step, including after joint repair and each asphalt concrete lift.
3.3 Data Analysis

The smoothness values were then summarized in a computerized database for easy access and for data analysis purposes. Plots of the smoothness values were prepared for all projects as presented in Appendix B, and means and standard deviations were computed. The computed values were further used to develop frequency distribution charts, study the effect of overlays, and develop a new smoothness specification.

Table 3.3 Frequency Distribution for Projects of Overlay Thickness Less than 4”

<table>
<thead>
<tr>
<th>Mays Number</th>
<th>Frequency</th>
<th>Frequency (%)</th>
<th>Cumulative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>4</td>
<td>0.67</td>
<td>0.67</td>
</tr>
<tr>
<td>35</td>
<td>12</td>
<td>2.00</td>
<td>2.66</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>3.33</td>
<td>5.99</td>
</tr>
<tr>
<td>45</td>
<td>41</td>
<td>6.82</td>
<td>12.81</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>14.98</td>
<td>27.79</td>
</tr>
<tr>
<td>55</td>
<td>94</td>
<td>15.64</td>
<td>43.43</td>
</tr>
<tr>
<td>60</td>
<td>110</td>
<td>18.30</td>
<td>61.73</td>
</tr>
<tr>
<td>65</td>
<td>99</td>
<td>16.47</td>
<td>78.20</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
<td>11.65</td>
<td>89.85</td>
</tr>
<tr>
<td>75</td>
<td>31</td>
<td>5.16</td>
<td>95.01</td>
</tr>
<tr>
<td>80</td>
<td>17</td>
<td>2.83</td>
<td>97.84</td>
</tr>
<tr>
<td>85</td>
<td>10</td>
<td>1.66</td>
<td>99.50</td>
</tr>
<tr>
<td>90</td>
<td>1</td>
<td>0.17</td>
<td>99.67</td>
</tr>
<tr>
<td>95</td>
<td>2</td>
<td>0.33</td>
<td>100.00</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>0.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Total    601  
Mean     59.17  
Standard Deviation 7.31  

As the in the current WV smoothness acceptance specifications, the projects were classified into two groups according to the overlay thickness. The first group contains the projects having overlay thickness between 3 and 4 inches, while the second group is for projects having overlay thickness greater than 4 inches. Table 3.3 illustrates the frequency distribution of the average Mays number for projects of overlay thickness between 3 and 4 inches. Figure 3.1 is histogram of these data. The current acceptance
limit for such projects is 81 inches per mile. As shown in Table 3.3, about 98 percent of sublots for the measurements of the final lift were below 80 percent. In other words, 13 sublots, about 2 percent, had smoothness values greater than 81 in/mi and would be penalized or subjected to corrective action under the current WV smoothness specifications. This analysis indicates that current limit for overlay thickness between 3 and 4 inches is much higher than what the contractors can achieve.

Figure 3.1 shows the frequency distribution of the Mays numbers. The distribution has the characteristics shape of normal distribution. 90 percent of the sections have a roughness less than 70 in/mi, suggesting this would be a reasonable upper limit for a smoothness specification.

The frequency distribution for the projects having overlay thickness greater than 4 inches is tabulated in Table 3.4, and graphed in Figure 3.2. The results in Table 3.4 and Figure 3.2 indicate that 15.9 percent of the sublots had smoothness values greater than 65 in/mi (the current WV limit for smoothness acceptance specifications). It is also evident that the frequency distribution is normal with a mean value of 53.93 in/mi and a standard deviation of 11.44 in/mi.
Table 3.4 Frequency Distribution for Projects of Overlay Thickness Greater than 4”

<table>
<thead>
<tr>
<th>Mays Number</th>
<th>Frequency</th>
<th>Frequency (%)</th>
<th>Cumulative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>5</td>
<td>0.38</td>
<td>0.38</td>
</tr>
<tr>
<td>30</td>
<td>9</td>
<td>0.69</td>
<td>1.08</td>
</tr>
<tr>
<td>35</td>
<td>57</td>
<td>4.38</td>
<td>5.46</td>
</tr>
<tr>
<td>40</td>
<td>122</td>
<td>9.38</td>
<td>14.85</td>
</tr>
<tr>
<td>45</td>
<td>202</td>
<td>15.54</td>
<td>30.38</td>
</tr>
<tr>
<td>50</td>
<td>238</td>
<td>18.31</td>
<td>48.69</td>
</tr>
<tr>
<td>55</td>
<td>209</td>
<td>16.08</td>
<td>64.77</td>
</tr>
<tr>
<td>60</td>
<td>198</td>
<td>15.23</td>
<td>80.00</td>
</tr>
<tr>
<td>65</td>
<td>98</td>
<td>7.54</td>
<td>87.54</td>
</tr>
<tr>
<td>70</td>
<td>85</td>
<td>6.54</td>
<td>94.08</td>
</tr>
<tr>
<td>75</td>
<td>39</td>
<td>3.00</td>
<td>97.08</td>
</tr>
<tr>
<td>80</td>
<td>12</td>
<td>0.92</td>
<td>98.00</td>
</tr>
<tr>
<td>85</td>
<td>17</td>
<td>1.31</td>
<td>99.31</td>
</tr>
<tr>
<td>90</td>
<td>6</td>
<td>0.46</td>
<td>99.77</td>
</tr>
<tr>
<td>95</td>
<td>2</td>
<td>0.15</td>
<td>99.92</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>0.08</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Total 1300

Mean 53.93

Standard Deviation 11.44

Figure 3.2 Frequency Distribution for Projects of Overlay Thickness Greater than 4”

Comparing the smoothness data of the projects having overlay thickness less than 4”, Table 3.3, and those having overlay thickness greater than 4”, Table 4.4, indicate that
the former have a higher mean value. This may be attributed to smoothness improvements achieved by the third lift of construction. However, a homoscedastic T-test of these two sets of data indicates that the probability associated with these data is 0.105, which is greater than confidence increment 0.05. This means that there is no significant statistical difference between these two sets of data. This is also indicated from the close values of the means (9% difference), and the size of the standard deviation.

Table 3.5 Frequency Distribution for All Projects.

<table>
<thead>
<tr>
<th>Mays Number</th>
<th>Frequency</th>
<th>Frequency (%)</th>
<th>Cumulative Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>5</td>
<td>0.26</td>
<td>0.26</td>
</tr>
<tr>
<td>30</td>
<td>13</td>
<td>0.68</td>
<td>0.95</td>
</tr>
<tr>
<td>35</td>
<td>69</td>
<td>3.63</td>
<td>4.58</td>
</tr>
<tr>
<td>40</td>
<td>142</td>
<td>7.47</td>
<td>12.05</td>
</tr>
<tr>
<td>45</td>
<td>243</td>
<td>12.78</td>
<td>24.83</td>
</tr>
<tr>
<td>50</td>
<td>328</td>
<td>17.25</td>
<td>42.08</td>
</tr>
<tr>
<td>55</td>
<td>303</td>
<td>15.94</td>
<td>58.02</td>
</tr>
<tr>
<td>60</td>
<td>308</td>
<td>16.20</td>
<td>74.22</td>
</tr>
<tr>
<td>65</td>
<td>197</td>
<td>10.36</td>
<td>84.59</td>
</tr>
<tr>
<td>70</td>
<td>155</td>
<td>8.15</td>
<td>92.74</td>
</tr>
<tr>
<td>75</td>
<td>70</td>
<td>3.68</td>
<td>96.42</td>
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<td>80</td>
<td>29</td>
<td>1.53</td>
<td>97.95</td>
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<tr>
<td>85</td>
<td>27</td>
<td>1.42</td>
<td>99.37</td>
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<td>90</td>
<td>7</td>
<td>0.37</td>
<td>99.74</td>
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<td>95</td>
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<td>Total</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>55.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>11.55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on the result of the T-test conducted on the two sets of data and close mean values, it seems more convenient to develop one smoothness specification for pavements whose overlay thickness greater than 3 inches. For this purpose, all data from the two sets were conglomerated into one database. This resulted in 190-lane miles worth of smoothness data. Table 3.5 illustrates the grouped statistics for the database.
The frequency distribution in terms of number of sublots is shown in Figure 3.3. It is apparent that the combined data follows a normal distribution with a mean of 55.61 in/mi and a standard deviation of 11.55 in/mi. The statistical summary for all the 14 projects is shown in Table 3.6. As seen from Table 3.6 the mean smoothness values

