University Transportation Research Center Region 2

Final Report:

Identification of The Source of Rutting in a Flexible Pavement System

Prepared by Yusuf Mehta,Ph.D; Neville Parker,Ph.D; Claude Villiers, Ph.D;
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16. Abstract

The primary objective of this proposal is to develop a framework to identify the most likely source of rutting within the pavement system and the presence of mixture instability in the surface layer within the first few years of the pavement life. Currently, the only accurate method of identifying the source of rutting is to cut trenches and observe deformation in the various layers of the pavement structure, a process that is inconvenient, destructive, and expensive. The proposed system encompasses analysis of routinely collected data including rut profile, measurement of air voids (AV) content from field cores, and backcalculation of in-situ moduli of each of the layers. The researchers are aware that sufficient data may not be available to conduct this analysis. A component is also added to quantify the risk due to difference in predicted performance using the proposed analysis and the traditional rut depth measurement tools. The proposed procedure is unique in the sense that it is independent of the rut depth magnitude, a feature that allows the early identification of rutting and instability of the surface layer so that the appropriate corrective action for remediation can be taken. The risk assessment showed that if agencies observe significant rutting in their states then they should use the proposed procedure rather than rut depth measurements from RSP. This procedure provides the necessary tool for the state agencies to implement appropriate pavement rehabilitation strategies.

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Progress Report January 2008 – June 2008

Principal Investigator: Yusuf Mehta, Ph.D., P.E.
Co-Principal Investigator: Claude Villiers, Ph.D. and Neville Parker Ph.D., P.E.
Starting Date: April 2007
Percentage of Completion: 100%

Task	% of Total	% of Task this quarter	% of Task to date	% of Total Complete
Task I Development of the Proposed Procedure	40	25	100	40
Task II. Field Validation	10	25	100	10
Task III. Risk Level Assessment	10	100	100	10
Task IV: Analysis	20	25	100	20
Task V: Dissemination of product	20	100	100	20
TOTAL	100	47.5	100	100

In this report the tasks completed during the period of January 1, 2008 to June 30, 2008 and a brief summary of the accomplishments are presented. The proposed work schedule for the following six months is also outlined. The work completed to date represents approximately 47.5% of the total budget.

GOALS AND OBJECTIVES

The primary objective of this proposal is to develop system to identify the source of rutting within the pavement system and/or the presence of mixture instability in the surface layer. The proposed approach for evaluating rutting integrates the use of Falling Weight Deflectometer (FWD), field core data, along with 12 to 15-ft transverse profile measurements to assess the contributions of different pavement layers on rutting, and identify the presence (or absence) of instability within the asphalt surface layer.

The major accomplishment of this quarter was to quantify the risk when sufficient data is not available while using this proposed procedure to predict the source of rutting. To accomplish this task, the following tasks were conducted:

a. Predict failure based on proposed procedure using transverse profilograph (TP) measurements.
b. Predict failure based on proposed procedure using road surface profiler (RSP).
c. Compare the difference in performance prediction and/or design life between those obtained from TP and RSP using the proposed procedure.

TASK I: CONTINUE DEVELOPMENT OF THE PROPOSED PROCEDURE

Effort was made to collect data such as core data, Falling Weight Deflectometer (FWD) measurements, layer thickness, and transverse profile measurements in order to continue with the development of the proposed procedure. As mentioned on the previous reports, this data mentioned above was not available from the State of New York Department of Transportation (DOT) and New Jersey DOT. Also, No FWD data and traverse profiles were available for the National Center for Asphalt Technology (NCAT) Test Tracks. However, complete data was obtained on ten (10) different roadways and six (6) test track sections from the Florida Department of Transportation (FDOT). These test sections are part of the Heavy Vehicle Simulator (HVS). These sections are located at the Florida Department of Transportation State Materials Test Track. Details about these sections are provided later in the report.

TASK II: FIELD VALIDATION

The purpose of this task is to identify and collect forensic data from the participating state agencies on sections that have been in-service for several years or subjected to significant amount of traffic. Extensive data was obtained from the FDOT on 10 roadways and 6 test tracks. Information such location, mixture type, and traffic level is provided on Table 1. Superpave mixes ranging from 9.5 mm to 19.0 mm mixes were used. Projects 1-8 were part of a Superpave Monitoring Project from the University of Florida. The two sections which are labeled as “I-10 High Rutting” and “I-10 Low Rutting” were located on the Westbound Outside Lane (travel lane) of State Route (SR-8) also known as I-10. The average rut depth on the sections was about 1.1 in and 0.5 in, respectively.

The test track sections, which were constructed around 2000, were located at FDOT State Materials. They were part of an Accelerated Pavement Testing (APT) facility, which uses the Heavy Vehicle Simulator (HVS). A photograph of the HVS is presented in Figure 1. This project was divided into 7 test track sections with 3 replicates per test tracks. Six of these sections for which the rut data is available was used in this study. The layout to the test track sections is presented in Figure 2. Each lane[1] was 90 feet long and 5 feet wide. Each lane was divided in 3 parts with identical mixes (replicates). As presented in Table 2, two different Superpave mixtures were used in these HVS sites. One was a Styrene Butadiene Styrene (SBS) polymer modifier, and a conventional binder was used on the other one (Gokhale et al. 2006). These mixtures will be labeled as HVS-Modified and HVS-Unmodified throughout this study.

Table 1. Projects Evaluated

Project ID[a]	Time of Construction	US Route[b]	Mile Post[c]		Mix Type[d]		Traffic Level[e]
			From	To	Top	Bottom	
1	Jan-1998	I-10 WB	5.138	0.500	9.5C	19.0C	D/5[2]
2	May-1998	I-75 SB	25.578	20.571	12.5C	19.0C	D/5
3	May-1998	I-75 SB	15.700	10.723	12.5C	19.0C	D/5
4	Jan-1998	I-10 EB	4.317	7.681	9.5C	19.0C	E/6
5	Jun-1998	I-95 NB	1.055	6.559	9.5C	12.5C	D/5
6	Aug-1998	US301 SB	4.565	0.750	12.5F	N/A	C/4
7	Oct-1998	FL-TPK NB	98.300	105.463	12.5F	12.5F	C/4
8	Dec-2000	I-10 WB	19.670	15.665	12.5C	12.5C	D/5
I-10 LR	Sept-1999	I-10 WB	N/A	N/A	9.5C	19.0C	N/A
I-10 HR	Sept-1999	I-10 WB	N/A	N/A	9.5C	19.0C	N/A
HVS U	Oct-2000	FDOT SMO	N/A	N/A	12.5C	12.5C	D/5
HVS M	Oct-2000	FDOT SMO	N/A	N/A	12.5C	12.5C	D/5

Note:

[a] LR = Low Rut
HR = High Rut
HVS-U = High Vehicle Simulator Unmodified Section
HVS-M = High Vehicle Simulator modified Section

[b] WB = Westbound
SB = Southbound
EB = Eastbound
NB = Northbound
FL-TPK = Florida Turnpike
FDOT SMO = Florida Department of Transportation State Materials Office

[c] N/A = Not Available

[d] C = Coarse mix
F = Fine mix

[e] Traffic Level D = 10 to < 30 ($1*10^6$ ESAL's)
Traffic Level C = 3 to <10 ($1*10^6$ ESAL's)

[1] Lane and Section are used interchangeable in this study

[2] Note: Starting around 2004 FDOT changes Traffic level from "number" to "letter" (i.e., Traffic Level D = Traffic Level 5) in their Standard Specifications (FDOT, 2004). Since the projects were constructed at different time the correspondent Traffic Level is provided for comparison purpose.

Figure 1. The Mark IV Heavy Vehicle Simulator device.

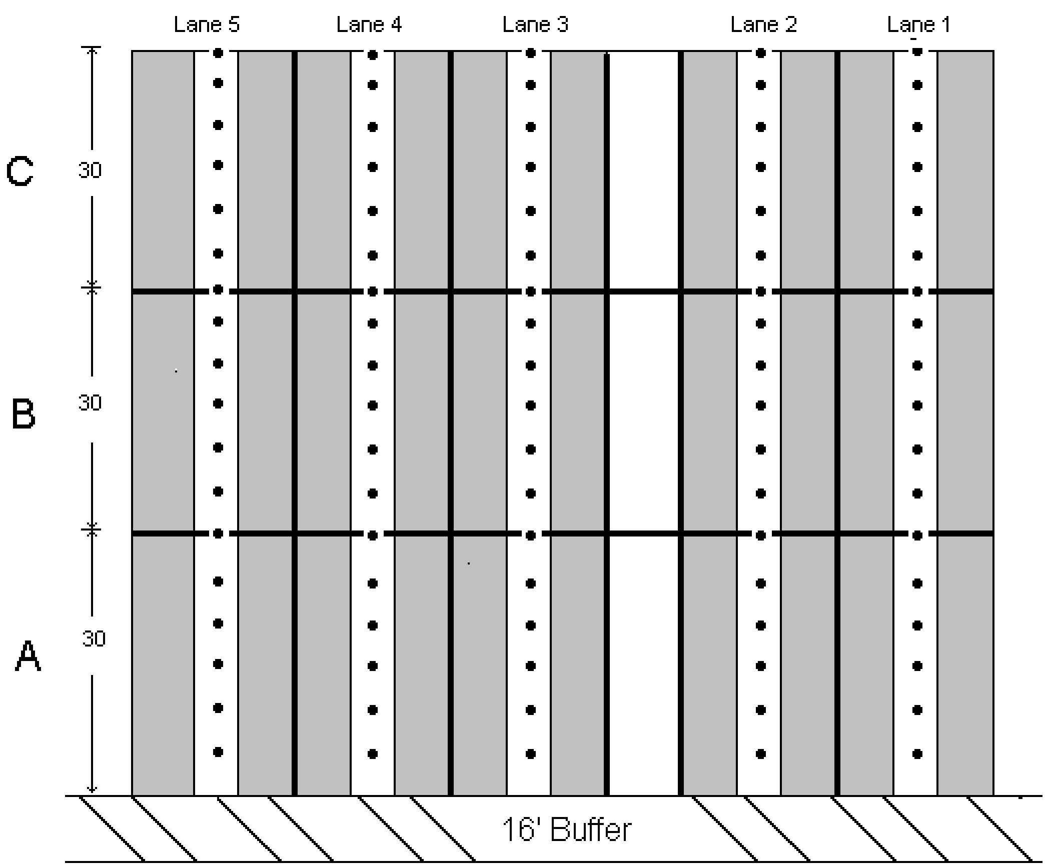

Figure 2. Test Track Sections Evaluated.

