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Seal Coat Binder Rate Adjustments Using LiDAR Data

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Federal Highway Administration and the
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16. Abstract

Texas continues to see the same recurring problems in seal coat construction, such as rock loss, flushing, and bleeding. Because of a loss of experienced inspectors and a shift in inspection forces, an increased risk to the Texas Department of Transportation (TxDOT) exists when making the appropriate field adjustments for construction. Better methods to identify changing pavement conditions and subsequently adjust construction binder rates have become available through the recently completed research project 0-6963 by using mobile light detecting and ranging (LiDAR) reflectivity data. In this study, researchers worked with the Bryan District on six 2019 and five 2020 seal coat projects, and with the Brownwood and Waco Districts on five projects in each district’s 2020 summer seal coat contract using LiDAR equipment. The evaluation included applying the algorithm to provide the district with suggested shot rates. Researchers applied the algorithm to the LiDAR data and recommended binder rate adjustments. Researchers analyzed actual shot rates and compared those rates to the predicted rates. According to the generated results, researchers recommend determining the starting rate from the design procedure developed in TxDOT research project 0-6989 and determining the binder rate adjustments from LiDAR data analysis. This procedure can help field engineers make real-time decisions and can lead to better seal coat performance.

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SEAL COAT BINDER RATE ADJUSTMENTS USING LIDAR DATA

by

Darlene C. Goehl
Research Engineer
Texas A&M Transportation Institute

Charles F. Gurganus
Associate Research Engineer
Texas A&M Transportation Institute

Kai-Wei Liu
Assistant Research Scientist
Texas A&M Transportation Institute

and

Jia-Lin Hsu
Research Associate
Texas A&M Transportation Institute

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College Station, Texas 77843-3135

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Darlene Goehl, P.E. #80195.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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CHAPTER 1: PROJECT OVERVIEW

Seal coats are a very important preventive maintenance method used throughout Texas. Through the preventive maintenance program, about 16,000 lane miles a year are routinely resurfaced with a seal coat by contracts, and about 3,000 lane miles per year of seal coats are placed with state forces. Additionally, seal coats are used in intermediate layers during construction to seal the pavement structure, which is a significant investment of over $300 million annually. For more than 40 years, there has been little change in the design and construction practices, including in the equipment used to place the binder or aggregate.

Because of little to no changes in design and construction methods, Texas continues to see the same recurring problems, such as rock loss, flushing, and bleeding. However, new technologies are being developed that could potentially reduce these types of problems. Recently completed research projects have submitted the following findings:

- 0-6989: Update Seal Coat Application Rate Design Method—developed an updated procedure to design seal coat application rates; however, the adjustment factors are subjective. The research found that additional research is needed to develop measures for adjustment rates.
- 0-6963: Planning the Next Generation of Seal Coat Equipment—found that the mobile light detecting and ranging (LiDAR) system shows much promise to remove a significant amount of subjectivity when determining variations in surface conditions. Identification of the surface conditions is needed in order to adjust the seal coat binder rates during construction as the conditions change.

The objective of this current project was to remove subjectivity from the rate adjustment process that led to reduced risk for the Texas Department of Transportation (TxDOT). Researchers used LiDAR reflectivity data to describe pavement condition changes through an efficient and effective automated data analysis method. Researchers reviewed the projects identified in research project 0-6963 and worked with the Bryan District on six summer 2019 seal coat projects to identify pavement condition changes and binder rate adjustments. For the 2020 seal coat projects, researchers worked with the Bryan District and two additional districts (Waco and Brownwood) to select five projects from each district. Researchers collected data on the selected locations, applied the algorithm, and provided the district with suggested application rate adjustments.

CHAPTER 2: 2018 PROJECT RATE VERIFICATION

OVERVIEW

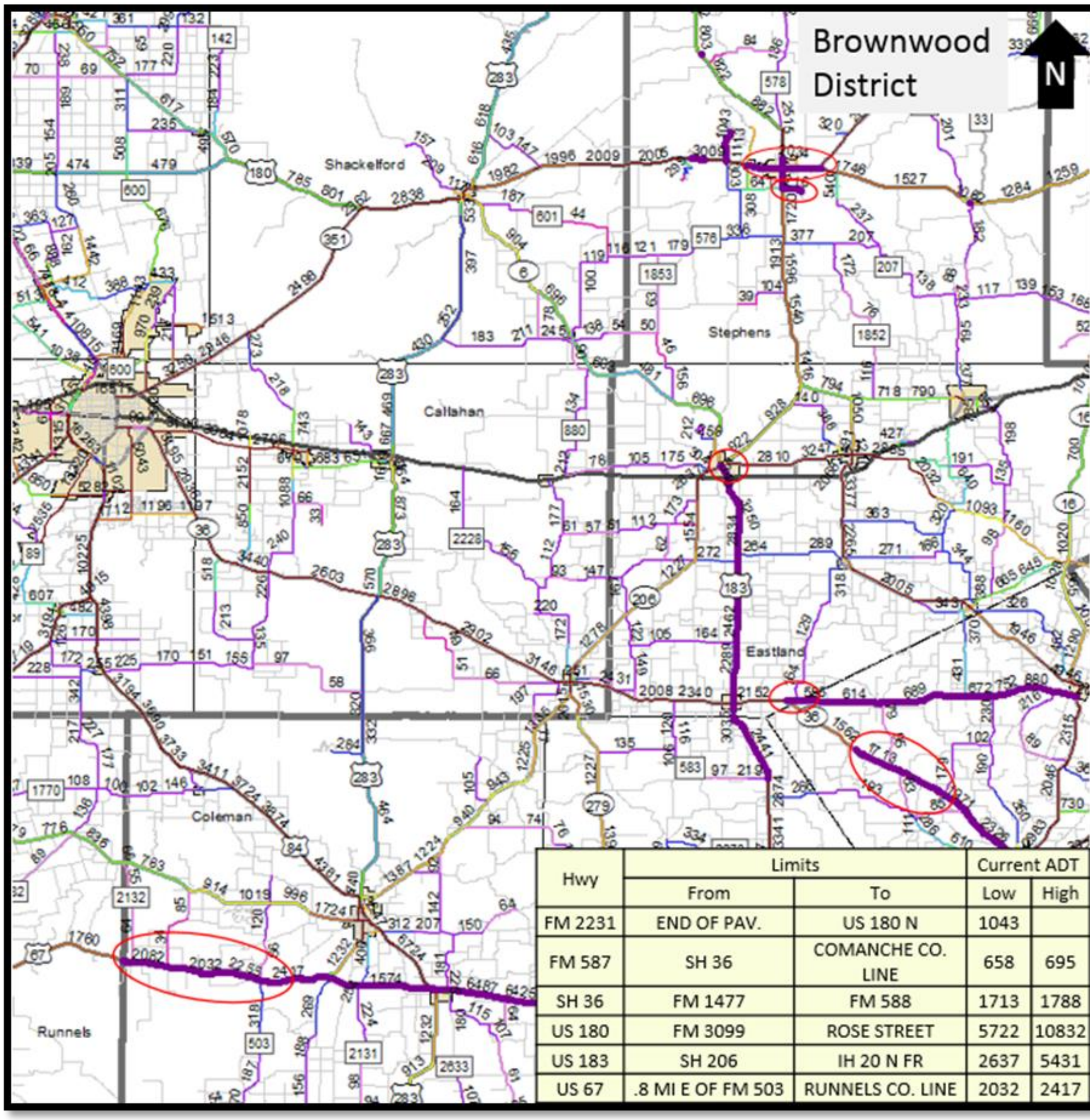
During research project 0-6963, Planning the Next Generation of Seal Coat Equipment, researchers ran the automated reflectivity process through the mobile LiDAR system to generate binder rate changes on six roadways each in the Brownwood, Bryan, and Waco Districts as part of the fiscal year 2018 seal coat program. In this chapter, researchers compare the generated binder rate to the actual rates from each roadway and describe an evaluation of pavement conditions performed using the high-definition video (HDV) system.