![Figure 3.3 Frequency Distribution in Terms of Number of Sublots.](image)

**Table 3.6 Statistical Summary of Smoothness Measurements**

<table>
<thead>
<tr>
<th>Year</th>
<th>No.</th>
<th>Project Name</th>
<th>Length (mi)</th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Lane 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>μ</td>
<td>σ</td>
<td>μ</td>
<td>σ</td>
</tr>
<tr>
<td>2003</td>
<td>1</td>
<td>R-119 Cor G</td>
<td>4.40</td>
<td>54.85</td>
<td>12.71</td>
<td>48.03</td>
<td>9.28</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>I-79 Frametown</td>
<td>2.40</td>
<td>41.81</td>
<td>5.83</td>
<td>42.59</td>
<td>8.49</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>I-79 Servia Rd</td>
<td>5.10</td>
<td>48.88</td>
<td>8.00</td>
<td>47.26</td>
<td>11.11</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>I-68 Sabraton</td>
<td>2.90</td>
<td>56.15</td>
<td>6.33</td>
<td>54.77</td>
<td>6.70</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>I-79 Star City</td>
<td>2.26</td>
<td>66.72</td>
<td>7.44</td>
<td>57.96</td>
<td>7.53</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>I-79 Frametown</td>
<td>3.61</td>
<td>52.71</td>
<td>9.61</td>
<td>63.28</td>
<td>8.23</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>I-79 Flatwoods</td>
<td>4.16</td>
<td>58.01</td>
<td>6.21</td>
<td>68.60</td>
<td>7.20</td>
</tr>
<tr>
<td>2002</td>
<td>8</td>
<td>Prj 68</td>
<td>1.50</td>
<td>45.03</td>
<td>4.35</td>
<td>46.91</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Prj 59</td>
<td>5.10</td>
<td>46.64</td>
<td>6.41</td>
<td>45.07</td>
<td>5.60</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Prj 46</td>
<td>4.30</td>
<td>57.40</td>
<td>10.30</td>
<td>60.80</td>
<td>11.50</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Prj 73</td>
<td>2.90</td>
<td>64.25</td>
<td>8.58</td>
<td>59.21</td>
<td>5.71</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Prj 145</td>
<td>5.90</td>
<td>49.80</td>
<td>9.27</td>
<td>55.80</td>
<td>10.19</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Prj 35</td>
<td>2.90</td>
<td>54.90</td>
<td>10.59</td>
<td>52.18</td>
<td>6.67</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Prj 44</td>
<td>2.30</td>
<td>69.17</td>
<td>7.90</td>
<td>67.40</td>
<td>11.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td>55.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std</td>
<td></td>
<td></td>
<td></td>
<td>11.55</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
ranged from a minimum of 32.66 in/mi to 69.17 in/mi. The scattered distribution of the smoothness means is further illustrated in Figure 3.4.

![Figure 3.4 Comparisons of Smoothness Means and Standard Deviations.](image)

The smoothness means for all the lanes are represented in Figure 3.4 and are compared to the current WV smoothness limit for overlays of 4-inch thickness or greater. Only three of the fourteen projects had smoothness means above the current state limit. This means that 21 percent of the projects considered in this study have high roughness. The rest of the projects had their lane smoothness means below the state limit of 65 in/mi. The roughest projects were built during 2002. A study was performed to check the number of sublots (0.1 mile sections) that fail the current WV limit. The results of the study are summarized in Figure 3.5. The key to the project number can be found in Table 3.6. The percentages indicate the amount of failed sublots in the specific lanes with respect to the project length. It is seen that while some projects high number of failing sublots (i.e. around 30%) others had very low number of failing sublots (around 1%). This illustrates the wide scatter that exists in the data. To achieve any form of repeatability, the smoothness specifications should include acceptance, bonus and penalty ranges. Clearly the projects in 2002 would come under the penalty regions and many lanes constructed in 1998 and 2003 would receive bonuses.
Development of the smoothness specification should reduce this wide scatter that is being observed from the past and present data. The existing smoothness limit of 65 in/mi was achieved 79 percent of the time. However, an upper limit for specifications is not sufficient. For any smoothness specifications to be effective it should have provisions for incentives/disincentives. This incentive should be made available to the contractors for exhibiting their extra effort in producing an extremely smooth final surface. The disincentives would make sure that the contractors are adhering to the allowed range and thus control the quality of paving.

3.4 Evaluate Roughness Improvements with Overlays

One of the major concerns with overlaying existing pavements is the quality of the original pavement. This section describes the steps taken to quantify the improvements that can be achieved with each lift of the overlay. This would enable us to develop a fair smoothness specification by considering the ability of the contractor to produce work to the level of specification.
The objective of this analysis was to measure smoothness soon after each lift has been placed. In the 2002 construction season, since the projects were spread across the state and were being constructed in the same time frame, it was not possible to build a complete database for all lifts. This problem was overcome in the 2003 construction season where all the three projects were very near to each other and hence we were successful in accumulating smoothness data for all the lifts.

The pavement resurfacing projects are usually performed in three different stages. The difference exists in the type and thickness of the material. The three stages include:

i. Preconstruction/Concrete Repair  
ii. Scratch Course/Lift #1 (~1.0”)  
iii. Base Course/Lift #2 (~1.5”-2.0”)  
iv. Skid Course/Lift #3 (~0.5”-1.0”)  

It is believed that the quality of construction of each of the above-mentioned lifts plays a major role in the quality of the final surface.

Figure 3.6 Comparison of Smoothness Results With Placement of Overlays

Smoothness data for all the lifts for all the 3 projects were collected and plotted in Appendix C. A summary of the smoothness values is shown in Figure 3.6. All the 3
projects started construction from initially rough pavement surface condition. The smoothness values after concrete repair were in the range of 130 in/mi to 220 in/mi (i.e. very rough).

The improvements achieved are statistically compared using the Student t-test. The means and standard deviations for all the lanes were calculated for each lift. These values were then used to evaluate the levels of improvements from one lift to the next. A confidence level of 95% was chosen for all the comparisons. The t-statistic and probability values are calculated using MS-EXCEL for a two tailed t-test with equal variance. The result is the probability value ‘p’, which indicates whether the means of the lifts are different or similar. Thus, a probability value less than 0.05 would indicate inequality of means (or very low probability of the means being equal). In terms of improvements in smoothness we could conclude that if the means are unequal then we can be 95% confident that there is a significant improvement in smoothness and on the other hand, if means are significantly equal indicates that we can be 95% confident that there was no improvement in smoothness.