Table 2. Type of Mixtures Used in the Test Track Sections

	Lane 5	**Lane 4**	**Lane 3**	**Lane 2**	**Lane 1**
Milling Depth	~3.5”	~3.5”	~3.5”	~3.5”	~3.5”
Top Lift	2.0”, 12.5mm Unmodified, Coarse-Graded	2.0”, 12.5mm SBS, Coarse-Graded	2.0”, 12.5mm SBS, Coarse-Graded	2.0”, 12.5mm SBS, Coarse-Graded	2.0”, 12.5mm SBS, Coarse-Graded
Bottom Lift	New 2.0”, 12.5mm, Unmodified, Coarse-Graded	New 2.0”, 12.5mm, Unmodified, Coarse-Graded	New 2.0”, 12.5mm, Unmodified, Coarse-Graded	New 2.0”, 12.5mm, SBS, Coarse-Graded	New 2.0”, 12.5mm, SBS, Coarse-Graded

For each of the first 8 projects in Table 1, rut depth measurements were taken in the travel lane along a five-mile section of pavement using the transverse profilograph. In each section, 30 transverse readings were taken at approximately equal distances. Similar to the previous reports, the layer moduli, including the base, subbase, and subgrade for the two sections were obtained from the FWD data using BISDEF backcalculation computer program. BISDEF is a multi-layer linear elastic analysis computer program. The layer moduli for projects 1 through 8 have already been reported by Villiers et al (2005). The FWD data along with the variation of the modulus values throughout the length of the project is presented in Appendix A for I-10 Low Rut, I-10 High Rut, and all the HVS sections. The vertical strain distribution at the surface of the subgrade is presented in Figure 3.

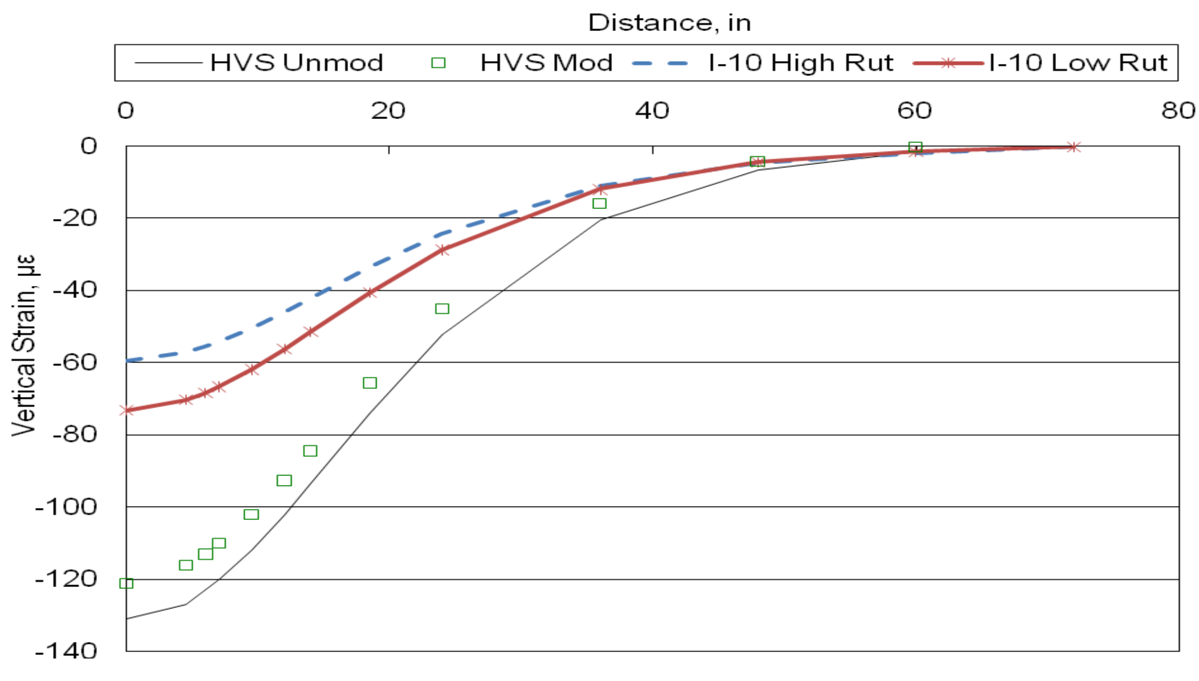

Figure 3. Vertical Strain Distributions at the Surface of the Subgrade

Field Validation Results

Roadway Sections

After the analysis was conducted using the proposed procedure, it was noted that rutting in Project 6 Round-I was associated with a significant reduction in air voids. Also in Project 7 Round-I, it was noted that about 70% of the rutting was attributed to significant changes in air voids. One can conclude that the rutting in these two projects was due primarily to compaction in the surface layer. Since no increase in air voids was noted in the cores for Projects 6, 7 (Round-II), and all the other projects the cause of rutting cannot be explained by surface compaction in the asphalt layer.

Permanent deformation associated with the compaction of the subgrade layer was identified when the projected shape of the subgrade strain matched the rut basin. The results presented in Figure 4 show that the source of rutting appeared to be primarily due to subgrade compaction for Project 4 (all rounds), Project 3 (Round-I), Project 5 (Rounds I and II), Project 6 (Rounds II and III), and Project 7 (Rounds II and III). Instability was present in Projects 1, 2, and 8 even after the first round of coring. The change in slope as compared to the subgrade was increased by over 100% for these projects. Other Projects including Projects 3, 5 and 7 have begun to exhibit signs of impending instability. However, these projects appeared to be performing better than Projects 1, 2 and 8, given that they have been subjected to similar traffic, but have begun the process of instability much later. Again, this sign of instability should not be interpreted as of these HMA mixtures were completely deficient.

For the two sections which are labeled as “I-10 High Rutting” and “I-10 Low Rutting” it appears that instability in the asphalt surface layer was the primary source of permanent. It appears that both sections were constructed with adequate base and subbase stiffness. Structural deficiency and air void reduction due to compaction by traffic did not appear to be primary contributors to rutting in either section. This information agreed with observations from the trench cuts taken from the sections by the FDOT. The information is presented in Appendix B. For both sections rut measurements were taken at each layer of the pavement. It should be noted that the results of the trench sections were not known a priori (i.e., the predictions were ‘blind’ predictions).

HVS Sections

The opportunity to analyze pavement performance including progression of instability rutting under controlled field conditions became a reality when the Florida Department of Transportation (FDOT) along with the South African Council of Scientific and Industrial Research (CSIR) purchased a Heavy Vehicle Simulator (HVS) Mark IV (Kim 2002). 20 to 30 years pavement performance can be obtained within a month period. The HVS machine is located at the FDOT State Materials Office in Gainesville Florida.

Figure 4. Average Slope Difference of Rut Profiles as Compared to Embankment with Standard Deviation Bar

A testing program was developed by the FDOT research engineers and the faculty at the University of Florida. The program consisted of the evaluation of the performance of modified and unmodified asphalt mixes under HVS conditions. Modified asphalt mixes refer to asphalt mixes where the binder used contains a polymer modifier. The polymer-modifying agent employed in this study was styrene-butadiene-styrene (SBS). The HVS employs a super-single radial tire with an average contact stress of 115 psi and a footprint of 12 inches wide by 8 inches long. The load is applied uni-directionally at a speed of 6 mph. The testing was performed at a uniform pavement temperature of 50° C made possible by an environmental control chamber. The modified and unmodified asphalt mixtures used in the study were both fine graded SP-12.5 mixtures, with the unmodified binder rated 67-22 and the SBS-modified binder rated 76-22 (Superpave nomenclature) (Novak 2007).

Six HVS sections (at least 1 per lane) were analysis in this report. The maximum rut depth for each section is presented in Figure 5. More rut measurement was recorded on the modified sections as compared to unmodified sections for the same load repetition (test wheel passes). Some of the unmodified sections were loaded to above half the load as compared to the modified sections. After about 100 passes, the modified sections' rut rate decreased and achieved a stable linear progression. The unmodified sections' rut rate continues at the same rate and does not reach a stable rut rate seen in the modified sections (Novac 2007). It is not clear why the two (2) "modified over unmodified" sections performed so differently. Section 4A was relatively high just like 5A unmodified section. Contrarily, Section 3A performed exceptionally well on average 1.3 times less rut depth as compared to Section 4A.