VALIDATE TEST PROJECTS FROM ORIGINAL RESEARCH PROJECT

The researchers contacted the Brownwood, Bryan, and Waco Districts to obtain the documentation for the actual shot rates. The actual shot rates were compared to those rates predicted by analyzing the LiDAR reflectivity data. A visual evaluation of the performance of the sections was documented to determine the accuracy of the automated method in terms of the flushing, bleeding, or drying condition of the seal coat.

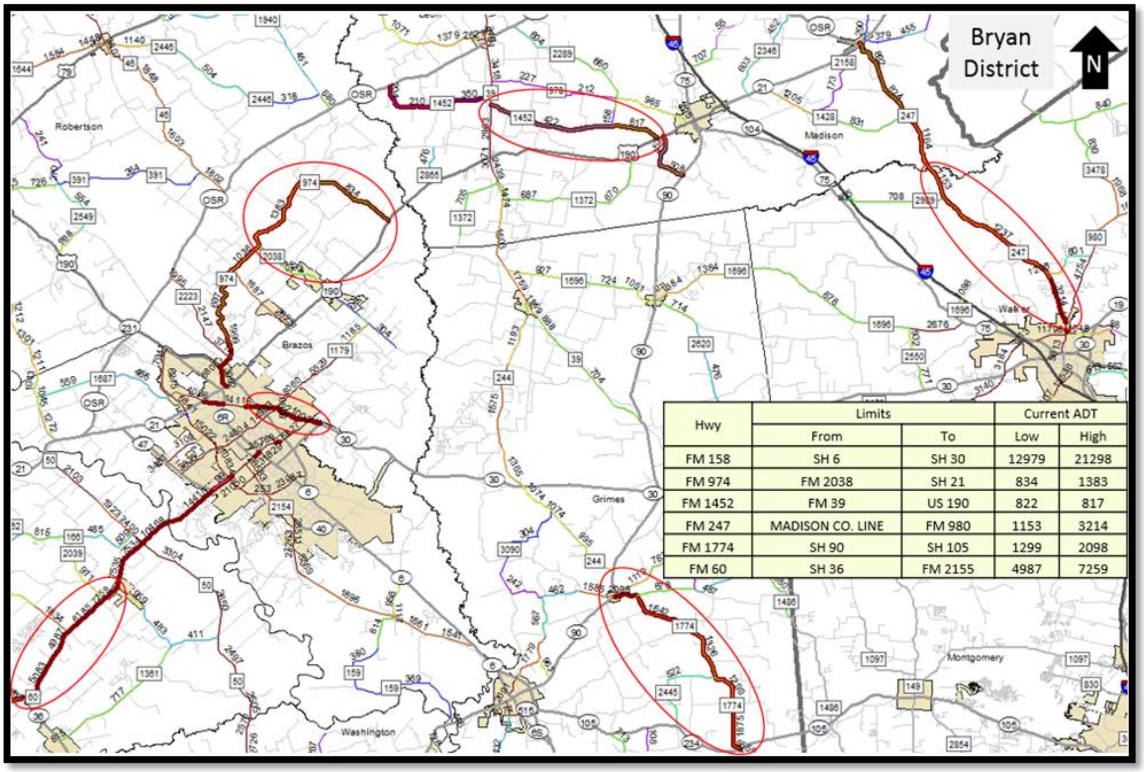
TEST SECTIONS

Six projects that represent various surface conditions expected in Texas and different traffic levels were validated from each district. Figure 1, Figure 2, and Figure 3 show the locations of the test sites for each district and the current annual daily traffic (ADT).



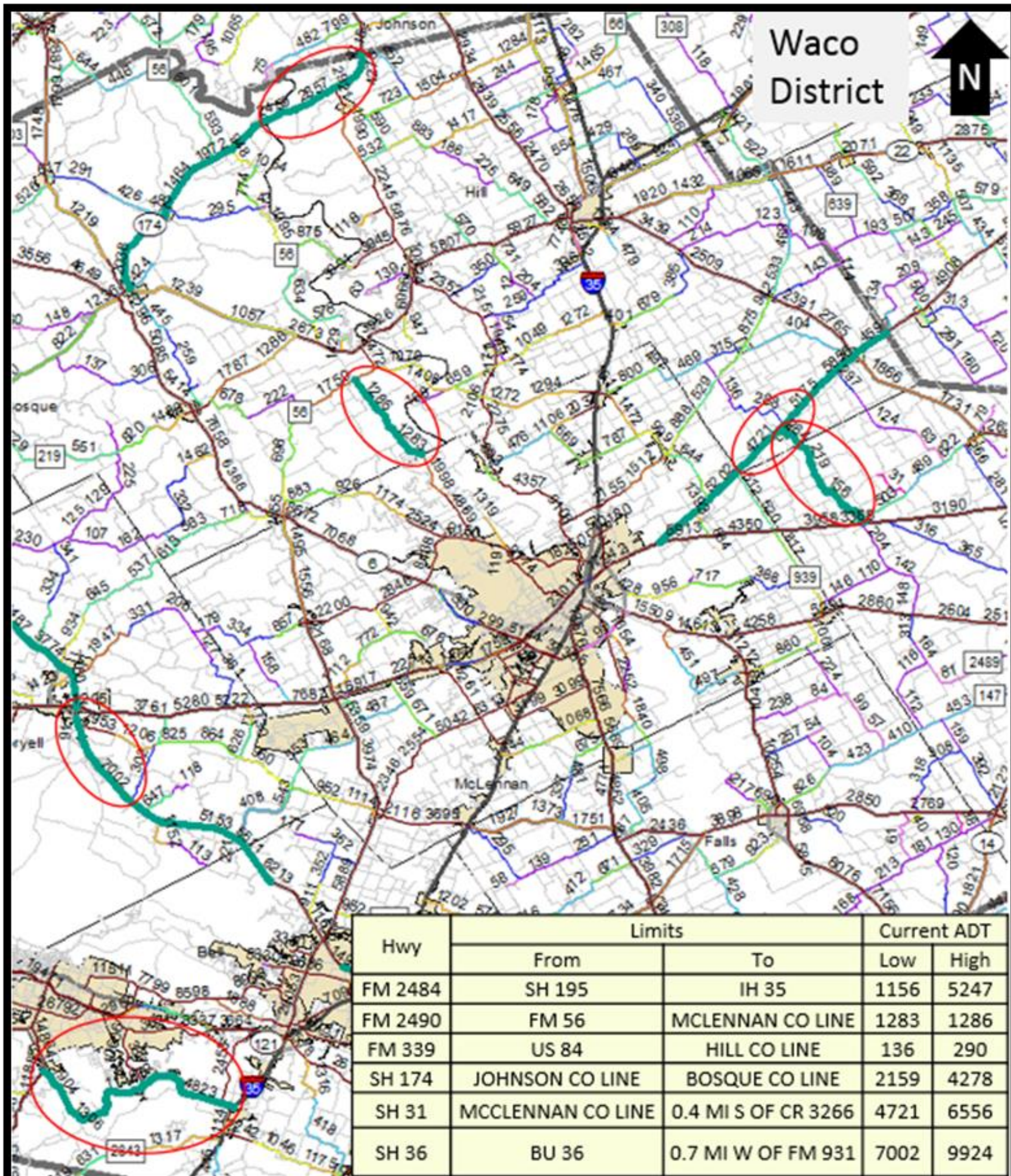
Hwy	Limits		Current ADT	
	From	To	Low	High
FM 2231	END OF PAV.	US 180 N	1043	
FM 587	SH 36	COMANCHE CO. LINE	658	695
SH 36	FM 1477	FM 588	1713	1788
US 180	FM 3099	ROSE STREET	5722	10832
US 183	SH 206	IH 20 N FR	2637	5431
US 67	.8 MI E OF FM 503	RUNNELS CO. LINE	2032	2417

Figure 1. Brownwood District 2018 Test Sites with Current ADT.