3.4.1 Roughness Improvements in the Corridor-G Project

The project construction began with very rough sections having smoothness values ranging from 156 in/mi to 216 in/mi. Table 3.7 illustrates the mean, standard deviation and the t-test probability between lifts. The minimum, maximum and average smoothness achieved by the contractor in each lift for each lane is shown in Figure 3.7. As observed from Table 3.7, the t-test resulted in the null hypothesis being rejected for all comparisons indicating unequal means between lifts. Hence the contractor has managed to achieve improvements in smoothness with every lift. At the completion of the project the contractor achieved smoothness values ranging from 45 in/mi to 55 in/mi.

The initial and final smoothness values for each lift were used to calculate the effective improvement achieved by the contractor after every lift. The percentage improvements are shown in the form of bar chart in Figure 3.8.
Table 3.7 Student T-Test Results for Corridor-G Project

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Pre-Construction (Concrete Repair)</th>
<th>Lift #1 (Scratch)</th>
<th>Lift #2 (Base)</th>
<th>Lift #3 (Skid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 44</td>
<td>$\bar{X}$</td>
<td>$S$</td>
<td>$\bar{X}$</td>
<td>$S$</td>
</tr>
<tr>
<td>Northbound Left Lane (NLL)</td>
<td>156.28</td>
<td>21.7</td>
<td>95.79</td>
<td>18.45</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Northbound Right Lane (NRL)</td>
<td>202.29</td>
<td>25.9</td>
<td>96.73</td>
<td>17.53</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Southbound Left Lane (SLL)</td>
<td>159.98</td>
<td>24.9</td>
<td>100.8</td>
<td>4</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Southbound Right Lane (SRL)</td>
<td>216.20</td>
<td>40.7</td>
<td>122.0</td>
<td>6</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Figure 3.7 Smoothness Range For Corridor-G Project.

Figure 3.8 Smoothness Range For Corridor-G Project.
Figure 3.8 Percentage Improvements in Smoothness with Overlays on the Corridor-G Project

From Figure 3.8 it can be observed that on an average around 50-60% of the improvement was achieved with the placement of the Scratch course (Lift #1). This improvement was augmented with the base course (Lift #2) by another 16-25% improvement. The final or the skid lift improved the smoothness by yet another 18-32% to have a final surface with smoothness values close to 45 in/mi. In this project the contractor has achieved improvements in every opportunity (every lift).

3.4.2 Roughness Improvement in the Frametown Project

The pre-construction roughness of the Frametown ranged from 116 in/mi to 133 in/mi for different lanes as shown in Figure 3.9. The t-test results, Table 3.8, indicated a probability value greater than 0.05 for the Northbound Right Lane (NRL) after the placement of the base course, Lift #2, which indicates that the means of Lift #1 and Lift #2 were not significantly different, and hence there was no improvement in smoothness during this stage of construction. However this is not reflected in the final surface condition of the lane. From Figure 3.10 it is clear that except for the NRL, all other lanes had 13 to 14% improvement in smoothness. On further close observation it is noted that in the NRL there was very significant improvement in smoothness after the placement of the Scratch course, Lift #1. The scratch course alone improved the smoothness by around 70%. For all the remaining lanes improvements were observed during all the 3 stages of construction.

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Pre-Construction (Concrete Repair)</th>
<th>Lift #1 (Scratch)</th>
<th>Lift #2 (Base)</th>
<th>Lift #3 (Skid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\bar{X}$</td>
<td>$S$</td>
<td>$\bar{X}$</td>
<td>$S$</td>
</tr>
<tr>
<td>Lane 1 (NLL)</td>
<td>116.16</td>
<td>19.82</td>
<td>72.70</td>
<td>13.69</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.0066</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Lane 2 (NRL)</td>
<td>124.29</td>
<td>21.87</td>
<td>67.00</td>
<td>9.60</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.78</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Lane 3 (SLL)</td>
<td>131.80</td>
<td>18.50</td>
<td>77.01</td>
<td>16.70</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.0050</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Lane 4 (SRL)</td>
<td>133.94</td>
<td>25.25</td>
<td>86.82</td>
<td>21.54</td>
</tr>
</tbody>
</table>
3.4.3 Roughness improvements in the Servia Road project

The observations were similar to the two previous projects. The Servia Road project and the Frametown project were very close to each other; separated only by a bridge. The initial condition of the pavement was very much similar to the Frametown project with roughness values in the range of 121 in/mi to 132 in/mi, Figure 3.11. Equality of means was observed in the North Right lane and also on the South Left Lane,
Table 3.10. In both lanes, there were no improvements in smoothness after the placement of the base course, Lift #2. As seen from Figures 3.11 and 12, there was a considerable improvement in smoothness with the placement of the scratch course, Lift #1, and hence the final condition of the pavement was not affected even without any improvement achieved after Lift #2. Improvements in smoothness were observed for all the remaining lifts as seen in Figure 3.12.

Table 3.9 Student T-Test Results for the Servia Road Project

<table>
<thead>
<tr>
<th></th>
<th>Sample Size N = 51</th>
<th>Pre-Construction (Concrete Repair)</th>
<th>Lift #1 (Scratch)</th>
<th>Lift #2 (Base)</th>
<th>Lift #3 (Skid)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\bar{X}$</td>
<td>$S$</td>
<td>$\bar{X}$</td>
<td>$S$</td>
<td>$\bar{X}$</td>
</tr>
<tr>
<td>Lane 1 (NLL)</td>
<td>126.75</td>
<td>27.35</td>
<td>79.75</td>
<td>17.92</td>
<td>67.40</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.00029</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Lane 2 (NRL)</td>
<td>132.92</td>
<td>21.73</td>
<td>73.95</td>
<td>16.52</td>
<td>74.74</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.79</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Lane 3 (SLL)</td>
<td>121.18</td>
<td>17.05</td>
<td>68.89</td>
<td>12.44</td>
<td>68.05</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.731</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Lane 4 (SRL)</td>
<td>124.23</td>
<td>22.57</td>
<td>82.11</td>
<td>13.70</td>
<td>69.07</td>
</tr>
<tr>
<td>$t$-value</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.11 Smoothness Range for the Servia Road Project
3.4.4 Summary of Observations from 2003 Projects

Evaluation of the roughness improvements lead to the following conclusions:

- There were twelve combinations of project-lane available in the data set. In three combinations, or 25 percent, the base layer did not improve the roughness.
- The scratch course (Lift #1) alone achieved 57 to 72% of the overall improvement in smoothness.
- The initial condition of the pavement did not play an important role in the final surface condition in all the 3 projects considered. The projects started with some very rough sections in the range of 200 in/mi. However at the completion all the projects had smoothness values around 50 in/mi.
- None of the projects had mean final smoothness values greater than 52 in/mi, considerably less than the current West Virginia smoothness acceptance limit.

The improvements in smoothness as observed in the 3 projects are illustrated in Table 3.10.
Table 3.10 Smoothness Improvements Achieved with Every Lift.