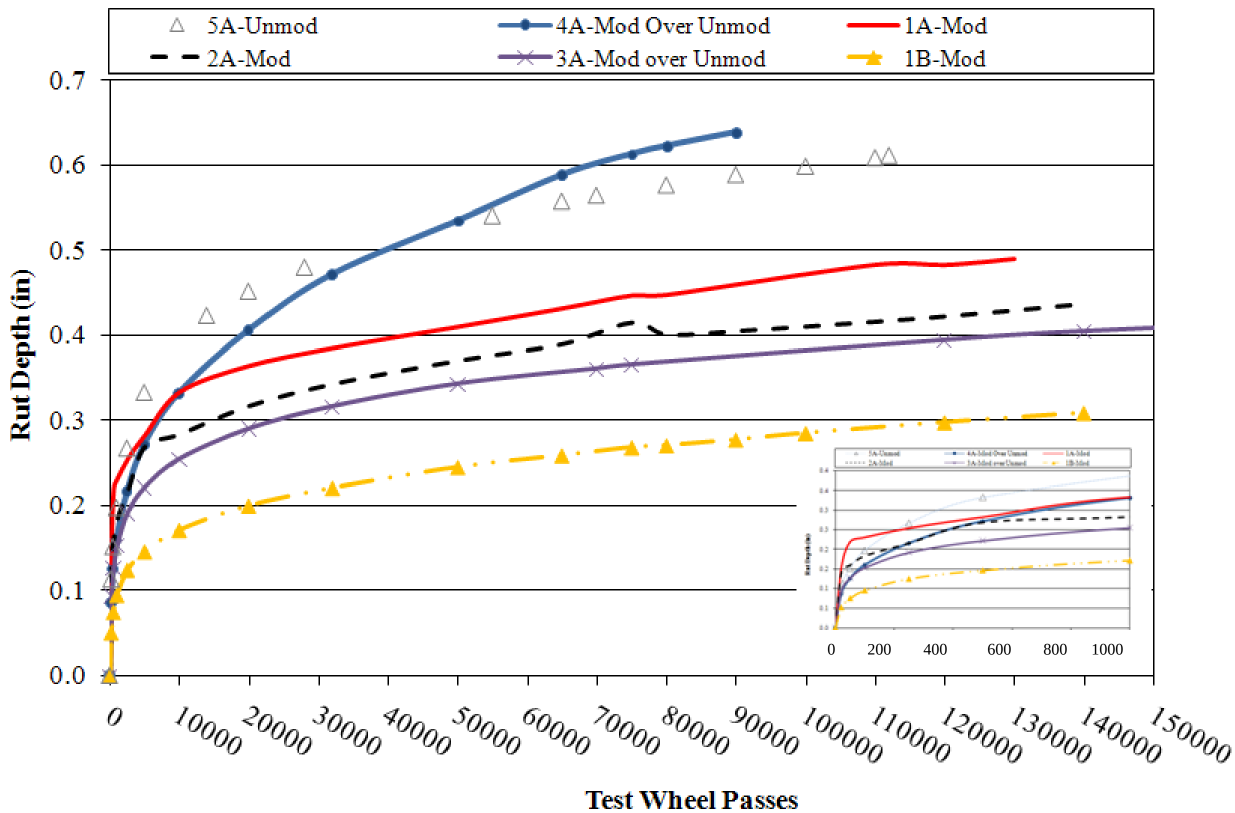

Figure 5. Rut depth rate for the HVS sections per Test Wheel Passes

As mentioned in Report 2, the information presented on Figure 5 although valuable does not give the full picture. For example it cannot be used to evaluate the contributions of different layers on rutting and the presence (or absence) of instability within the hot mix asphalt mixtures. Section 1A showed a different rut pattern as compared to the other sections. It had the highest rut measurements for the first 500 passes. Behind this loading, it stabilized. It performed better than the unmodified sections, but not as good as the other modified sections. Surprisingly, Section 3A (Modified over Unmodified) performed extremely well. Except for Section 1B, it had the lowest rut depth. Unfortunately this section was not considered in Novak analysis (Novak 2007).

The proposed procedure was used to determine the primary source of rutting. The average slope difference per load repetitions of the rut profiles as compared to that of the subgrade for the HVS sections (presented in Figure 6). Recall that based on the information presented on Figure 5, one may have the impression that both the modified and unmodified sections have same early response (first 1,000 passes). Similar information was observed by Novak (2007). However, using this proposed procedure; instability rutting could have been detected in the first 200 passes. It appears that the cause of rutting in the modified sections for the first 200 passes were due to air voids compaction. However, this air voids data was not available for verification. Except for section 1 A for which an anomaly was observed during first 1,000 passes of loading, the change in slope as compared to the subgrade for the unmodified sections was about 7 times more as compared the modified sections. 5,000 passes on the HVS corresponds to roughly 1 year of traffic load on a highway. This analysis clearly validates the fact this proposed procedure is independent of rut depth. Early determination and accurate assessment of mixtures behavior is critical especially for State DOT's who implemented warranty and/or performance related specifications.

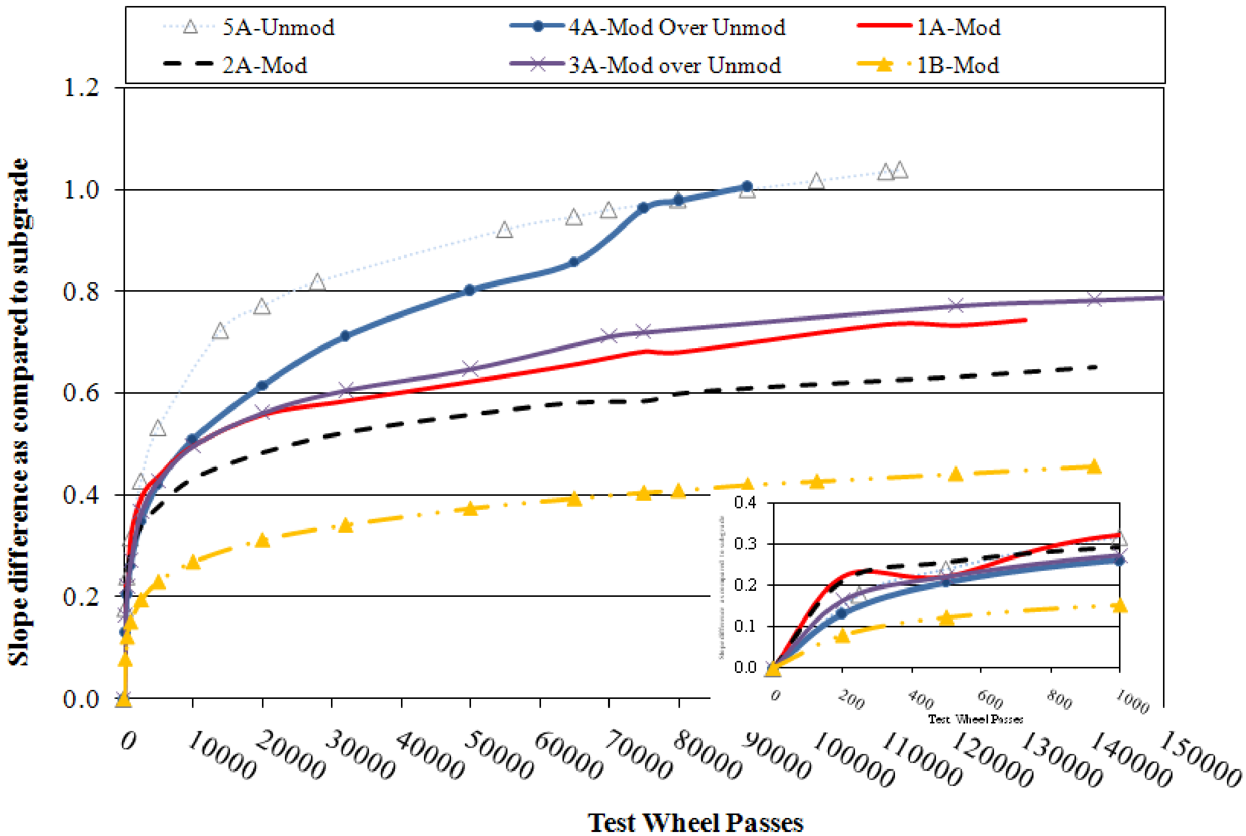

Figure 6. Average Slope Difference of Rut Profiles as Compared to Compared to Subgrade for the HVS Sections

Based on the information presented in Figure 6, it was clear the most contributing factor of rutting on the unmodified sections was due to instability. The slope difference as compared to subgrade was higher at all times on the unmodified sections as compared to modified sections. This information agreed with observations from the trench cuts taken from the HVS sections (see Appendix B). The slope of difference for Section 1B was 0.40 at 140,000 load repetitions; whereas, for section 4A at 5,000 load repetitions the slope difference was already 0.42. Also from Figure 6, it appears that section 3A did not perform as well as was suspected based on the rut depth measurements (Figure 5). The slope difference in this section was higher than any modified sections. Recall that it was expected that 3A and 4A (Modified over Unmodified) sections to perform better than sections 5A but not as well as Sections 1B and 2A. The information obtained from the rut depth measurements (Figure 5) could not be used to make that distinction. However, that was not the case using this proposed procedure. Although the rut measurement was relatively low in section 3A, it appears that the unmodified mixture in second layer, in which instability was present, displaced laterally due to confinement of vertical movement resisted by the base layer. This is evidence that continued instability may not result in an increase in rut depth. Therefore, absolute rut depth should not be used to interpret the performance of the asphalt mixture. One must evaluate mixture performance carefully using this proposed approach developed.

TASK 3 RISK LEVEL ASSESSMENTS

Recall that this procedure requires transverse profile measurements as input data to predict the possible source of rutting. A transverse profilograph is a simple manually operated instrument that produces a chart displaying the cross section profile, wheel path ruts, imperfections and superelevations. In order to obtain such data, it requires lane closure for the particular roadway; which is very expensive and oftentimes not an option for some DOTs. Road surface profiler (RSP) is often used to determine rut depth. RSP is a vehicle-mounted instrument used to produce a series of measurements related in a well-defined way to a true longitudinal profile. Figure 7 shows the picture of the Road surface profiler. For the most part, rut depths are measured using a three-sensor system. The sensor spacing for a three-sensor system was selected so that the two lasers on either side are in the wheel path. The ASTM E-950 specifies a range for sensor spacing from 29 to 35.5 inches (ASTM Standard E-950, 1994)

Figure 7. Road Surface Profiler

The purpose of this task was to quantify the risk level (or the error incurred) if the proposed procedure cannot be used due to lack of data such as transverse profile measurement. To meet this objective, a sensitivity analysis was conducted by generating a series of possible scenarios which will be referred as “runs” using the HVS rut profile measurements. A RSP with three sensors system was used to simulate the runs. Figure 8 shows a schematic of the rut depth measurement from the transverse profilograph and the road surface profiler.