Hwy	Limits		Current ADT	
	From	To	Low	High
FM 158	SH 6	SH 30	12979	21298
FM 974	FM 2038	SH 21	834	1383
FM 1452	FM 39	US 190	822	817
FM 247	MADISON CO. LINE	FM 980	1153	3214
FM 1774	SH 90	SH 105	1299	2098
FM 60	SH 36	FM 2155	4987	7259

Figure 2. Bryan District 2018 Test Sites with Current ADT.



Hwy	Limits		Current ADT	
	From	To	Low	High
FM 2484	SH 195	IH 35	1156	5247
FM 2490	FM 56	MCLENNAN CO LINE	1283	1286
FM 339	US 84	HILL CO LINE	136	290
SH 174	JOHNSON CO LINE	BOSQUE CO LINE	2159	4278
SH 31	MCCLENNAN CO LINE	0.4 MI S OF CR 3266	4721	6556
SH 36	BU 36	0.7 MI W OF FM 931	7002	9924

Figure 3. Waco District 2018 Test Sites with Current ADT.

Each district was contacted to obtain the documentation for the actual shot rates, and then those rates were compared to the rates predicted during the research project. Researchers visually evaluated and documented the performance of the sections to draw a conclusion as to the accuracy of the automated method. Researchers also documented the conditions of flushing, bleeding, or rock loss of the seal coat placed during the summer of 2018. Table 1 summarizes the range of actual shot rates for each test site.

Table 1. Test Sections from Each District.

District	Hwy	Limits		Shot Rates	
		From	To	cy/sy	gal/sy
Brownwood	FM 2231	END OF PAV.	US 180 N	120	0.29–0.3
	FM 587	SH 36	COMANCHE CO. LINE	115	0.25
	SH 36	FM 1477	FM 588	119–121	0.22–0.32
	US 180	FM 3099	ROSE STREET	120	0.25–0.29
	US 183	SH 206	IH 20 N FR	119–120	0.24–0.27
	US 67	.8 MI E OF FM 503	RUNNELS CO. LINE	119–121	0.22–0.35
Bryan	FM 158	SH 6	SH 30	n/a	n/a
	FM 974	FM 2038	SH 21	125	0.32–0.38
	FM 1452	FM 39	US 190	125	0.34–0.36
	FM 247	MADISON CO. LINE	FM 980	125	0.34–0.37
	FM 1774	SH 90	SH 105	123–124	0.32–0.41
	FM 60	SH 36	FM 2155	n/a	n/a
Waco	FM 2484	SH 195	IH 35	120	0.33–0.4
	FM 2490	FM 56	MCLENNAN CO LINE	120	0.38–0.45
	FM 339	US 84	HILL CO LINE	120	0.41–0.56
	SH 174	JOHNSON CO LINE	BOSQUE CO LINE	120	0.35–0.51
	SH 31	MCCLENNAN CO LINE	0.4 MI S OF CR 3266	120	0.25–0.42
	SH 36	BU 36	0.7 MI W OF FM 931	120	0.35–0.40

SURFACE DETECTION USING MOBILE LIDAR SYSTEM

In research project 0-6963, mobile LiDAR was found to effectively capture the pavement surface reflectivity. Reflectivity data accurately detected surface changes that, when compared to a desired condition, could be used to determine flushing, patching, and other surface type changes. Using mobile LiDAR reflectivity data, the location and length of surface changes could be accurately found and noted for design or construction needs. The selected examples (Table 2 to Table 6) from each district show the descriptions combined with rate adjustments for each wheel path for each lane of the test sections. The terminology used for the wheel path description is a comparison of the changes along the section compared to a reference section. The reference section is the expected surface condition of either a hot mix or seal coat uniform surface in good condition. These descriptions combined with rate adjustments were evaluated for each test section in each district.

In research project 0-6963, the researchers found that when more clusters are generated by the k-means algorithm, the entire length of roadway being analyzed has a more varied pavement surface. The second to fourth columns in Table 2 to Table 6 show the overall surface description in terms of surface variabilities: the less cluster, the more uniformity of pavement surface. The suggested adjustments of binder rates are presented in the fifth to seventh columns (the left wheel path [LTWP], between the wheel path [BTWP], and the right wheel path [RTWP)]) in Table 2 to Table 6. This information implies that variable-rate nozzles will be required for the roadways, and in general, the LTWPs and RTWPs suggest a higher change in binder rate than the BTWPs. However, nozzle rate changing at every 100-ft station is not operational from a construction standpoint. Therefore, using the average binder adjustment in the LTWP and RTWP every 1000 ft is recommended. Table 7 summarizes the recommended binder adjustments/shot rates along with the actual shot rates for the selected 1000-ft section listed in Table 2 to Table 6 from each district.

Table 2. Binder Rate Adjustment Tabular Output for 1000 ft of FM 587 Eastbound (EB) in Brownwood District.

Beginning Reference Location (ft)	Overall LTWP Description	Overall BTWP Description	Overall RTWP Description	LTWP Binder Adjustment (gal/sy)	BTWP Binder Adjustment (gal/sy)	RTWP Binder Adjustment (gal/sy)
574.3228	Varied	Fairly Uniform	Varied	0.01	0.01	0.02
674.3228				0.01	-0.03	0.01
774.3228				0.00	-0.02	0.00
874.3228				0.01	0.02	0.01
974.3228				0.00	-0.03	0.00
1074.323				0.02	0.01	0.02
1174.323				0.01	0.00	0.02
1274.323				0.00	0.00	0.02
1374.323				0.00	0.00	0.01
1474.323				0.00	0.00	-0.01

Table 3. Binder Rate Adjustment Tabular Output for 1000 ft of US 67 EB in Brownwood District.

Beginning Reference Location (ft)	Overall LTWP Description	Overall BTWP Description	Overall RTWP Description	LTWP Binder Adjustment (gal/sy)	BTWP Binder Adjustment (gal/sy)	RTWP Binder Adjustment (gal/sy)
446.3786	Externly Varied	Fairly Uniform	Highly Varied	-0.02	-0.01	-0.03
546.3786				-0.02	-0.01	-0.03
646.3786				-0.01	0.00	-0.04
746.3786				-0.02	-0.01	-0.03
846.3786				-0.03	-0.01	-0.04
946.3786				-0.03	-0.01	-0.04
1046.379				-0.03	-0.01	-0.04
1146.379				-0.04	-0.01	-0.05
1246.379				-0.04	-0.01	-0.04
1346.379				-0.05	-0.01	-0.03

Table 4. Binder Rate Adjustment Tabular Output for 1000 ft of FM 1452 Westbound (WB) in Bryan District.