<table>
<thead>
<tr>
<th>Opportunity (Lift)</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Repair-Lift #1</td>
<td>65-70%</td>
</tr>
<tr>
<td>Lift #1 – Lift #2</td>
<td>12-15%</td>
</tr>
<tr>
<td>Lift #2 – Lift #3</td>
<td>12-15%</td>
</tr>
</tbody>
</table>

The results in Table 3.10 indicate that the contractors were able to achieve a final smoothness value ranging from 40 in/mi to 50 in/mi. Hence the smoothness specification could also be set around this value.

Since the performance of only one contractor was observed during 2003, we might need to include a tolerance of 5 in/mi when setting the smoothness specification. This tolerance would take into account all the difficulties involved by the contractor in the construction process, the standard error in the measurement process and also allow flexibility in meeting the smoothness requirement.

### 3.5 Pay Adjustment Factors

An important section included in the smoothness specifications of many states is the pay adjustment factors. When included, they describe positive pay adjustments based on smoothness levels that are higher than specified (incentives) or negative pay adjustments based on smoothness levels lower than specified (disincentives). The pay adjustments are included in the specification to encouraging construction of smooth pavements. Bonuses can be justified based on the assumption that lower initial pavement roughness will result in better long-term pavement performance. The importance of including pay adjustments to the smoothness specifications from the experiences of other states is presented below.

#### 3.5.1 Texas DOT Specifications

The TDOT smoothness specification allows payment incentives and disincentives based in the profile index (PI), defined as the ratio of vertical deviations in the surface
over a length of pavement (Ksaibati and Al-Mahmood, 2002). The pay adjustment factor is a flat rate per sublot rather than a percent of unit bid price as shown in Table 3.11.

<table>
<thead>
<tr>
<th>Table 3.11 Pay Adjustment Criteria of Texas DOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profilograph Index</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>1.5 or less</td>
</tr>
<tr>
<td>1.6 thru 2.0</td>
</tr>
<tr>
<td>2.1 thru 3.0</td>
</tr>
<tr>
<td>3.1 thru 4.0</td>
</tr>
<tr>
<td>4.1 thru 6.0</td>
</tr>
<tr>
<td>6.1 thru 8.0</td>
</tr>
<tr>
<td>8.1 thru 9.0</td>
</tr>
<tr>
<td>9.1 thru 10.0</td>
</tr>
<tr>
<td>10.1 thru 11.0</td>
</tr>
<tr>
<td>11.1 thru 12.0</td>
</tr>
<tr>
<td>Over 12.0</td>
</tr>
</tbody>
</table>

3.5.2 Connecticut DOT specifications

Pay adjustments are based on the IRI obtained from the profilograph. The percent adjustments are applied to payment(s) for the total quantity of the top two surface courses. The newly constructed pavement is divided into 160-meter length segments and an average IRI value is computed for each 160-meter segment (Dougan, 2001; Ksaibati and Al-Mahmood, 2002). Each segment IRI value is then categorized into one of the five IRI ranges shown in Table 3.12 and the applicable payment factor (PF) value is derived for each individual section. The payment factor is multiplied by the length of that segment to compute a segment adjustment factor. The total pay adjustment factor is then calculated as:

\[
RA = \frac{AF_{s1} + AF_{s2} + AF_{s3} \ldots \ldots + AF_{sx}}{L_{s1} + L_{s2} + L_{s3} + \ldots \ldots L_{sx}} \times 100
\]

where

RA = Rideability adjustment for complete project
AF_{sx} = Adjustment factor for each segment (x) = PF_{sx} L_{sx}
PF = Rideability adjustment for complete project
L_{sx} = Length of applicable segment (160 m)
X = Number of segments
Table 3.12 Pay Adjustment Criteria of Connecticut DOT

<table>
<thead>
<tr>
<th>IRI (m/km)</th>
<th>Percent Adjustment (PF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.789</td>
<td>10</td>
</tr>
<tr>
<td>0.789-0.947</td>
<td>63.29 (0.947-IRI)</td>
</tr>
<tr>
<td>0.948-1.262</td>
<td>0</td>
</tr>
<tr>
<td>1.263-1.893</td>
<td>39.69 (1.263-IRI)</td>
</tr>
<tr>
<td>&gt;1.893</td>
<td>-50</td>
</tr>
</tbody>
</table>

3.5.3 Montana DOT Specifications

Montana DOT specifications are based on the International Roughness Index (IRI). The surface profile is generated using the profile index (PI) measurements of the finished pavement surface. Surface smoothness and surface profile are analyzed from the data collected by the DOT personnel using a Class I Laser Road Profiler. The IRI values are determined for 0.2-mile long sections. Partial sections are prorated or added to an abutting section. Pay adjustment factors are classified as shown in Table 3.13 and are applied to each section along the length of the project (Montana DOT, 2004; Ksaibati and Al-Mahmood, 2002).

Table 3.13 Pay Adjustment Factors of Montana DOT

<table>
<thead>
<tr>
<th>Pavement Classification</th>
<th>Actual IRI (in/mi)</th>
<th>Pay Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>&lt;40</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>40-45</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>46-65</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>&gt;65</td>
<td>0.90</td>
</tr>
<tr>
<td>Class II</td>
<td>&lt;45</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>45-55</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>56-75</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>&gt;75</td>
<td>0.90</td>
</tr>
<tr>
<td>Class III</td>
<td>&lt;45</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>45-55</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>56-80</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>&gt;80</td>
<td>0.90</td>
</tr>
<tr>
<td>Class IV</td>
<td>&lt;50</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>50-60</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>61-90</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>&gt;90</td>
<td>0.90</td>
</tr>
</tbody>
</table>
3.5.4 Virginia DOT Specifications

The VDOT uses the South Dakota-style inertial road profiler (SDRP) for smoothness acceptance of both interstate and Non-Interstate roadways (McGhee, 1999). The smoothness specification charts are based on the lowest site average IRI produced by a minimum of two test runs. The IRI in in/mi is established for each 0.01 mi section for each travel lane of the overlay. The first and the last 0.01 mi before and after a bridge, and the beginning and the end 0.01 mi section of the overlay are not subjected to a pay adjustment. Pay adjustments are applied to the theoretical tonnage of the surface mix asphalt material for the lane width and section length tested (generally 12’ wide and 52.8’ long) based on testing prior to any corrective action directed by the engineer. The overlay thickness does not influence the specifications in any form. The specification charts for the pay adjustments are as shown in Tables 3.14 and 3.15 for Interstate and Non-Interstate roadways respectively.

Table 3.14 Pay Adjustment Criteria of Virginia DOT (Interstate Roadways)

<table>
<thead>
<tr>
<th>IRI after Completion (in/mi)</th>
<th>Pay Adjustment (Percent payment unit price)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.45.0 and under</td>
<td>110</td>
</tr>
<tr>
<td>.45.10-55.0</td>
<td>105</td>
</tr>
<tr>
<td>.55.10-70.0</td>
<td>100</td>
</tr>
<tr>
<td>70.10-80.0</td>
<td>90</td>
</tr>
<tr>
<td>80.10-90.0</td>
<td>80</td>
</tr>
<tr>
<td>90.10-100.0</td>
<td>60</td>
</tr>
<tr>
<td>Over 100.0</td>
<td>Corrective action</td>
</tr>
</tbody>
</table>

Table 3.15 Pay Adjustment criteria of Virginia DOT (Non-Interstate Roadways)

<table>
<thead>
<tr>
<th>IRI after Completion (in/mi)</th>
<th>Pay Adjustment (Percent payment unit price)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.55.0 and under</td>
<td>110</td>
</tr>
<tr>
<td>.55.10-65.0</td>
<td>105</td>
</tr>
<tr>
<td>65.10-80.0</td>
<td>100</td>
</tr>
<tr>
<td>80.10-90.0</td>
<td>90</td>
</tr>
<tr>
<td>90.10-100.0</td>
<td>80</td>
</tr>
<tr>
<td>100.10-110.0</td>
<td>60</td>
</tr>
<tr>
<td>Over 110.0</td>
<td>Corrective action</td>
</tr>
</tbody>
</table>
3.6 Smoothness Specification

The review of the pay adjustment factors of other states indicates that direct comparison is not possible due to the variety in equipment, roughness indices, and evaluation procedures used. A constructive methodology has been developed to implement the pay adjustment factors to the proposed Smoothness Specifications.