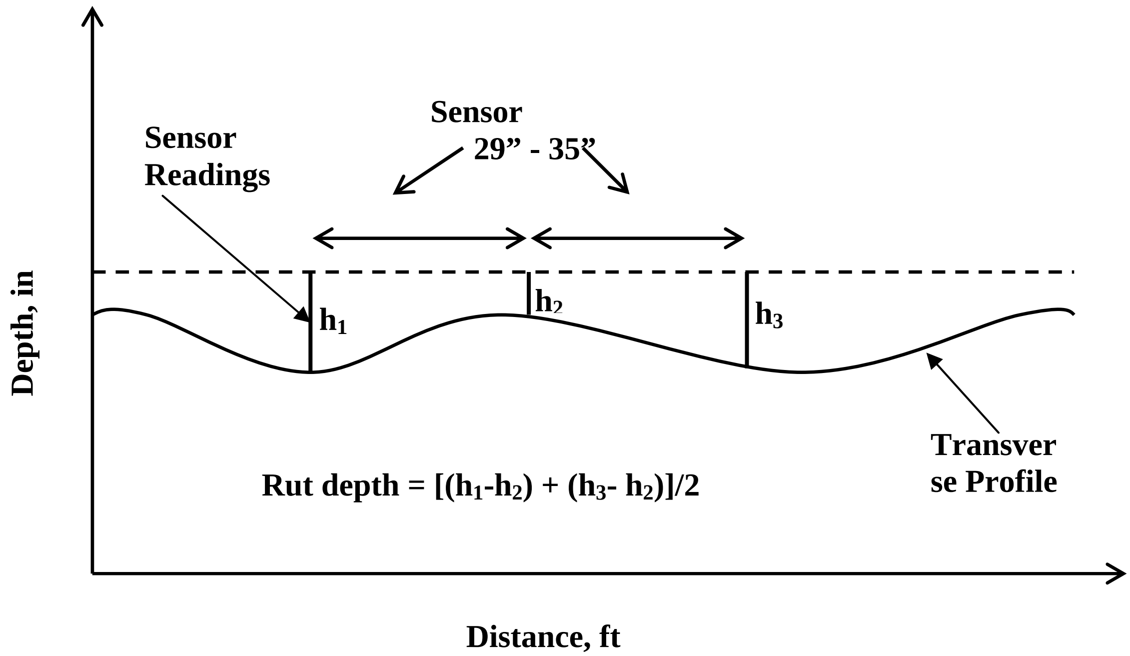

Figure 8. Schematic of the Rut Depth Measurement from Road Surface Profiler

Risk Level Definition

As mentioned in the original proposal, to determine if rutting is mainly due to subgrade compaction, base compaction, or instability the shape of the subgrade strain obtained from the BISAR analysis was projected into the rut profile. The maximum slope over 1-foot range (using TP data) was calculated on each side of the wheel paths at relatively the same location of the subgrade (Figure 9). The average slope difference of the rut profile as compared to the subgrade was used to evaluate the severity of the instability. This is referred as the control or original prediction (“Run 1”). The results for Run-1 have already been reported in Figures 4 and 6 for the roadway projects and HVS sections, respectively. However, as mentioned above TP data is seldom available. Four other scenarios were generated from run 1. These scenarios are typical prediction of rut depth when RSP is used in lieu of TP data. **The risk level is defined as the difference in performance prediction between those obtained from TP versus RSP using the proposed procedure**. The additional runs are defined as follow

- Run 2: Instead of measuring the slope of the rut profile over a 1-foot range, a straight line was drawing from the peak of hump to the tip of the rut profile (Figure 9) considering that a RSP unit has three sensors (Figure 8). Under this condition, the sensors would report readings on the tip of the rut profile as well as the peak of the hump. This will be the ideal condition under which the rut measurement from RSP would be equal with TP.

- Run 3: This run was generated to simulate conditions under which the rut measured from the RSP was approximately ten (10) times less than the rut measured from TP. This information was observed by Mehta et al. (2005). Similarly to Run 2 the new slope will be determined from the hump to new tip of the rut profile.

- Run 4: This run is identical to Run 3 except the rut depth was decreases to 25 %.

- Run 5: At times, the hump is not well pronounced in a given roadway. This condition was observed during the analysis of transverse profile for the roadway projects. Under this condition, the rut depth will be measured from the surface to the tip of the rut profile (Figure 10). Under this circumstance, the rut depth measure will be lower that actual rut depth. The slope for this run was therefore measured from the surface to the tip of the rut profile.

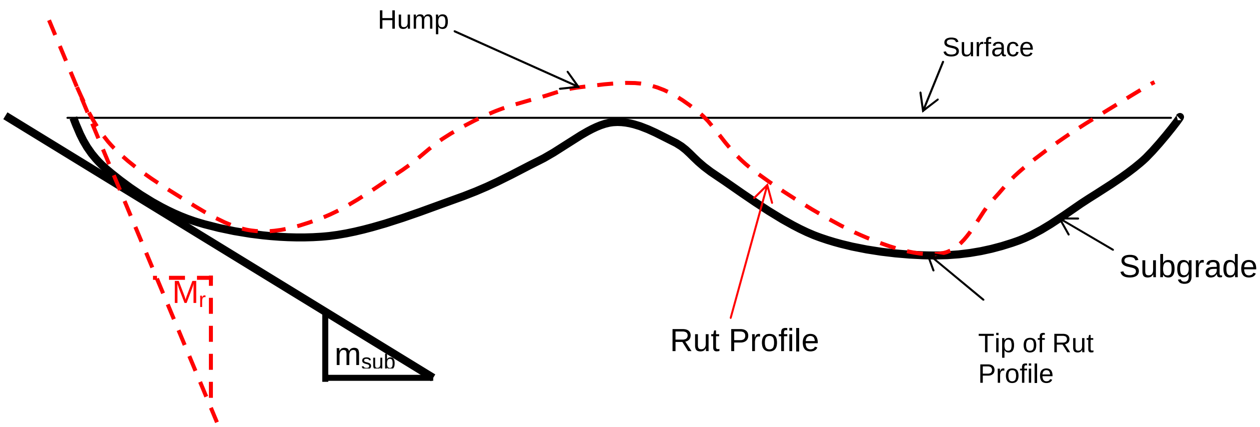

Figure 9. Schematic Representation of Identifying Instability in Asphalt Layer using the Proposed Approach

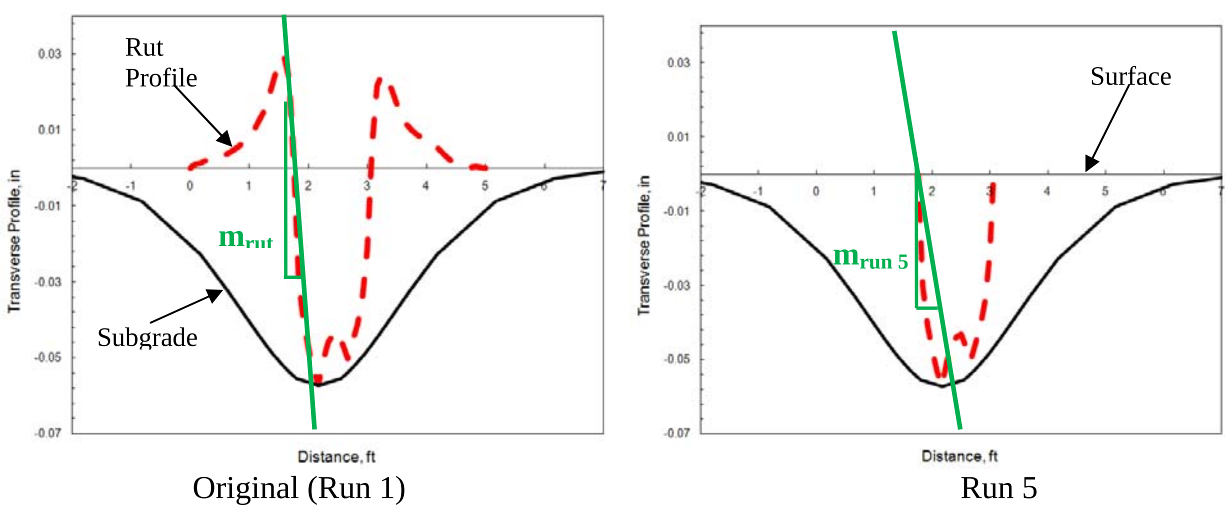

Figure10. Schematic Representation of Run 5

Results

A sensitivity analysis was conducted by simulating the rut depth measurements that would be obtained from the HVS section if RSP data were used. The result for section 1B is presented in Figure 11. The data for the other sections is presented in Appendix C. The information is summarized in Table 2.

Base on the analysis conducted, it appears that RSP data could be utilized for predicting the source of rutting within the pavement layer in lieu of TP data using the proposed procedure. However, DOTs would be taken a risk by doing so. As presented in Figure 11 and Table 3, even under ideal condition (run 2; rut depths from RSP are equal to those of TP) the risk level would be 35%. In order word, there is a 35% chance of error of assuming that instability rutting is not present in a mixture when using RSP data (as defined in Run 2) in lieu of TP data. Similarly, if the hump is not well pronounced (which is the case when the total rut values are small (0.05 to .1 inches) in a given roadway, there is about a 39% error of predicting that instability is not present when it actually exist. Therefore, if the state agency is concerned about excessive rutting, then using an RSP would lead to a considerably different conclusion than those obtained when using the proposed procedure. On the other hand, if the rut values are low (<.1 inches), then the state agency could continue to use the RSP. Furthermore, when the rut depth measurements from the road surface profiler is half that of the actual (Run 3) as compared to the actual rut depth (those measured using the transverse profilograph), the risk level increased to about 47%. Decreasing the rut data of the RSP from as explained in Run 3 versus that in Run 4, the risk level did not increase by much (47% to 52%).