Beginning Reference Location (ft)	Overall LTWP Description	Overall BTWP Description	Overall RTWP Description	LTWP Binder Adjustment (gal/sy)	BTWP Binder Adjustment (gal/sy)	RTWP Binder Adjustment (gal/sy)
5279.461	Varied	Fairly Uniform	Varied	0.01	0.01	0.00
5379.461				0.03	0.02	0.05
5479.461				0.07	0.03	0.07
5579.461				0.01	0.00	0.01
5679.461				0.00	0.00	-0.01
5779.461				0.00	0.00	-0.01
5879.461				0.00	0.00	-0.01
5979.461				0.00	0.00	-0.01
6079.461				0.06	0.03	0.06
6179.461				0.06	0.03	0.07

Table 5. Binder Rate Adjustment Tabular Output for 1000 ft of FM 339 Southbound (SB) in Waco District.

Beginning Reference Location (ft)	Overall LTWP Description	Overall BTWP Description	Overall RTWP Description	LTWP Binder Adjustment (gal/sy)	BTWP Binder Adjustment (gal/sy)	RTWP Binder Adjustment (gal/sy)
7023.392	Varied	Fairly Uniform	Varied	-0.03	0.00	-0.01
7123.392				-0.02	0.00	0.00
7223.392				-0.02	0.00	0.00
7323.392				-0.04	0.00	0.01
7423.392				-0.03	0.00	0.01
7523.392				-0.06	0.00	0.01
7623.392				-0.05	0.00	0.01
7723.392				-0.05	0.00	0.01
7823.392				-0.06	0.00	0.01
7923.392				-0.04	0.00	0.00

Table 6. Binder Rate Adjustment Tabular Output for 1000 ft of FM 2490 Northbound (NB) in Waco District.

Beginning Reference Location (ft)	Overall LTWP Description	Overall BTWP Description	Overall RTWP Description	LTWP Binder Adjustment (gal/sy)	BTWP Binder Adjustment (gal/sy)	RTWP Binder Adjustment (gal/sy)
6576.379	Highly Varied	Varied	Varied	-0.05	0.00	-0.01
6676.379				-0.03	0.00	-0.01
6776.379				-0.05	0.00	-0.02
6876.379				-0.05	0.00	-0.02
6976.379				-0.05	0.00	-0.02
7076.379				-0.05	0.00	-0.02
7176.379				-0.04	0.00	-0.03
7276.379				-0.04	0.00	-0.01
7376.379				-0.05	0.00	-0.01
7476.379				-0.06	-0.03	-0.04

Table 7. Binder Rate Adjustment Recommended for the 1000 ft of Tested Sections Listed in Table 2 to Table 6 from Each District.

1000 ft of Section	District	Recommended Binder Adjustment (gal/sy)	Recommended Shot Rate (gal/sy)	Actual Shot Rate (gal/sy)	Expected Surface Condition
FM 587 EB	Brownwood	0.01	0.26	0.25	Good
US 67 EB	Brownwood	-0.03	0.18	0.23	Flushed/ Bleeding
FM 1452 WB	Bryan	0.02	0.36	0.34	Dry
FM 339 SB	Waco	-0.02	0.50	0.49	Good
FM 2490 NB	Waco	-0.03	0.27	0.32	Flushed/ Bleeding

Based on the comparison between recommended shot rate and actual shot rate (the fourth and fifth column in Table 7), the expected surface condition is provided in the sixth column in Table 7. It is expected that the surface condition should be good when the recommended shot rate and actual shot rate are similar (e.g., FM 587 EB in Brownwood District, FM 339 SB in Waco District). However, if the actual shot rate is higher than the recommended rate, the surface might be flushed or bleeding (e.g., US 67 EB in Brownwood District, FM 2490 NB in Waco District). Since the actual shot rate is lower than the recommended rate, FM 1452 WB in the Bryan District is expected to be dry. These expected surface conditions were evaluated using an HDV system and are described in the next section.

FIELD TEST SITE EVALUATIONS USING THE HDV SYSTEM

A low-cost and easy-to-use methodology was applied for collecting and processing high-definition right-of-way images of the pavement. The surface changes performed using the HDV system and PaveView software for each of the selected 1000-ft test sites (Table 2 to Table 6) are summarized below.

Brownwood District

FM 587 EB—A Rural Two-Lane Highway with Low ADT

The challenges to designing a successful seal on this road are (a) some slight flushing in curves and (b) narrow lanes. The binder application rate based on the LiDAR measurement was determined to be 0.26 gal/sy (Table 7). Since the actual shot rate is 0.25 gal/sy (~ 0.26 gal/sy) for this rural roadway with low ADT, the overall surface condition looks good. Figure 4 shows an example section of the before and after seal coat application on FM 587 EB.

Figure 4. FM 587 EB Surface Conditions: Before (Left) and After (Right) Seal Coat.

US 67 EB—Rural Two-Lane Highway with High ADT

The challenges to designing a successful seal on this road are (a) short sections of level-up, dry; and (b) flushing. The binder application rate based on the LiDAR measurement was determined to be 0.18 gal/sy (Table 7). Since the actual shot rate is 0.23 gal/sy (> 0.18 gal/sy) for this high ADT rural roadway, the overall surface condition might be flushed/bleeding. Figure 5 shows an example section of the before and after seal coat application on US 67 EB.

Figure 5. US 67 EB Surface Conditions: Before (Left) and After (Right) Seal Coat.

Bryan District

FM 1452 WB—A Rural Two-Lane Highway with Low ADT

The challenges to designing a successful seal on this road are (a) slight flushing in the wheel paths; (b) long section of level-up, dry; and (c) loss of aggregate outside wheel paths. The binder application rate based on the LiDAR measurement was determined to be 0.36 gal/sy (Table 7). Since the actual shot rate is 0.34 gal/sy (< 0.36 gal/sy) for this low ADT rural roadway, the overall surface condition might be dry. Figure 6 shows an example section of the before and after seal coat application on FM 1452 WB.

Figure 6. FM 1452 WB Surface Conditions: Before (Left) and After (Right) Seal Coat.

Waco District

FM 339 SB—A Rural Two-Lane Highway with Low ADT

The challenges to designing a successful seal on this road are (a) patch, fresh level-up; (b) flushing; and (c) milled surface. The binder application rate based on the LiDAR measurement was determined to be 0.50 gal/sy (Table 7). Since the actual shot rate is 0.49 gal/sy (~ 0.50 gal/sy) for this low ADT rural roadway, the overall surface condition should be good. Figure 7 shows an example section of the before and after seal coat application on FM 339 SB.

Figure 7. FM 339 SB Surface Conditions: Before (Left) and After (Right) Seal Coat.

FM 2490 NB—A Rural Two-Lane Highway with Moderate ADT

The challenges to designing a successful seal on this road are (a) short sections of level-up, and (b) flushing wheel paths with rock loss outside wheel paths. The binder application rate based on the LiDAR measurement was determined to be 0.27 gal/sy (Table 7). Since the actual shot rate is 0.32 gal/sy (> 0.27 gal/sy) for this moderate ADT rural roadway, the overall surface condition might be flushed/bleeding. Figure 8 shows an example section of the before and after seal coat application on FM 2490 NB.

Figure 8. FM 2490 NB Surface Conditions: Before (Left) and After (Right) Seal Coat.

SUMMARY

Based on the results obtained in this task, the following conclusions were reached:

- Although only selected sections (Table 2 to Table 6) were shown as examples, comparisons between the actual shot rates and the rates predicted by analyzing LiDAR reflectivity data (Table 7) and the visual evaluation and documentation of the performance of the sections by the HDV system (Figure 4 through Figure 8) were performed for each test section in each district.