The smoothness database suggested for this project was used for the development of the specifications. The following guidelines were used to develop the new specifications:

i. The main intention was to reduce the scatter of initial roughness exhibited by the contractors, thus encouraging them to build smoother pavements.

ii. The improvements in smoothness achieved by the contractors.

iii. The smoothness specification should have both, an incentive and disincentive policy.

iv. The specification would be valid only for quality acceptance when the department’s Mays Ride Meter is used to measure the initial smoothness of asphalt overlays having thickness greater than 3 inches.

v. The implementation of the specifications should be first performed on a few selected experimental projects to check its effectiveness.

The frequency distribution tabulated in Table 3.5 indicates that the smoothness measurements follow a normal distribution with a mean value of about 55 in/mi and a standard deviation of 11.55 in/mile. Setting the acceptable range for the smoothness at 55 in/mile with a tolerance equal to the standard deviation (11.55 in/mile and will be rounded to 10 in/mi) means that 66 percent of the projects will fall within 45 to 65 inches/mile and hence satisfy the smoothness requirements. Projects of roughness values higher than 65 in/mi would be subjected to penalty or corrective actions. Projects with at least 10 sequential sublots of roughness values lower than 45 in/mi would receive bonus. Table 3.16 summarizes the proposed new smoothness specifications.
Table 3.16 Smoothness Specification for Asphalt Overlays with Thickness > 3”

<table>
<thead>
<tr>
<th>Testing Device</th>
<th>Mays Ride Meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>Mays Ride number</td>
</tr>
<tr>
<td>Testing Interval</td>
<td>0.1 mile</td>
</tr>
<tr>
<td>Bonus Range</td>
<td>( \leq 45 \text{ in/mi} )</td>
</tr>
<tr>
<td>Acceptance or Full Pay Range</td>
<td>55 ( \pm 10 \text{ in/mi} )</td>
</tr>
<tr>
<td>Penalty Range</td>
<td>( \geq 65 \text{ in/mi} ) and ( \leq 75 \text{ in/mi} )</td>
</tr>
<tr>
<td>Correction Range</td>
<td>&gt; 75 \text{ in/mi}</td>
</tr>
</tbody>
</table>

The incentives/disincentives should be implemented on projects with a posted speed limit equal to or greater than 50 mph. Each lane would be divided into 0.1-mile sublots. Taking the average of three runs by the Mays Ride Meter the smoothness means for each lane are calculated. Smoothness would be determined for all sublots and the price adjustment should be made for each sublot according to the pay adjustment criteria proposed herewith. The specification in Table 3.16 is based on Figure 3.13 depicting the bonus, penalty and acceptance ranges.

![Frequency distribution](image)

Figure 3.13 Smoothness Specification Chart
### 3.6.1 Specification Guidelines

**General**

1. The smoothness data should be collected within 24 hours of completion of the paving portion of the project.
2. All paving projects having overlay thickness of 3” or greater should be subjected to this specification.
3. The following project sections are specifically excluded from all terms of this specification:
   3.1 Bridge decks and joints
   3.2 Beginning 0.1 mi section and ending 0.1 mi section of the project
   3.3 Shoulders and ramps

**Equipment**

1. The specification is valid only when the division uses the Mays Ride Meter to collect smoothness data.

**Measurement methodology**

1. The measuring speed of the Mays Ridemeter will be 50 ± 2 mph.
2. Calibration of the Mays Ride Meter should be performed with the results of the SHRP Inertial Profilometer.
3. The calibration interval should be reduced to 15 days during construction seasons and 45 days during non-construction seasons.
4. The Mays Ride Meter is driven over each lane throughout the length of the project and measurements should be taken for every 0.1 mi increment.
5. 3 runs of the Mays Ride Meter should be made for every 0.1 mi increment.
6. All smoothness measurements are reported as Mays number (in/mi) also referred to as Mays Ridenumber.
Calculations

1. Raw Mays-meter measurements should be reduced to equivalent SHRP Inertial Profilometer Mays numbers through a correlation equation obtained during calibration.
2. The most recent calibration equation should be used to calculate the final or true smoothness values.
3. The 3 individual measurements for each 0.1 mi section should be average and recorded to the nearest 0.1 in/mi.

Report

A report should be prepared for each project tested. It should include the following:

i. The date of the test
ii. The name of the test operator
iii. Test Vehicle Parameters (such as tire pressure)
iv. Project Number
v. The location of each 0.1 mi increment
vi. The 3 individual readings, in Mays Ridenumber (in/mi) for each 0.1 mi section
vii. The average of the above 3 readings.

Payment Adjustment Criteria

1. Payment will be made for each 0.1 mi section included in the specification.
2. Payment factors based on average Mays number are shown in Figure 3.14 based in the ranges identified in Table 3.17.
3. Any 0.1 mi section resulting in no or zero payment should be corrected at the contractor’s expense.
4.
Table 3.17 Pay Adjustment Factors

<table>
<thead>
<tr>
<th>Percent payment (PF&lt;sub&gt;1&lt;/sub&gt;)</th>
<th>Mays Number (in/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>&lt; 35</td>
</tr>
<tr>
<td>105</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>45 – 65</td>
</tr>
<tr>
<td>90</td>
<td>70</td>
</tr>
<tr>
<td>80</td>
<td>70 – 75</td>
</tr>
<tr>
<td>0</td>
<td>&gt; 75</td>
</tr>
</tbody>
</table>

Bonus range : \((145-x)/100\) for \(35 \leq x \leq 45\)…………………………(1)

Penalty range : \((230-2x)/100\) for \(65 \leq x \leq 75\)………………………..(2)

Where \(x = \text{Mays number (in/mi)}\)

Figure 3.14 Pay Ranges for Mays Ride Meter Measurements

5. In order to effectively capture the variability in the entire project, it is suggested to make use of another payment factor based on standard deviation over the entire length of the project. The payment factors based on standard deviation is shown in Table 3.18.
Table 3.18 Pay factor based on Standard Deviation

<table>
<thead>
<tr>
<th>Payment Factor (PF\textsubscript{2})</th>
<th>Standard Deviation (in/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0.02</td>
<td>0 – 5</td>
</tr>
<tr>
<td>+0.01</td>
<td>6 – 10</td>
</tr>
<tr>
<td>0</td>
<td>11 – 15</td>
</tr>
<tr>
<td>-0.01</td>
<td>16 – 20</td>
</tr>
<tr>
<td>-0.02</td>
<td>21 – 25</td>
</tr>
<tr>
<td>-0.03</td>
<td>26 – 30</td>
</tr>
<tr>
<td>-0.04</td>
<td>31 – 35</td>
</tr>
</tbody>
</table>

Example 1: An individual 0.1 mi section consisting of 100 tons of HMA has a Mays-number of 70 in/mi with a project standard deviation of 17.0.