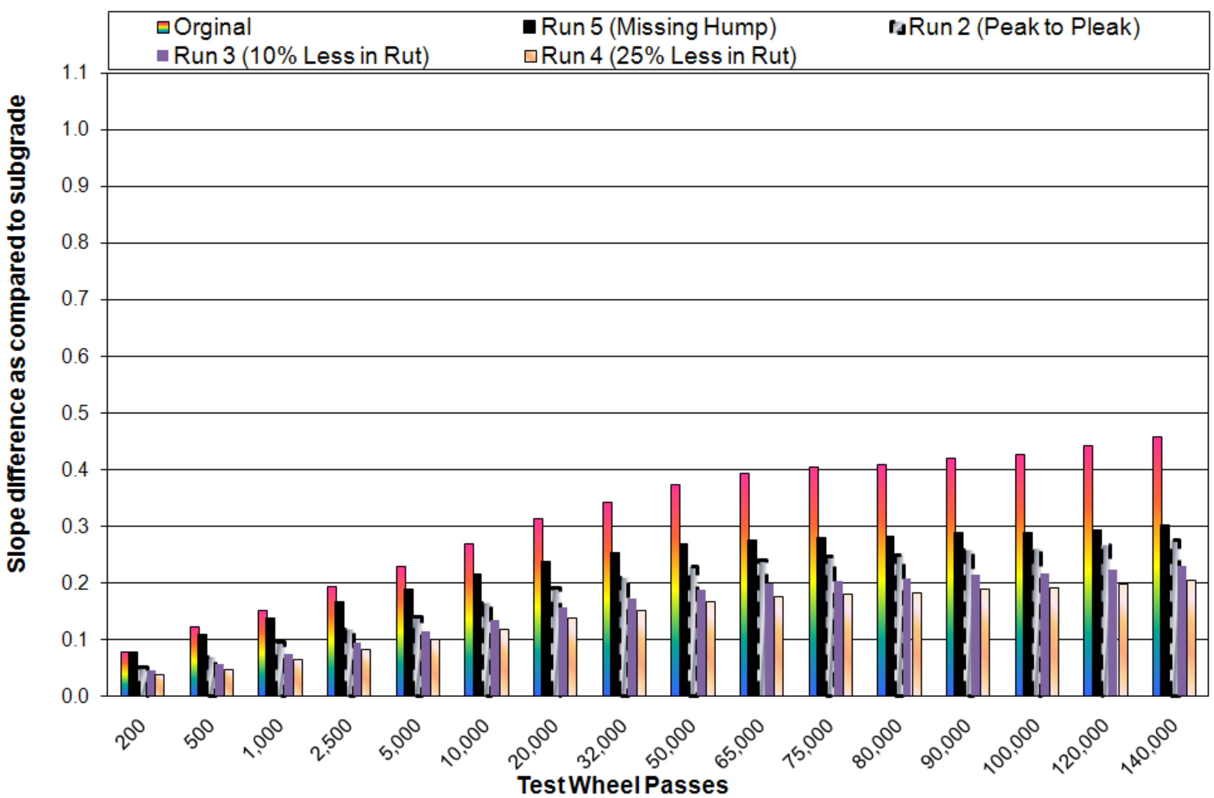

Figure11. Risk Level of Using RSP Data when TP is not Available for Project 1B

Table 3. Percent Difference in Risk Level of Runs 2 to 5 as Compared to Run 1

	5A-Unmod	4A-Mod Over Unmod	3A-Mod over Unmod	1A-Mod	2A-Mod	1B-Mod	Average
Run 5 (Missing Hump)	44	43	34	48	44	23	39
Run 2 (Peak to Pleak)	36	31	40	35	28	39	35
Run 3 (10% Less in Rut)	48	43	52	46	41	50	47
Run 4 (25% Less in Rut)	53	45	57	52	48	56	52

TASK V: DISSEMINATION OF PRODUCT/IMPLEMENTATION

The research team is well placed to disseminate this information at various forums. This would include publications in leading pavement conferences and avenues such as the NJDOT Research showcase. In addition, the research team will develop Excel-based free software that conducts analysis proposed in this study.

CONCLUSION

Accomplishments and findings resulting from this work may be summarized as follows:

- This study successfully demonstrated that the proposed procedure can identify instability with data routinely collected by most of the state agencies.
- The proposed procedure successfully detected instability even when rut depths were relatively low.
- The risk assessment showed that if agencies observe significant rutting in their states then they should use the proposed procedure rather than rut depth measurements from RSP. This procedure provides the necessary tool for the state agencies to implement appropriate pavement rehabilitation strategies.

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APPENDIX A
FALLING WEIGHT DEFLECTOMETER (FWD) and backcalculatuion TEST RESULTS

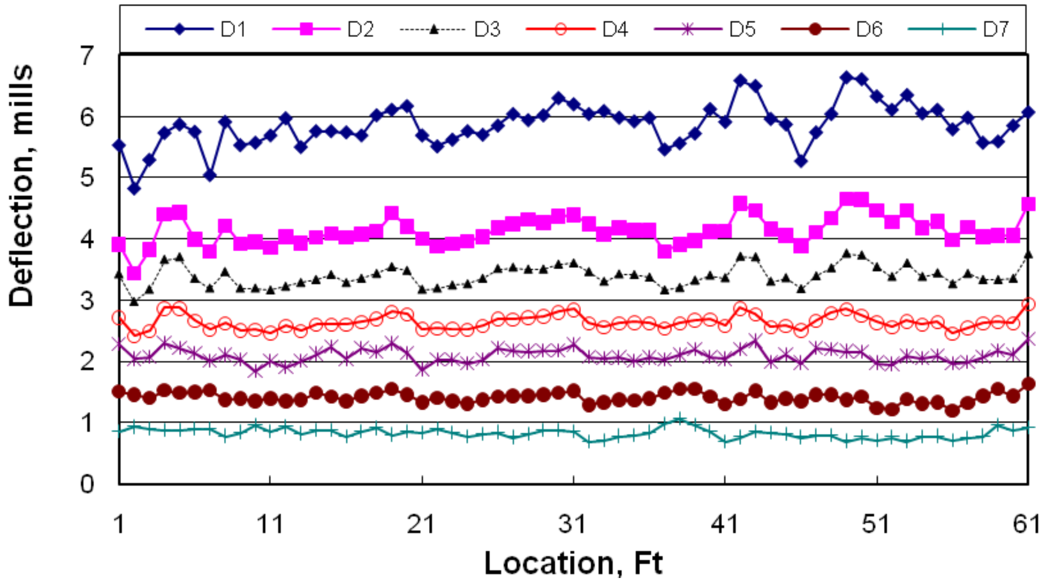

Figure A-1. Variation of deflection measurements along location for I-10 Low Rut

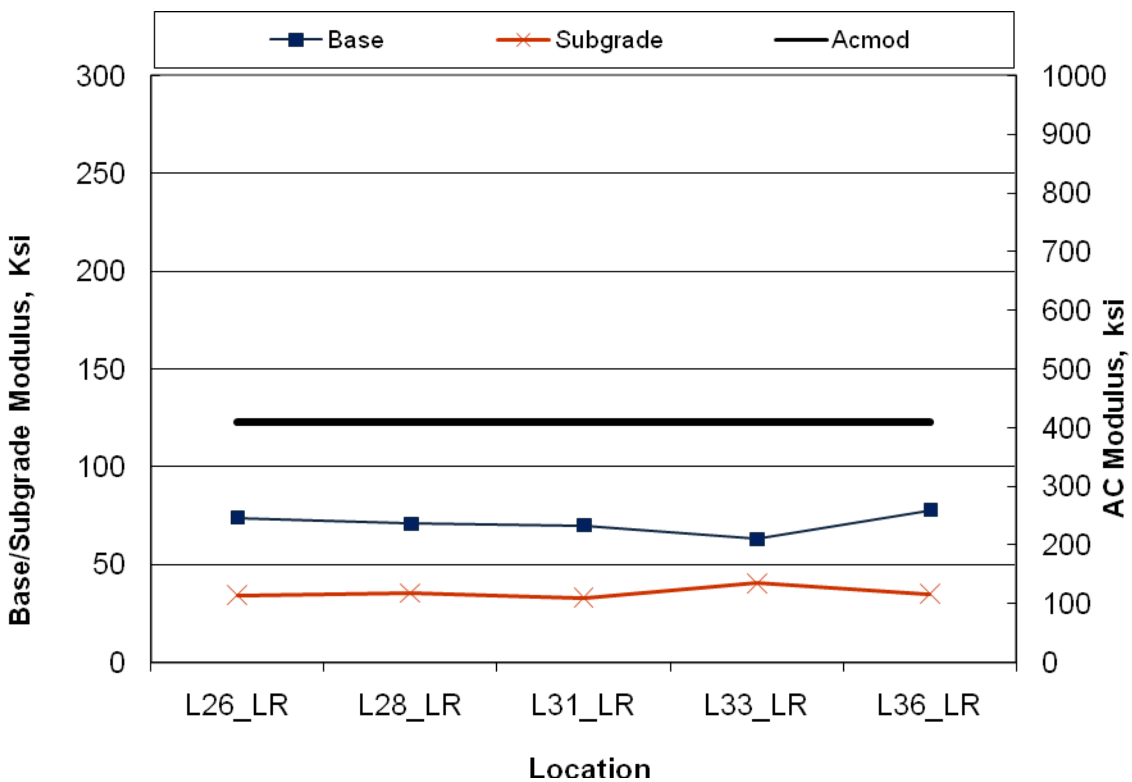

Figure A-2. Layer moduli versus location for I-10 Low Rut

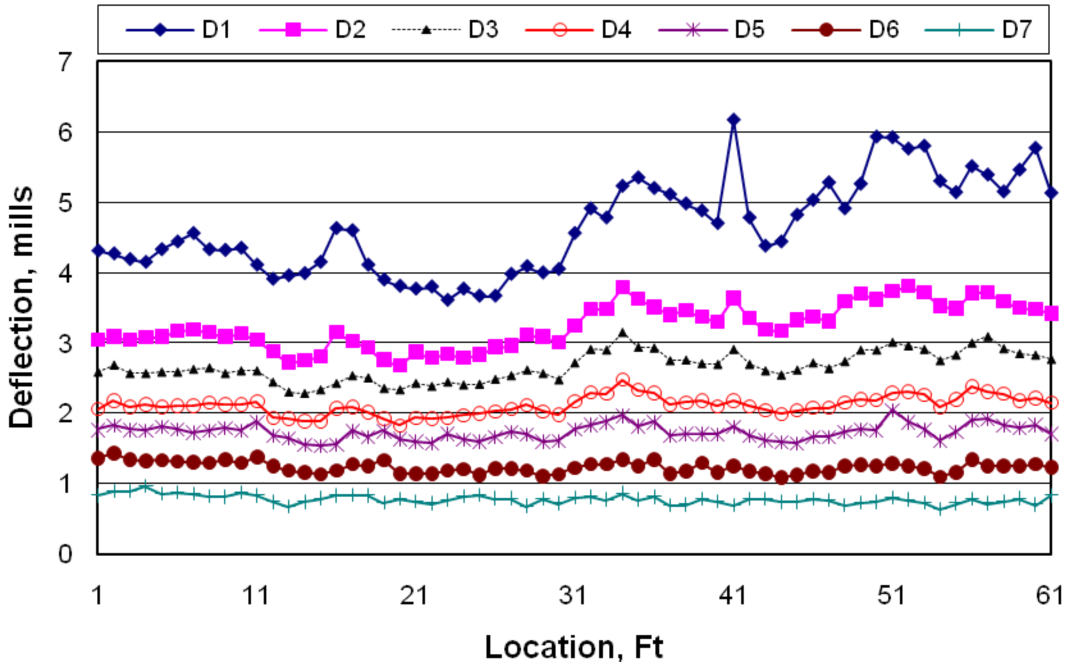

Figure A-3. Variation of deflection measurements along location for I-10 High Rut