- The LiDAR information (Table 2 to Table 6) implies that variable-rate nozzles are required for the roadways, and in general, the LTWPs and RTWPs suggest a higher change in binder rate than the BTWPs. However, changing nozzle rate at every 100-ft station is not operational from a construction standpoint. Therefore, using the average binder adjustment in the LTWP and RTWP, every 1000 ft (Table 7) was estimated for the evaluation. For future work, a reporting method for binder rate changes will be developed with construction method limitations taken into account.
- The laser-reflected signal intensity of a pavement surface collected using a LiDAR unit can be processed and analyzed to generate binder rate adjustments for seal coat projects without subjectivity. The HDV system can be used to document the surface condition without traffic control.
- Overall, the expected surface conditions based on the comparisons between actual and predicted shot rates were validated and matched up well with the observations from the HDV system. Thus, LiDAR can improve seal coat construction by collecting surface information in a safe manner and analyzing it in an automated fashion to describe actual surface characteristics. It can also be deployed shortly before actual construction and offers managing agencies the ability to provide detailed binder rates that more accurately address the existing surface conditions, thus leading to better performance.

CHAPTER 3: 2019 CASE STUDIES

OVERVIEW

The previous chapter described how the researchers validated test projects from original research project 0-6963—Planning the Next Generation of Seal Coat Equipment. In general, the expected surface conditions based on the comparisons between actual and predicted shot rates were validated and matched up well with the observations from the HDV system. Researchers concluded that LiDAR can improve seal coat construction by collecting surface information in a safe manner and analyzing it in an automated fashion to describe changes in surface characteristics.

This chapter presents how the researchers identified new test sites and conducted test measurements for new seal coats using mobile LiDAR reflectivity measurements. Six projects were selected in the Bryan District's 2019 seal coat project to represent various surface conditions and different traffic levels. Table 8 shows the locations of the test sites and the current ADT.

Table 8. 2019 Bryan District Test Sites.

HWY	County	From	To	ADT	
				Low	High
FM 391	Robertson	SH 6	FM 46	285	1253
FM 1331	Milam	Williamson CL	FM 486	916	1374
FM 1915	Milam	US 190	FM 437	221	669
FM 2095	Milam	US 77	FM 3242	918	1579
FM 2446	Robertson	FM 46	FM 1940	373	1278
FM 1940	Robertson	US 79	OSR	517	873

BINDER APPLICATION RATE ADJUSTMENT

As discussed in the previous chapter, mobile LiDAR was shown to effectively capture the pavement surface reflectivity to aid in the determination of surface change. This chapter describes how the binder application rate adjustment was estimated for new seal coats. Table 9 lists the rate adjustments and Figure 9 shows the distributions of rate adjustments for each wheel path for each lane of the test section in a selected example from FM 2095 EB. These estimates, including rate adjustments and rate adjustment distributions, were performed for every test section in each project.

Table 9. Binder Rate Adjustment Tabular Output for 1000 ft of FM 2095 EB.

Beginning Reference Location (ft)	Overall LTWP Description	Overall BTWP Description	Overall RTWP Description	LTWP Binder Adjustment (gal/sy)	BTWP Binder Adjustment (gal/sy)	RTWP Binder Adjustment (gal/sy)
4096	Fairly Uniform	Varied	Fairly Uniform	-0.02	-0.01	0.02
4196				-0.03	-0.01	0.00
4296				-0.03	-0.02	0.00
4396				-0.04	-0.02	-0.02
4496				0.00	-0.01	0.00
4596				-0.03	-0.01	0.00
4696				-0.04	-0.02	-0.02
4796				-0.04	-0.02	0.00
4896				-0.04	-0.02	0.00
4996				-0.03	-0.01	-0.01

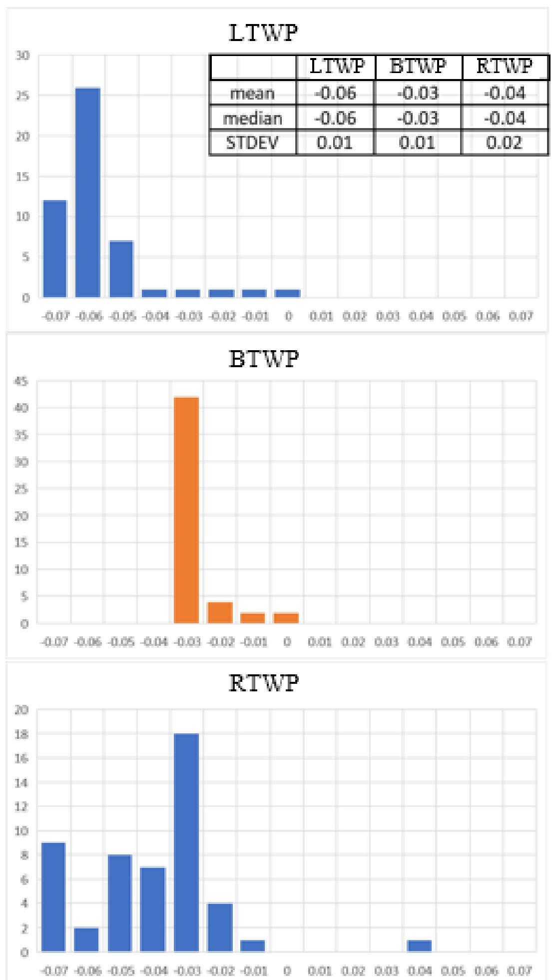


Figure 9. Distribution of Binder Rate Adjustment Output for 1 Mile of FM 2095 EB (horizontal axis: rate adjustment; vertical axis: distance ft).

The suggested adjustments of binder rates are presented in the fifth to seventh columns (LTWP, BTWP, and RTWP) in Table 9. In general, the LTWPs and RTWPs suggest a higher change in binder rate than the BTWPs. As mentioned in the previous chapter, changing nozzle rates at every 100-ft station is not operational from a construction standpoint. Therefore, use of the average binder adjustment in the LTWP and RTWP was recommended by researchers. However, in order to reveal the applicability of use of the average binder adjustment for each tested section, the distributions of rate adjustments for every 1-mile section in each project were evaluated; Figure 9 shows an example. The information implies that when the difference in the median rate between the LTWP and RTWP is equal to or less than 0.03, the use of the average binder adjustment in the LTWP and RTWP for a 1-mile roadway is feasible with a single-rate spray bar setup. Table 10 summarizes the recommended binder adjustment, recommended shot rates, and actual shot rates for the 5-mile section of FM 2095 EB.

Table 10. Binder Rate Adjustment Recommended for the First 5 Miles of FM 2095 EB.

Section	Recommended Binder Adjustment (gal/sy)	Recommended Shot Rate (gal/sy)	Actual Shot Rate (gal/sy)
1st 1-mile	-0.05	0.35	0.37
2nd 1-mile	-0.04	0.36	0.38
3rd 1-mile	-0.02	0.38	0.43
4th 1-mile	-0.02	0.38	0.40
5th 1-mile	-0.02	0.38	0.42

Among all six projects, around 10 percent of test sections indicated variable-rate nozzles would be required for the roadways. Figure 10 shows the distributions of rate adjustments for the first 1-mile section of FM 1915 NB. The information implies that when the difference in the median rate between the LTWP and RTWP is greater than 0.03, the use of the average binder adjustment in the LTWP and RTWP for a 1-mile roadway is not feasible, and a variable-rate nozzle is highly recommended. It is expected that the surface of this mile might be flushed or bleeding, especially in the LTWP, due to a greater negative adjustment binder rate (i.e., −0.04 to −0.07). These expected surface conditions were evaluated by researchers using a video system, and Figure 11 shows an example section of the after-seal-coat application in the first mile on FM 1915 NB.