Assuming that on average HMA is $30/ton

Final Payment Factor (PF) = (PF\textsubscript{1} + PF\textsubscript{2})

PF\textsubscript{1} = (230-2*70)/100 = 0.90………………………………Equation 2

PF\textsubscript{2} = -0.01 .........................................................Table 3.18

PF = (0.90 – 0.01) = 0.89

Total Payment = ( PF )*($/ton)*(Quantity in tons)

= ( 0.89 )*(30)*(100) = $2,670

Total payment without specification = (30)*(100) = $3,000

Disincentive imposed on the Contractor for the individual 0.1 mi section = $330

Example 2: An individual 0.1 mi section consisting of 100 tons of HMA has a Mays Ridenumber of 40 in/mi with a project standard deviation of 6.0 (assuming the Mays-numbers for 10 consecutive sublots were below 45 in/mi).

Assuming that on average HMA is $30/ton

Final Payment Factor (PF) = (PF\textsubscript{1} + PF\textsubscript{2})
PF₁ = (145-40)/100 = 1.05...........................Equation 1
PF₂ = +0.01 .............................................Table 3.19
PF = (1.05 +0.01) = 1.06

Total Payment = (PF)*($/ton)*(Quantity in tons)
               = (1.06)*(30)*(100) = $3,180

Total payment without specification = (1.00)*(30)*(100) = $3,000

Incentive awarded to the Contractor for the individual 0.1 mi section = $180

**Corrective Action**

1. All 0.1 mi sections subjected to corrective actions shall be performed by the Contractor with the approval of the engineer. This should include grinding, milling and applying a lift of skid course.
2. The corrected sections shall be retested by the engineer for acceptance. However these sections would not be subjected to incentive payments.
CHAPTER FOUR
CONCLUSIONS

1. Due to operational problems, the Low Speed Profilometer was not evaluated during this project. All data were collected with Mays Ride Meter.

2. The smoothness means achieved by various contractors during 2003 were in the range of 45 in/mi to 65 in/mi.

3. The roughness improvement with the placement of each lift in the overlay was quantified for the 2003 construction season. The maximum improvement in roughness takes place after the placement of the scratch course (Lift #1). However it was also noticed that the contractors were able to achieve improvements in roughness with every lift irrespective of the initial condition of the pavement.

4. New smoothness specification is proposed based on the Mays Ride Meter data. The smoothness specification could be implemented on some experimental projects to check for its effectiveness in controlling the scatter in data and make sure that the contractors build smooth pavements.

5. Incentive/Disincentive policies have been recommended within the smoothness specification to achieve good quality and smooth pavements.

The following measurement methodology is recommended for effective quality control on the smoothness of the pavement:

1. Each lane of the entire project is tested for quality acceptance.

2. Each lane is further divided into sublots of 0.1 mi length.

3. The Mays Ride Meter is used to determine the smoothness values for all sublots.

4. Sublots containing bridges and those containing the beginning and end of the project are not included for quality acceptance.

5. A Pay adjustment must be made for every sublot that has smoothness value higher than the specified upper limit.
6. If the smoothness value of the sublot is greater than half the upper limit specified, the sublot should be subjected to corrective actions at the expense of the contractor. The corrected sublot would be again tested for quality acceptance.

7. If the number of sublots failing the specification is more than half the length of the lane, the entire lane should be repaved at the expense of the contractor.
References


Appendix- A

Maysmeter Calibration

Date: 17-Apr-02  Time: 9:30 AM
Weather Condition: Sunny
Temperature: 64°F
Tire Pressure: 32 PSI

<table>
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<th>SHRP Profilometer (m/km)</th>
<th>SHRP Avg</th>
<th>SHRP Avg (in/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1  2  3 Mays Avg</td>
<td>1  2  3 SHRP Ave</td>
<td></td>
<td></td>
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<tr>
<td>1</td>
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<td>0.463  0.451  0.465</td>
<td>0.46</td>
<td>29.12</td>
</tr>
<tr>
<td>2</td>
<td>Ruth Road North</td>
<td>23  21  8  17.33</td>
<td>0.521  0.518  0.515</td>
<td>0.52</td>
<td>32.82</td>
</tr>
<tr>
<td>3</td>
<td>Childress Road South</td>
<td>22  18  22  20.67</td>
<td>0.478  0.479  0.475</td>
<td>0.48</td>
<td>30.24</td>
</tr>
<tr>
<td>4</td>
<td>Childress Road North</td>
<td>16  22  16  18.00</td>
<td>0.632  0.621  0.609</td>
<td>0.62</td>
<td>39.32</td>
</tr>
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<td>5</td>
<td>Rabel Farm South</td>
<td>20  23  23  22.00</td>
<td>0.573  0.555  0.565</td>
<td>0.56</td>
<td>35.76</td>
</tr>
<tr>
<td>6</td>
<td>Rabel Farm North</td>
<td>21  24  21  22.00</td>
<td>1.565  1.568  1.583</td>
<td>1.57</td>
<td>99.60</td>
</tr>
<tr>
<td>7</td>
<td>Alum Creek/Friendly Drive North</td>
<td>72  58  70  66.67</td>
<td>1.438  1.441  1.407</td>
<td>1.43</td>
<td>90.52</td>
</tr>
<tr>
<td>8</td>
<td>Alum Creek/Friendly Drive South</td>
<td>52  62  54  56.00</td>
<td>1.84   1.789  1.823</td>
<td>1.82</td>
<td>115.14</td>
</tr>
<tr>
<td>9</td>
<td>Julian Mini-Mart West</td>
<td>118 110 134  120.67</td>
<td>2.152  2.297  2.298</td>
<td>2.25</td>
<td>142.49</td>
</tr>
<tr>
<td>10</td>
<td>Julian Mini-Mart East</td>
<td>100  98  96  96.00</td>
<td>1.675  1.654  1.654</td>
<td>1.66</td>
<td>105.24</td>
</tr>
<tr>
<td>11</td>
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<td>70  66  70  68.67</td>
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<td>91.70</td>
</tr>
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<td>1.45</td>
<td></td>
</tr>
</tbody>
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Maysmeter Calibration

\[ y = 1.0584x + 17.173 \]

\[ R^2 = 0.8732 \]
# Maysmeter Calibration

**Date:** 5-Jun-02  
**Time:** 10:30 AM  
**Weather Condition:** Sunny  
**Temperature:** 83°F  
**Tire Pressure:** 32 PSI