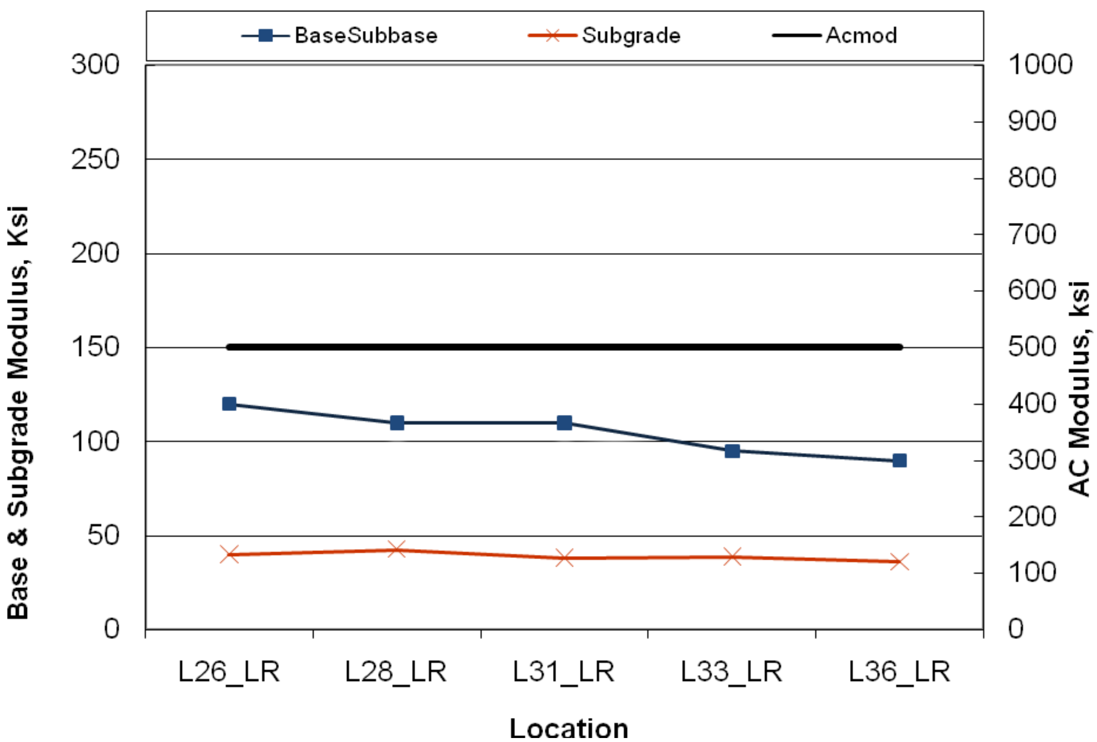

Figure A-4. Layer moduli versus location for I-10 High Rut

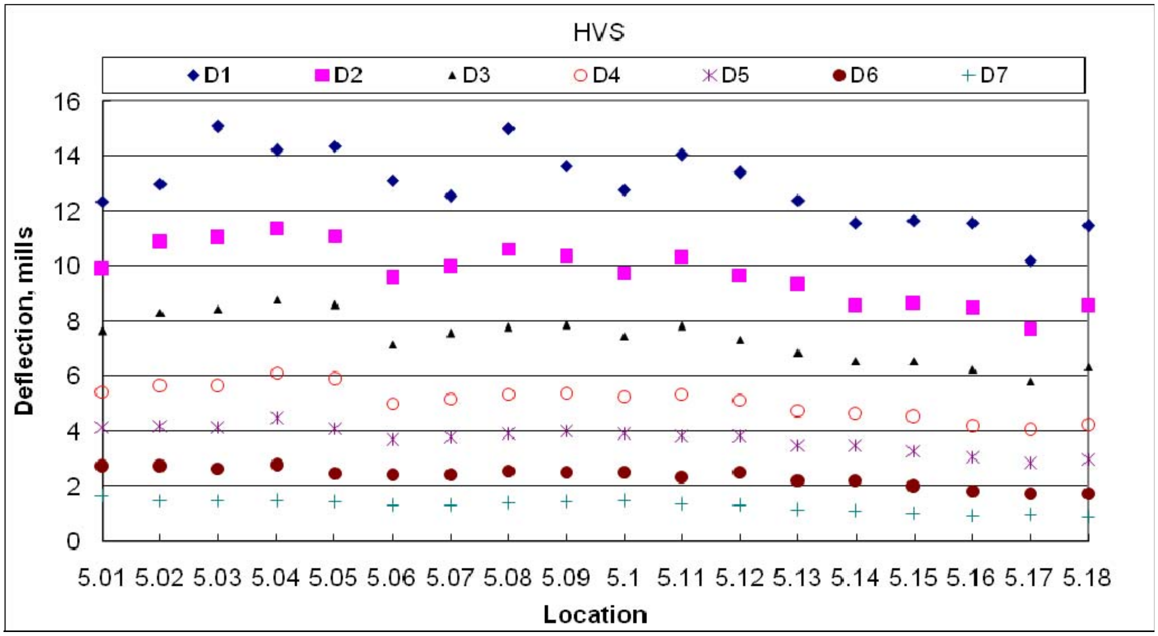

Figure A-5. Variation of deflection measurements along location for HVS Project

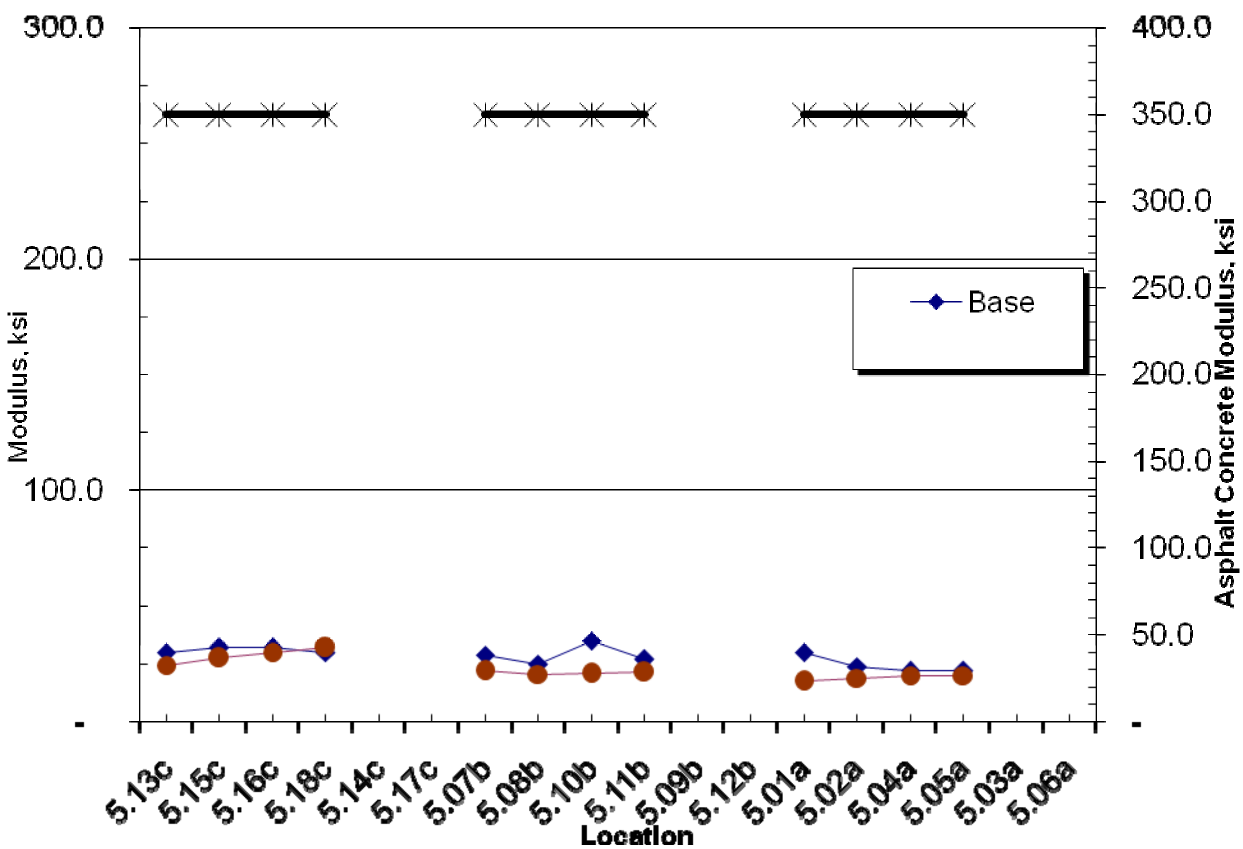

Figure A-6. Layer moduli versus location for HVS Project

APPENDIX B
TRENCH CUT TAKEN ON I-10 SECTIONS AND THE HVS TEST SECTIONS

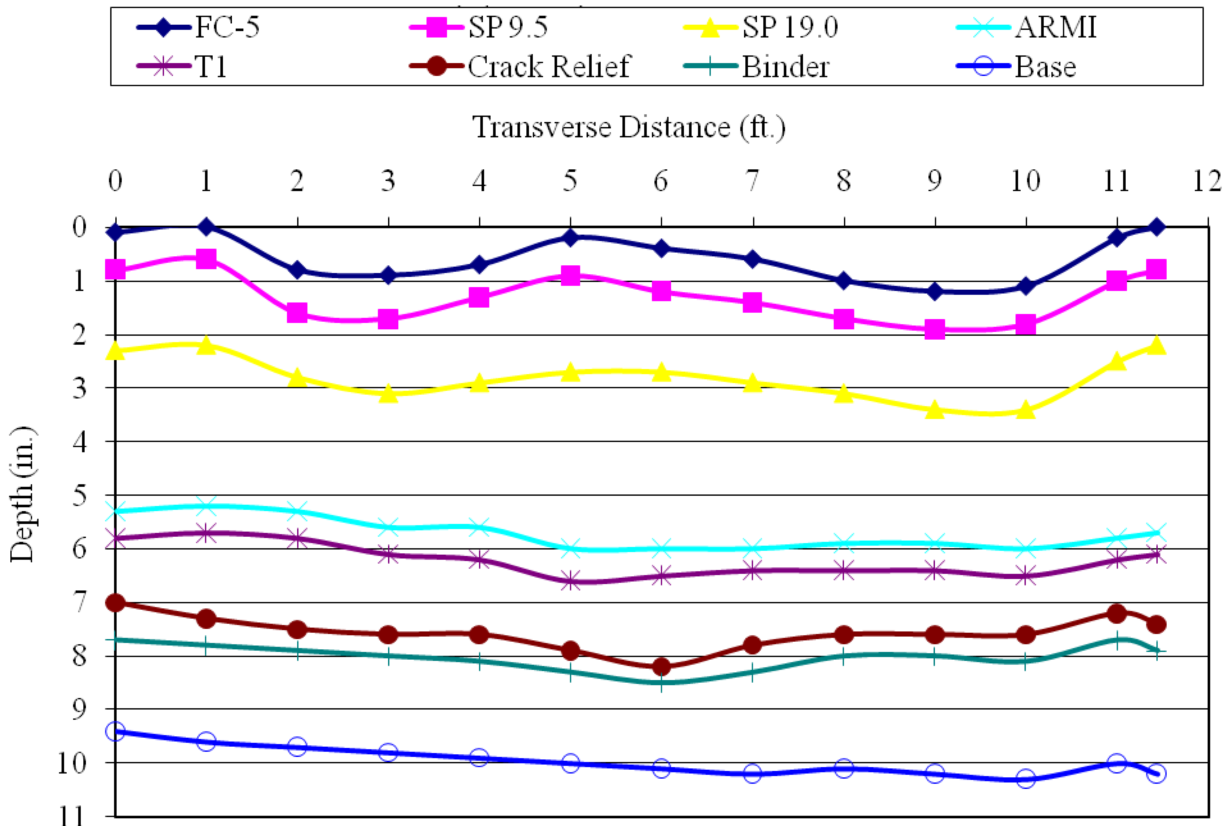

FIGURE B-1. Transverse Profile Taken on I-10 High Rut

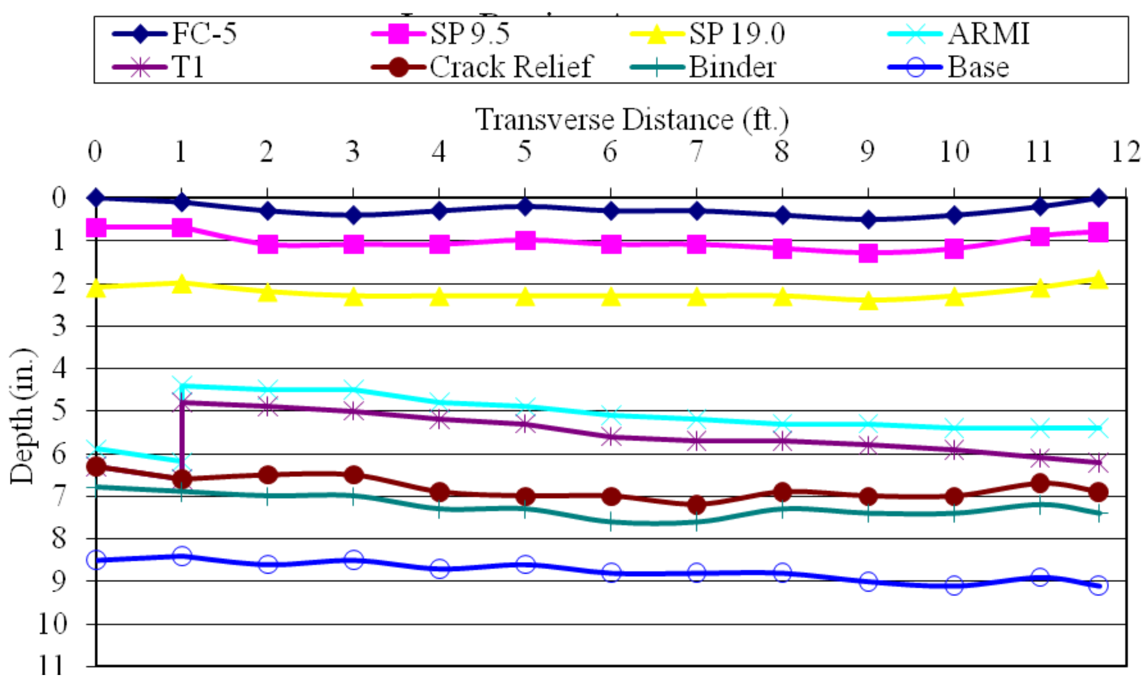

Figure B-2. Transverse Profile Taken on I-10 Low Rut

Figure B-3 Section 1-B showing no deformation of the base layer – Most of the deformation is due to asphalt compaction

Figure B-4. Section 4-A showing no deformation of the base layer – Most of the deformation is due to instability in the asphalt concrete.