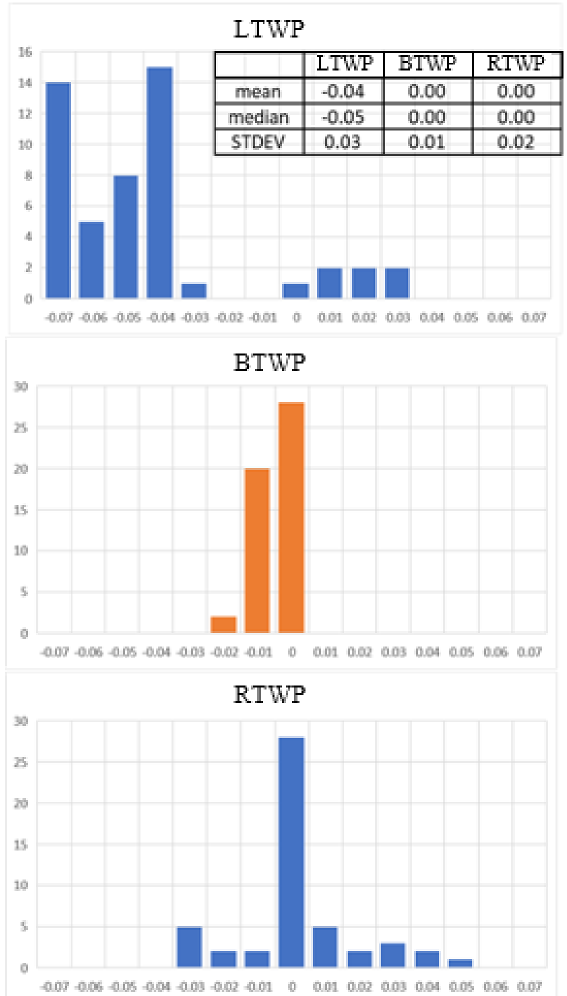


Figure 10. Distributions of Binder Rate Adjustment Output for 1 Mile of FM 1915 NB (horizontal axis: rate adjustment; vertical axis: distance ft).

Figure 11. FM 1915 NB Surface Conditions: After Seal Coat.

DATA ANALYSIS SUMMARY

Based on the results obtained in this task, the following conclusions were drawn:

- Although only selected sections (Table 9) were shown as examples, comparisons between the actual shot rates and the rates predicted by analyzing LiDAR reflectivity data (Table 10) were performed for each test section.
- According to the distributions of rate adjustments (Figure 9) for every 1-mile section in each project, when the difference in median rate between the LTWP and RTWP is equal to or less than 0.03, use of the average binder adjustment in the LTWP and RTWP for a 1-mile roadway is feasible using a single-rate nozzle. However, when the difference in median rate between the LTWP and RTWP is greater than 0.03 (Figure 10), the use of a variable-rate nozzle for the LTWP and RTWP is highly recommended.
- The laser-reflected signal intensity of a pavement surface collected using a LiDAR unit has been found to generate binder rate adjustments for seal coat projects without subjectivity. It can also be used to identify the challenging areas on pavement surfaces for reasonable binder application rates and to address existing surface conditions more accurately, thus leading to better performance.

VALIDATION OF 2019 TEST SITES

The main objective was to validate test projects at the 2019 test sites identified in the previous section. The work performed in this task included (a) collecting mobile LiDAR reflectivity measurements for the 2019 test sites, (b) applying the automated algorithm to the collected data to identify surface changes and estimate binder application rate adjustments, (c) comparing the estimated rates to the actual shot rates, (d) visually evaluating and documenting the performance of the sections and drawing a conclusion as to the accuracy of the automated method, and (e) using the lessons learned from the test sites to tweak the algorithm to provide better performance.

2019 BINDER APPLICATION RATE ADJUSTMENT

In general, the LTWPs and RTWPs suggest a higher change in binder rate than the BTWPs, and use of the average binder adjustment in the LTWP and RTWP for every 1-mile section in each project was recommended by researchers. However, among all six projects, around 10 percent of test sections indicate variable-rate nozzles are required for the roadways. Therefore, based on a detailed analysis, researchers suggest that when the difference in median rate between the LTWP and RTWP is greater than 0.03, the use of the average binder adjustment in the LTWP and RTWP for a 1-mile roadway is not feasible and a variable-rate nozzle is highly recommended. Surface conditions were validated by the researchers using the HDV system. Table 11 to Table 13 present the recommended binder adjustment, recommended shot rates, and actual shot rates for selected sections of FM 2095 EB, FM 1331 EB, and FM 1915 SB.

Table 11. Binder Rate Adjustment Recommended for the First 5 Miles of FM 2095 EB.

Section	Recommended Binder Adjustment (gal/sy)	Recommended Shot Rate (gal/sy)	Actual Shot Rate (gal/sy)	Expected Surface Condition
1st 1-mile	-0.05	0.35	0.37/0.38	SFB
2nd 1-mile	-0.04	0.36	0.38/0.43	SFB/FB
3rd 1-mile	-0.02	0.38	0.43/0.40	FB/SFB
4th 1-mile	-0.01	0.39	0.40/0.42	G/SFB
5th 1-mile	-0.02	0.38	0.42/0.39	SFB/G

Note: SFB: Slightly Flushed/Bleeding; FB: Flushed/Bleeding; G: Good.

Table 12. Binder Rate Adjustment Recommended for the First 3 Miles of FM 1331 EB.

Section	Recommended Binder Adjustment (gal/sy)	Recommended Shot Rate (gal/sy)	Actual Shot Rate (gal/sy)	Expected Surface Condition
1st 1-mile	-0.02	0.41	0.39/0.43	SD/SFB
2nd 1-mile	0.02	0.45	0.43/0.38	SD/D
3rd 1-mile	-0.02	0.41	0.38	SD

Note: SD: Slightly Dry; D: Dry.

Table 13. Binder Rate Adjustment Recommended for the First 5 Miles of FM 1915 SB.

Section	Recommended Binder Adjustment (gal/sy)	Recommended Shot Rate (gal/sy)	Actual Shot Rate (gal/sy)	Expected Surface Condition
1st 1-mile	0	0.47	0.47	G
2nd 1-mile	0.02	0.49	0.47/0.43	SD/D
3rd 1-mile	0.03	0.50	0.43/0.45	D
4th 1-mile	0.01/0.05[a]	0.48/0.52	0.45/0.44	SD/D
5th 1-mile	0.04	0.51	0.44/0.45	D

[a] Variable-rate nozzles recommended.

FM 2095 EB—A Rural Two-Lane Highway with a Low/Moderate ADT

Based on the comparison between recommended shot rate and actual shot rate (the third and fourth column in Table 11), the expected surface condition is provided in the fifth column in Table 11. It is expected that the surface condition might be good or just slightly flushed/bleeding since the actual shot rate is close to the recommended rate. Although the actual shot rate is higher than the recommended rate, flushing or bleeding might appear on the surface. These expected surface conditions were evaluated using an HDV system, and Figure 12 shows example sections of the surface conditions on FM 2095 EB.