## Maysmeter Calibration

<table>
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<tr>
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<th>Mays Average</th>
<th>SHRP Profilometer (m/km)</th>
<th>SHRP Average (inch/mile)</th>
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<tbody>
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<td>0.463 0.451 0.465 0.46</td>
<td>29.12</td>
</tr>
<tr>
<td>3</td>
<td>Childress Road South</td>
<td>22 14 22</td>
<td>19.33</td>
<td>0.521 0.518 0.515 0.52</td>
<td>32.82</td>
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<tr>
<td>4</td>
<td>Childress Road North</td>
<td>24 20 28</td>
<td>24.00</td>
<td>0.478 0.479 0.475 0.48</td>
<td>30.24</td>
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<td>19.67</td>
<td>0.632 0.621 0.609 0.62</td>
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<td>0.573 0.555 0.565 0.56</td>
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<td>Alum Creek/Friendly Drive North</td>
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<td>8</td>
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<td>55 52 53</td>
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<td>9</td>
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<td>1.84 1.789 1.823 1.82</td>
<td>115.14</td>
</tr>
<tr>
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<td>106 116 109 110</td>
<td>110.33</td>
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<td>142.49</td>
</tr>
<tr>
<td>11</td>
<td>Pennzoil Station West</td>
<td>56 55 54</td>
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<td>1.675 1.654 1.654 1.66</td>
<td>105.24</td>
</tr>
<tr>
<td>12</td>
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<td>71 76 86</td>
<td>77.67</td>
<td>1.426 1.463 1.453 1.45</td>
<td>91.70</td>
</tr>
</tbody>
</table>

## Graph

![Maysmeter Calibration Graph](image)

\[ y = 1.0566x + 17.334 \]

\[ R^2 = 0.835 \]
Maysmeter Calibration

Date: 22-Jul-02  Time: 9:00 AM
Weather Condition: Sunny  Temperature: 89°F  Tire Pressure: 32 PSI

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<th>Site Name</th>
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<th>SHRP Average (inch/mile)</th>
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<td>50</td>
<td>67</td>
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<tr>
<td>9</td>
<td>Julian Mini-Mart West</td>
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<td>126</td>
<td>132</td>
</tr>
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<td>10</td>
<td>Julian Mini-Mart East</td>
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</tbody>
</table>

Maysmeter Calibration

\[ y = 1.0144x + 10.556 \]

\[ R^2 = 0.8808 \]
Maysmeter Calibration

Date: 28-Mar-03  Time: 8:30 AM
Weather Condition: Sunny
Temperature: 60°F
Tire Pressure: 32 PSI

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<th>SHRP Profilometer (m/km)</th>
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</thead>
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<td>52</td>
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<tr>
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<td>Alum Creek/Friendly Drive North</td>
<td>106</td>
<td>96</td>
</tr>
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<td>Alum Creek/Friendly Drive South</td>
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<td>96</td>
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<td>9</td>
<td>Julian Mini-Mart West</td>
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Maysmeter Calibration

y = 1.0168x - 5.5251
R² = 0.8917
### Maysmeter Calibration

**Date:** 24-Jun-03  
**Time:** 9:00 AM  
**Weather Condition:** Sunny  
**Temperature:** 80°F  
**Tire Pressure:** 32 PSI

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</tr>
<tr>
<td>1</td>
<td>Ruth Road South</td>
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\[ y = 0.9864x - 3.3364 \]

\[ R^2 = 0.9188 \]
**Maysmeter Calibration**

**Date:** 10-Jul-03  
**Time:** 9:00 AM  
**Weather Condition:** Sunny  
**Temperature:** 80°F  
**Tire Pressure:** 32 PSI

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**Graph:**

- **Equation:** \( y = 0.9977x - 9.3772 \)
- **Correlation Coefficient:** \( R^2 = 0.8969 \)
Maysmeter Calibration

Date: 7-Nov-03    Time: 8:45 AM
Weather Condition: Sunny
Temperature: 50°F
Tire Pressure: 32 PSI

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y = 1.1027x - 0.2773
$R^2 = 0.9518$
Appendix B

Plots of Smoothness Values
2003 Projects

Project: S332-119/3.43
Name: Cor G
Route: US-119
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 4.4 Miles
Date: 24 June 2003

Date: 24-Jun-03

Lift #3

North Left Lane

Mays Number

North Right Lane

Mays Number

South Left Lane

Mays Number

South Right Lane

Mays Number

Date: 24-Jun-03

..........

-.-.-.-.-

-.-.-.-.-

μ + σ

μ + 2σ

μ: 59.38 σ: 12.50
μ: 52.08 σ: 9.41
μ: 50.36 σ: 12.76
μ: 51.85 σ: 8.04

Mile Position

Mile Position

Mile Position

Mile Position
Project: S304-79/-51.61
Name: Frametown
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 2.4 Miles
Date: 20 August 2003

Date: 20-Aug-03

Lift #3

North Left Lane

Mile Position  | Mays Number
0 | 0
0.5 | 
1 | 
1.5 | 
2 | 
2.5 | 

South Left Lane

Mile Position  | Mays Number
0 | 0
0.5 | 
1 | 
1.5 | 
2 | 
2.5 | 

South Right Lane

Mile Position  | Mays Number
0 | 0
0.5 | 
1 | 
1.5 | 
2 | 
2.5 | 

North Right Lane

Mile Position  | Mays Number
0 | 0
0.5 | 
1 | 
1.5 | 
2 | 
2.5 | 

\[
\mu: 51.31 \quad \sigma: 5.84
\]

\[
\mu: 57.97 \quad \sigma: 7.62
\]

\[
\mu: 52.08 \quad \sigma: 8.51
\]

\[
\mu: 60.28 \quad \sigma: 8.83
\]
Project: S304-79/-42.22
Name: Servia Rd
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 5.1 Miles
Date: 20 August 2003

Date: 20-Aug-03

Lift #3

North Left Lane

```
\begin{itemize}
  \item \(\mu: 57.61\), \(\sigma: 9.00\)
  \item \(\mu: 58.39\), \(\sigma: 8.02\)
  \item \(\mu: 60.27\), \(\sigma: 9.01\)
  \item \(\mu: 56.77\), \(\sigma: 11.14\)
\end{itemize}
```

North Right Lane

```
\begin{itemize}
  \item \(\mu: 56.77\), \(\sigma: 11.14\)
\end{itemize}
```

South Left Lane

```
\begin{itemize}
  \item \(\mu: 57.61\), \(\sigma: 9.00\)
\end{itemize}
```

South Right Lane

```
\begin{itemize}
  \item \(\mu: 60.27\), \(\sigma: 9.01\)
\end{itemize}
```
2002 Projects

Project: S331-68/-4.31
Name: Sabraton
Route: I-68
Contractor: Carl Kelly Paving
Oly Thickness: 3.5"
Length: 2.9 Miles
Date: 18 October 2002

Date: 18-Oct-02

West Left Lane

West Right Lane

East Left Lane

Right Lane

$\mu$: 54.77 $\sigma$: 6.70

$\mu$: 57.47 $\sigma$: 6.46

$\mu$: 56.15 $\sigma$: 6.33

$\mu$: 56.15 $\sigma$: 6.33

$\mu$: 57.45 $\sigma$: 6.59

$\mu$: 57.45 $\sigma$: 6.59

$\mu$: 56.15 $\sigma$: 6.33

$\mu$: 57.45 $\sigma$: 6.59
Project: S331-79/-158.31
Name: Star City-Penn State
Route: I-79
Contractor: Carl Kelly Paving
Oly Thickness: 4.00"
Length: 2.26 Miles
Date: 08 August 2002