APPENDIX C
RISK LEVEL ASSESSMENTS

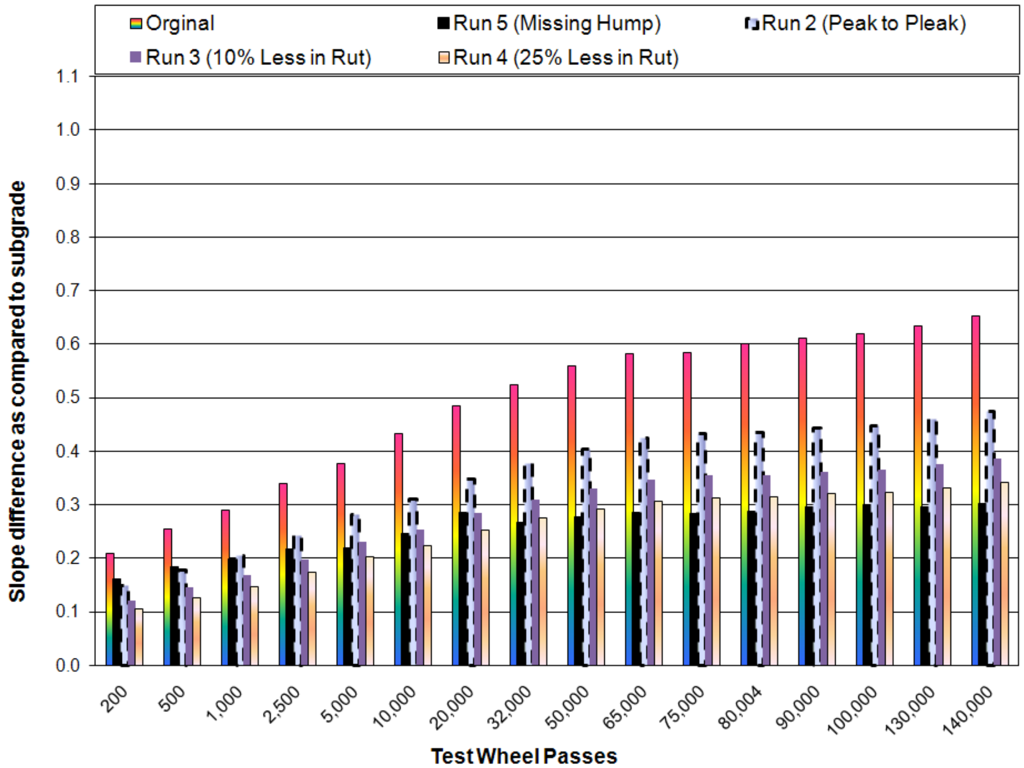

Figure C 1. Risk Level of Using RSP data when TP is not available for Project 2A

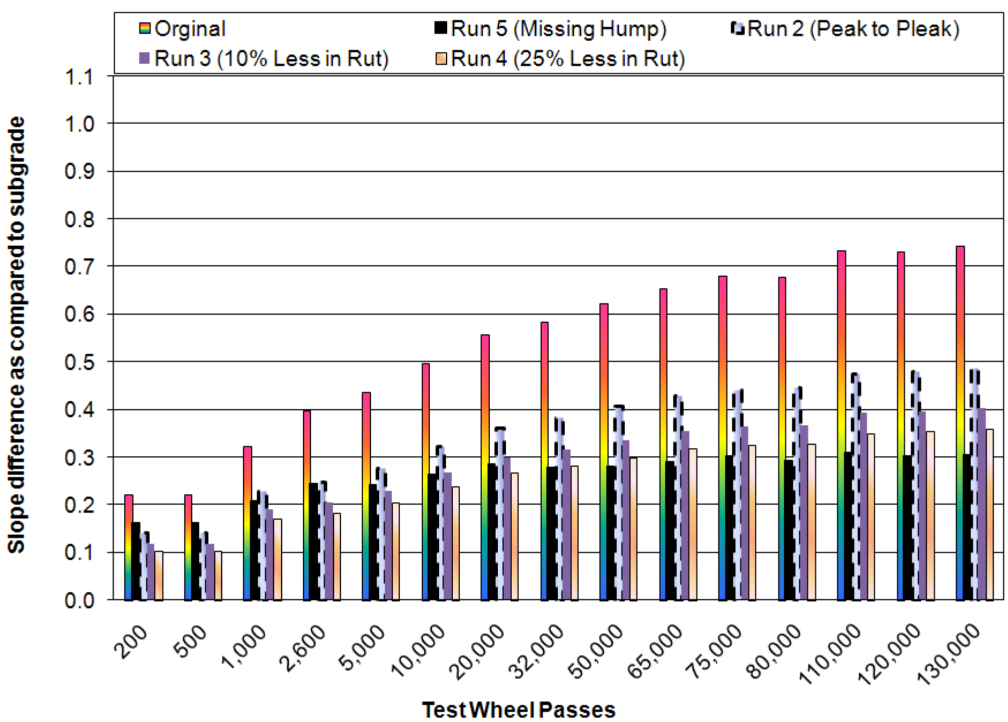

Figure C 2. Risk Level of Using RSP data when TP is not available for Project 1A

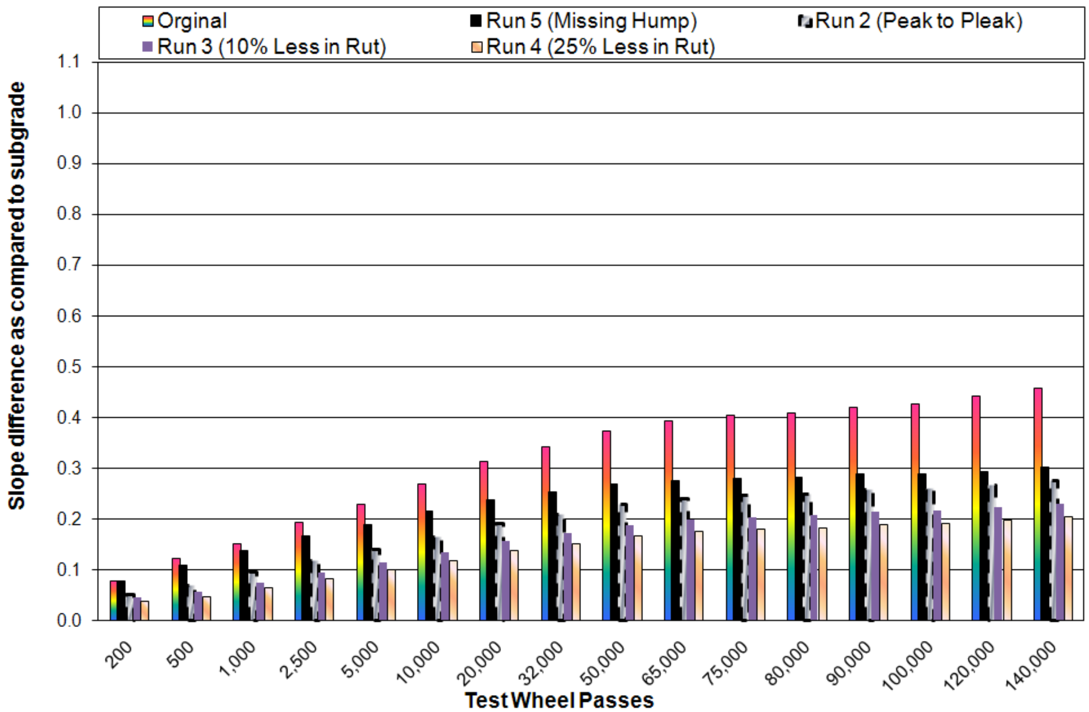

Figure C 3. Risk Level of Using RSP data when TP is not available for Project 1B