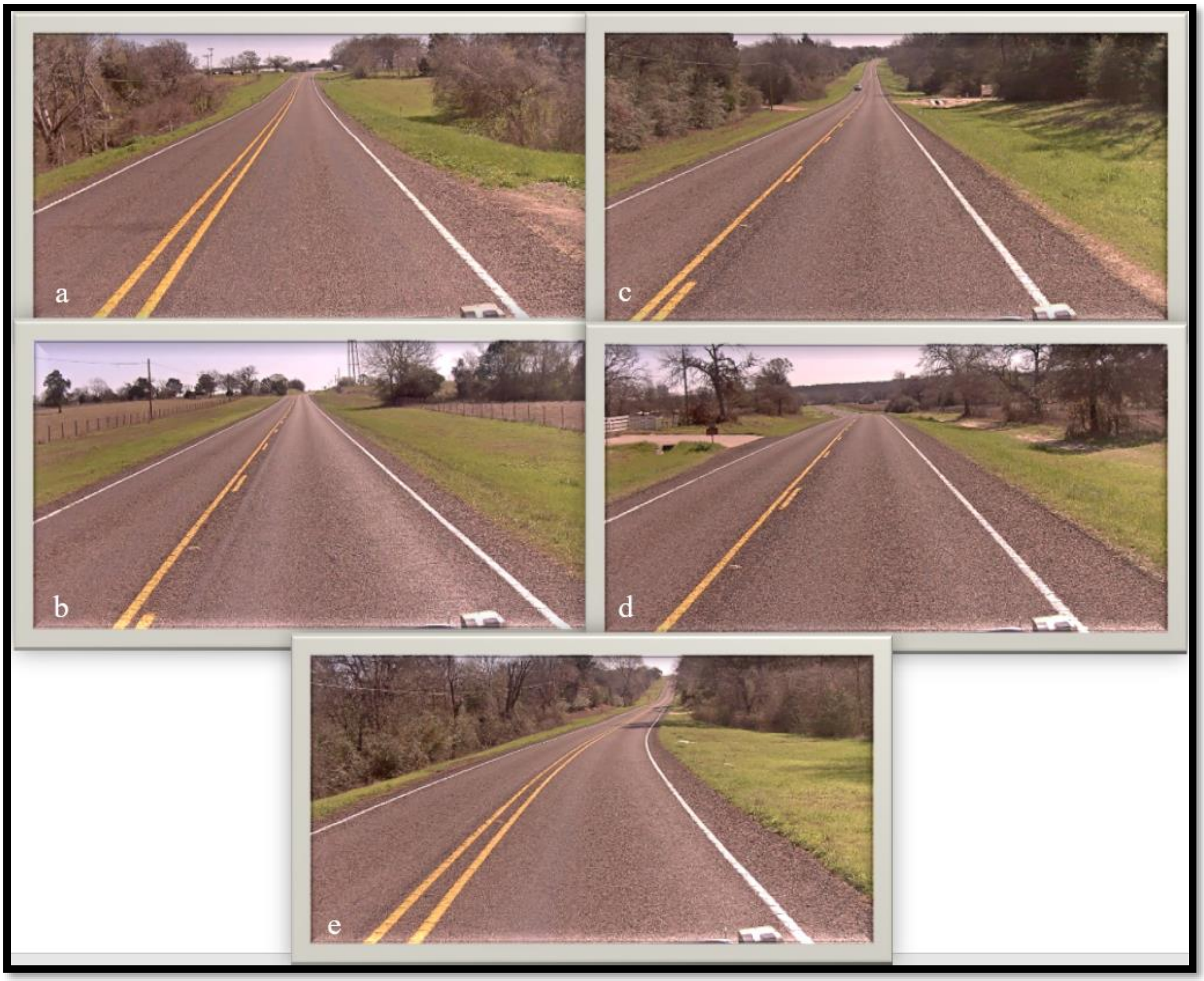


Figure 12. FM 2095 EB Surface Conditions: (a) First 1-Mile, (b) Second 1-Mile, (c) Third 1-Mile, (d) Fourth 1-Mile, and (e) Fifth 1-Mile Section.

FM 1311 EB—A Rural Two-Lane Highway with a Low/Moderate ADT

Based on the comparison between recommended shot rate and actual shot rate (the third and fourth column in Table 13), the expected surface condition is provided in the fifth column in Table 13. It is expected that the majority surface condition might be slightly dry/loose rock since the actual shot rate is lower than the recommended rate. These expected surface conditions were evaluated using an HDV system, and Figure 13 shows example sections of the surface conditions on FM 1311 EB.

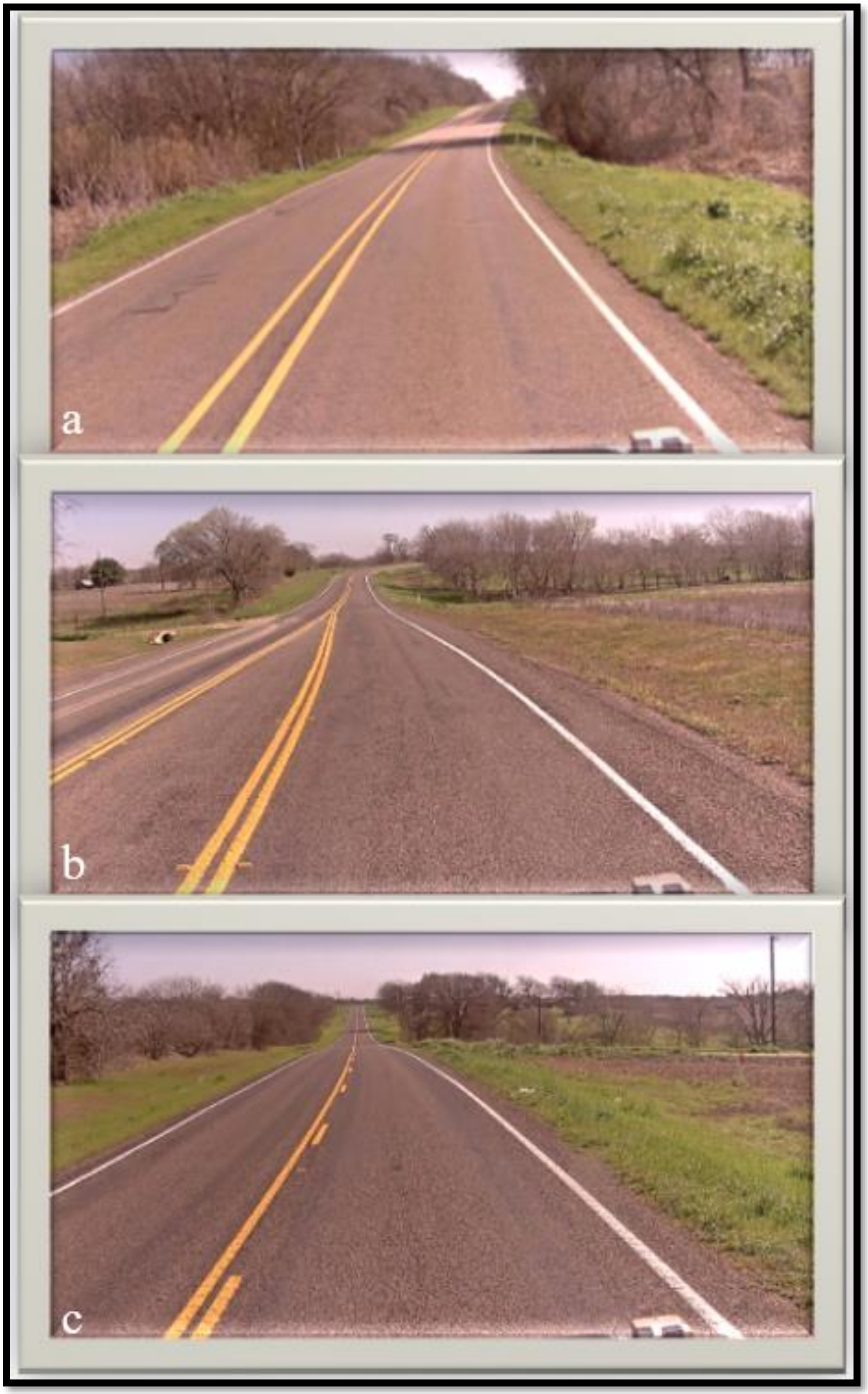


Figure 13. FM 1311 EB Surface Conditions: (a) First 1-Mile, (b) Second 1-Mile, and (c) Third 1-Mile Section.