Date: 08-Aug-02

North Left Lane

Lift #3

North Right Lane

South Left Lane

South Right Lane

\[ \mu: 66.72 \quad \sigma: 7.44 \]

\[ \mu: 68.97 \quad \sigma: 8.00 \]

\[ \mu: 57.56 \quad \sigma: 7.53 \]

\[ \mu: 66.72 \quad \sigma: 7.44 \]
Project: S304-79/54.21
Name: Frametown-Sutton Rd
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 3.5"
Length: 3.61 Miles
Date: 08 August 2002

Date: 08-Aug-02

North Left Lane

\[ \mu: 52.71 \quad \sigma: 9.61 \]

North Right Lane

\[ \mu: 63.28 \quad \sigma: 8.23 \]

South Left Lane

\[ \mu: 45.25 \quad \sigma: 6.88 \]

South Right Lane

\[ \mu: 59.35 \quad \sigma: 5.83 \]
Project: S304-79/-71.39
Name: Flatwoods
Route: I-79
Contractor: JF Allen Company
Oly Thickness: 3.5"
Length: 3.61 Miles
Date: 18 September 2002

Date: 18-Sep-02

Lift #3

North Left Lane

South Left Lane

North Right Lane

South Right Lane

\[ \mu: 68.60 \quad \sigma: 7.20 \]

\[ \mu: 63.33 \quad \sigma: 9.81 \]

\[ \mu: 59.24 \quad \sigma: 12.00 \]

\[ \mu: 58.01 \quad \sigma: 6.21 \]
1998 Projects

Project: S320-79/7.58
Name: Prj68
Route: NH-0791(88)
Oly Thickness: 3"
Length: 1.5 Miles
Date: 1998

Date: 1998

West Left Lane

Lift #3

West Right Lane

East Left Lane

East Right Lane
Date: 30-Sep-1998

North Left Lane

Mays Number

0 2 4

0

20

40

60

80

Mile Position

North Right Lane

Lift #3

Mays Number

0 2 4

0

20

40

60

80

Mile Position

South Left Lane

Mays Number

0 2 4

0

20

40

60

80

Mile Position

South Right Lane

Mays Number

0 2 4

0

20

40

60

80

Mile Position

μ: 45.07 ± 5.60

μ: 46.64 ± 6.41

μ: 47.30 ± 9.09

μ: 41.40 ± 11.25
Project: S317-50/15.46
Name: Prj46
Route: NH-50
Oly Thickness: 4"
Length: 4.3 Miles
Date: 21-September 1998

Date: 21-Sep-1998

West Left Lane

Lift #3

West Right Lane

East Left Lane

East Right Lane

\[
\begin{align*}
\mu & \approx 60.80 \quad \sigma & \approx 11.45 \\
\mu & \approx 57.40 \quad \sigma & \approx 10.83 \\
\mu & \approx 57.70 \quad \sigma & \approx 12.46 \\
\mu & \approx 57.40 \quad \sigma & \approx 10.30 \\
\end{align*}
\]
Date: 29-Sep-1998

West Left Lane

\[ \mu: 64.25 \quad \sigma: 8.58 \]

West Right Lane

\[ \mu: 59.21 \quad \sigma: 5.71 \]

East Left Lane

\[ \mu: 62.05 \quad \sigma: 9.42 \]

East Right Lane

\[ \mu: 58.37 \quad \sigma: 6.87 \]
Project: S331-79/145.68
Name: Prj145
Route: NH-793
Oly Thickness: 4"
Length: 5.9 Miles
Date: 06-November 1998

Date: 06-Nov-1998

North Left Lane

Mays Number

0 2 4 6

0

20

40

60

80

100

120

Mile Position

µ: 49.80 σ: 9.27

North Right Lane

Mays Number

0 2 4 6

0

20

40

60

80

100

120

Mile Position

µ: 55.60 σ: 10.19

South Left Lane

Mays Number

0 2 4 6

0

20

40

60

80

100

120

Mile Position

µ: 51.70 σ: 10.60

South Right Lane

Mays Number

0 2 4 6

0

20

40

60

80

100

120

Mile Position

µ: 53.60 σ: 15.30
Project: S313-64/68.35
Name: Prj35
Route: NH-644
Oly Thickness: 3"
Length: 2.9 Miles
Date: 19-August 1998

**Date: 19-Aug-1998**

**West Left Lane**
- Mile Position
- Mays Number
- \( \mu: 54.90 \quad \sigma: 9.39 \)

**West Right Lane**
- Mile Position
- Mays Number
- \( \mu: 52.18 \quad \sigma: 6.67 \)

**East Left Lane**
- Mile Position
- Mays Number
- \( \mu: 50.93 \quad \sigma: 7.61 \)

**East Right Lane**
- Mile Position
- Mays Number
- \( \mu: 49.73 \quad \sigma: 5.50 \)
Project: S304-79/63.44
Name: Prj4
Route: I-79
Oly Thickness: 4"
Length: 2.3 Miles
Date: 21-September 1998

Date: 21-Sep-1998

![Graphs showing Mays Number distribution for different lanes and positions.](image-url)
Appendix C

Roughness Improvements With Overlays In The 2003 Construction Season.
Project: S332-119-3.43
Name: Cor G
Route: US-119
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 4.4 Miles
Date: 24 June 2003

Pr # S332-119-3.43 Route: 119 (COR-G) North Left Lane

- Concrete Repair
- Lift #1 (Scratch)
- Lift #2 (Base)
- Lift #3 (Skid)
Pr # S332-119-3.43  Route: 119 (Cor-G)  North Right Lane

Concrete Repair
Lift #1 (Scratch)
Lift #2 (Base)
Lift #3 (Skid)
Project: S332-119-3.43
Name: Cor G
Route: US-119
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 4.4 Miles
Date: 24 June 2003

Pr # S332-119-3.43  Route: 119 (Cor-G)  South Right Lane

Mays Number

Concrete Repair
Lift #1 (Scratch)
Lift #2 (Base)
Lift #3 (Skid)

Mile Position
Project: S304-79/-51.61
Name: Frametown
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25”
Length: 2.4 Miles
Date: 20 August 2003
Project: S304-79/-51.61
Name: Frametown
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25”
Length: 2.4 Miles
Date: 20 August 2003
Project: S304-79/51.61
Name: Frametown
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 2.4 Miles
Date: 20 August 2003
Project: S304-79/-51.61
Name: Frametown
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 2.4 Miles
Date: 20 August 2003

Pr # S304-79/-51.61 Route: I-79 (Frametown) South Right Lane

- Concrete repair
- Lift #1 (Scratch)
- Lift #2 (Base)
- Lift #3 (Skid)
Project: S304-79/-42.22
Name: Servia Rd
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 5.1 Miles
Date: 20 August 2003

**Graph**
Pr # S304-79/-42.22  Route: I-79 (Servia Rd)  North Left Lane

- Concrete Repair
- Lift #1 (Scratch)
- Lift #2 (Base)
- Lift #3 (Skid)
Project: S304-79/-42.22
Name: Servia Rd
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 5.1 Miles
Date: 20 August 2003
Project: S304-79/-42.22
Name: Servia Rd
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25"
Length: 5.1 Miles
Date: 20 August 2003

Pr # S304-79/-42.22  Route: I-79 (Servia Rd)  South Left Lane

Concrete Repair
Lift #1 (Scratch)
Lift #2 (Base)
Lift #3 (Skid)
Project: S304-79/-42.22
Name: Servia Rd
Route: I-79
Contractor: West Virginia Paving
Oly Thickness: 4.25”
Length: 5.1 Miles
Date: 20 August 2003