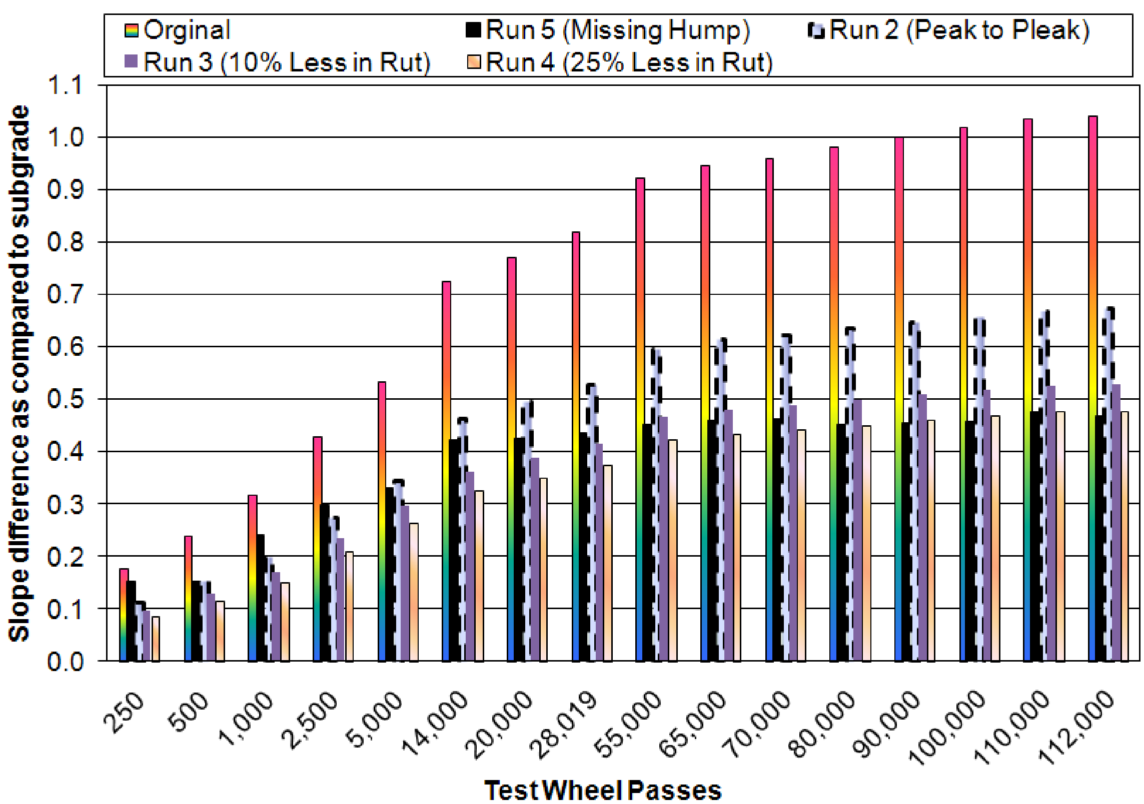

Figure C 4. Risk Level of Using RSP data when TP is not available for Project 5A

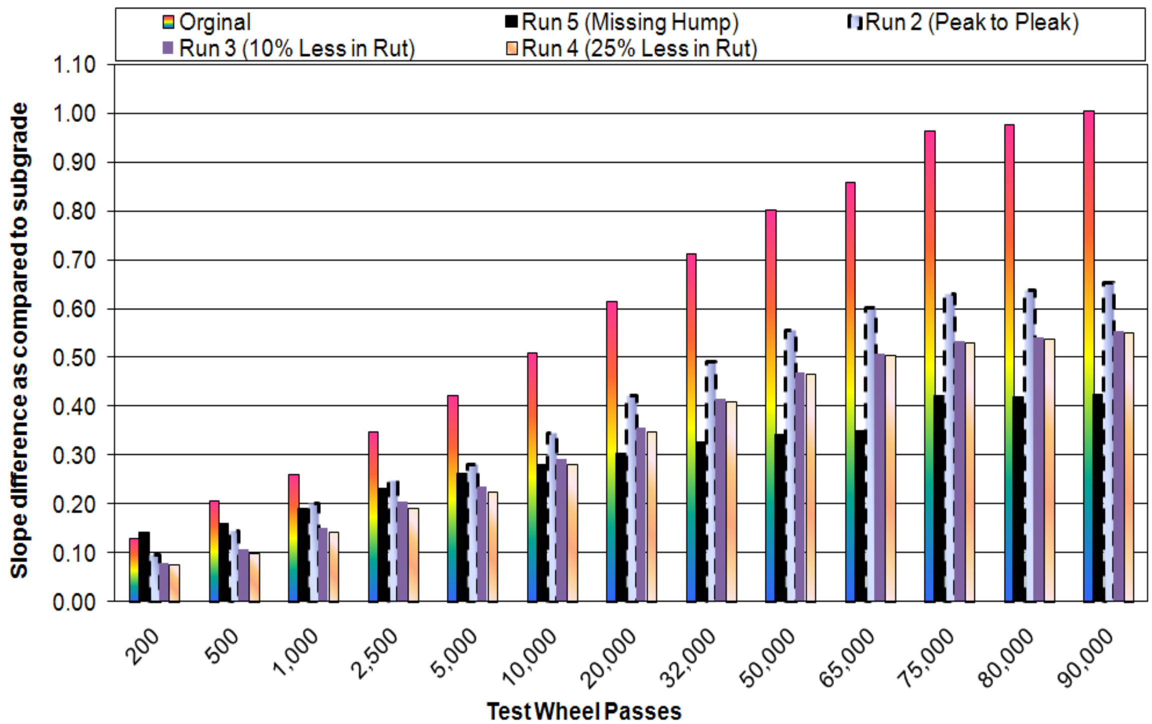

Figure C 5. Risk Level of Using RSP data when TP is not available for Project 4A

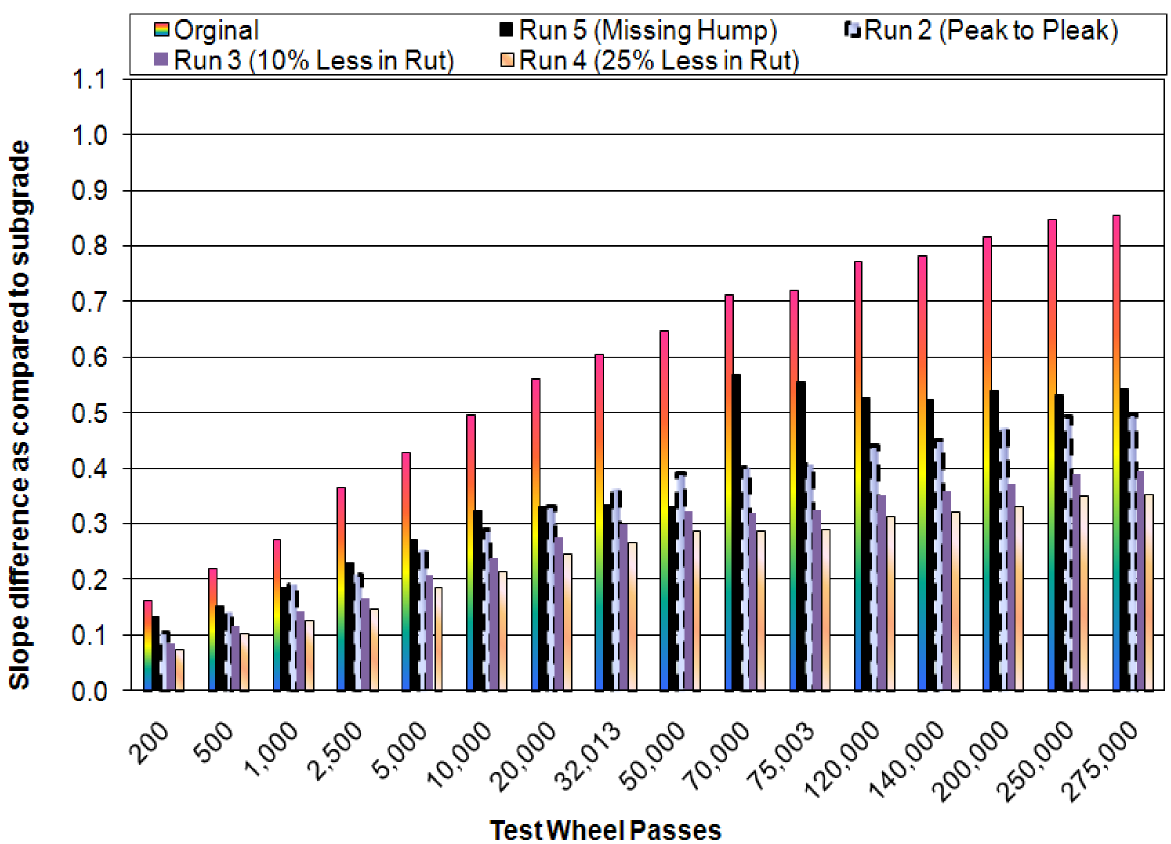

Figure C 6. Risk Level of Using RSP data when TP is not available for Project 3A