FM 1915 SB—A Rural Two-Lane Highway with a Low ADT

Based on the comparison between recommended shot rate and actual shot rate (the third and fourth column in Table 13), the expected surface condition is provided in the fifth column in Table 13. It is expected that the majority surface condition might be slightly dry/rock loose since the actual shot rate is lower than the recommended rate. These expected surface conditions were evaluated using the HDV system, and Figure 14 shows example sections of the surface conditions on FM 1915 SB.

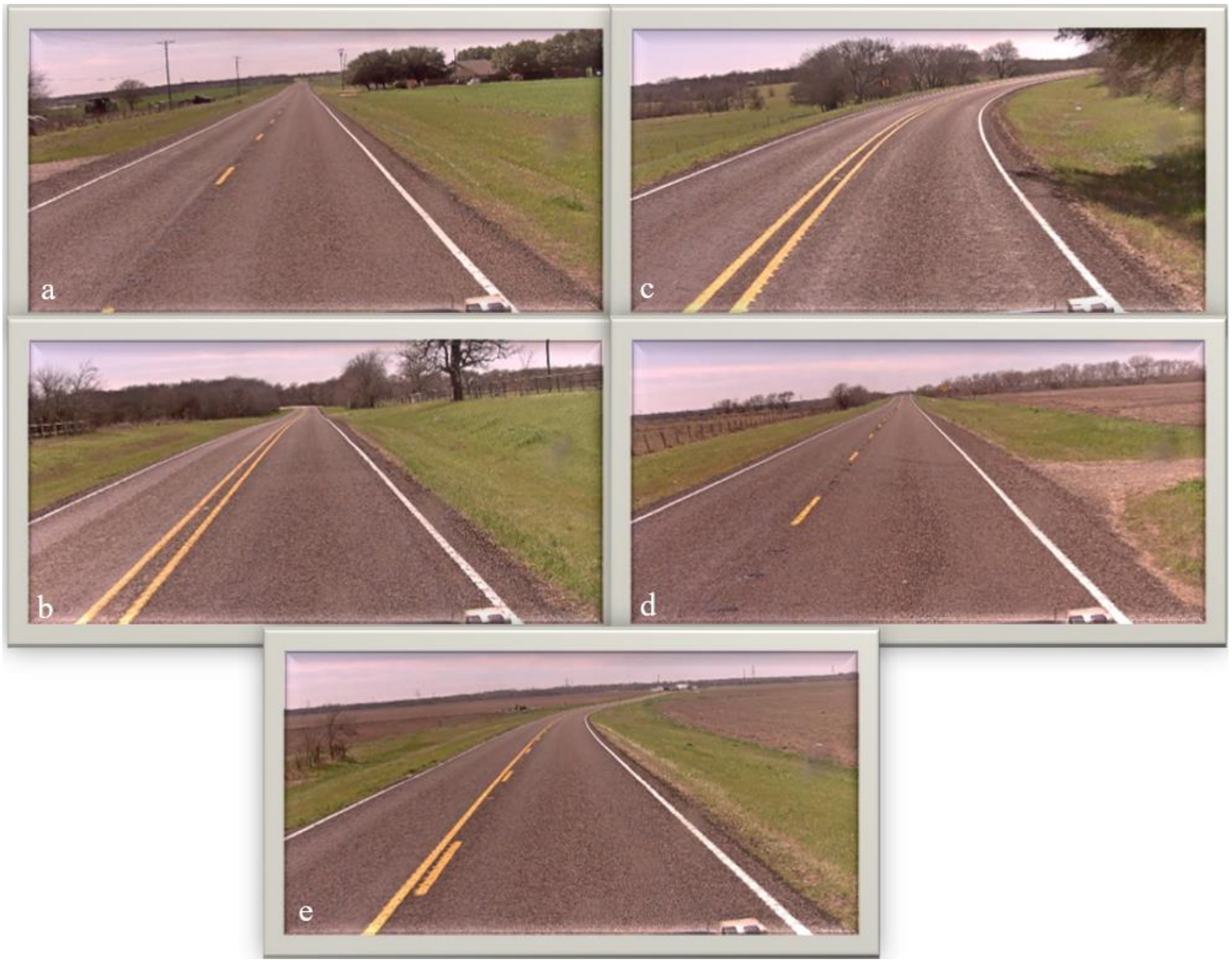


Figure 14. FM 1915 SB Surface Conditions: (a) First 1-Mile, (b) Second 1-Mile, (c) Third 1-Mile, (d) Fourth 1-Mile, and (e) Fifth 1-Mile Section.

2019 CASE STUDY SUMMARY

Applying the automated algorithm to the collected data using LiDAR can identify surface changes and estimate binder application rate adjustments. In general, the expected surface conditions based on the comparisons between actual and predicted shot rates were validated and matched up well with the observations from the HDV system.

CHAPTER 4: 2020 CASE STUDIES

OVERVIEW

The 2020 case studies had five test locations per district in each of the three participating districts (Bryan, Brownwood, and Waco). Table 14 contains the test locations, and Figure 15 through Figure 17 contain the location maps of the test sites. Researchers collected reflectivity data on the selected roadways, applied the algorithm, and provided the districts with suggested shot rates.

Table 14. 2020 Test Sites.

Project ID	Ref No	Hwy	Project Length	County	From Limit	To Limit
0057-03-042, etc.						
011604105	3	SH 21	1.382	Brazos	PLEASANT HILL RD.	FM 2818
131601074	7	FM 1179	6.540	Brazos	SH 6	SH 47
005002111	1	SH 6	12.997	Brazos	SH 6 East Frontage Road (EFR) @ SH 40	.5 MI N OF GRIMES CO. LINE
005002112	2	SH 6	12.418	Brazos	SH 6 West Frontage Road (WFR) @ SH 40	1.1 MI N OF GRIMES CO. LINE
059901010	6	SH 308	1.328	Brazos	SULPHER SPRINGS RD.	FM 60
0274-01-035, etc.						
004903069	8	SH 6	8.944	Falls	FM 2307	BIG CREEK
004903068	9	SH 6	5.932	Falls	MCLENNAN CO. LINE	FM 2307
075205030	12	FM 147	11.49	Falls	SH 6	LIMESTONE CO. LINE
080801060	11	FM 413	6.885	Falls	SH 6	FM 1373
081901028	10	FM 431	5.729	Falls	US 77	FM 2027
0186-02-019, etc.						
025104027	9	US 281	10.349	Lampasas	CORYELL C/L	ADAMSVILLE
313103012	46	FM 2657	2.732	Lampasas	FM 2808	BURNET C/L
219901014	39	FM 2313	5.951	Lampasas	FM 580	US 190
027205032	13	US 190	10.903	Lampasas	SAN SABA C/L	US 183
278601016	46	FM 2657	1.747	Lampasas	US 190	FM 2808
278601017	44	FM 2808	4.444	Lampasas	US 190	FM 2657

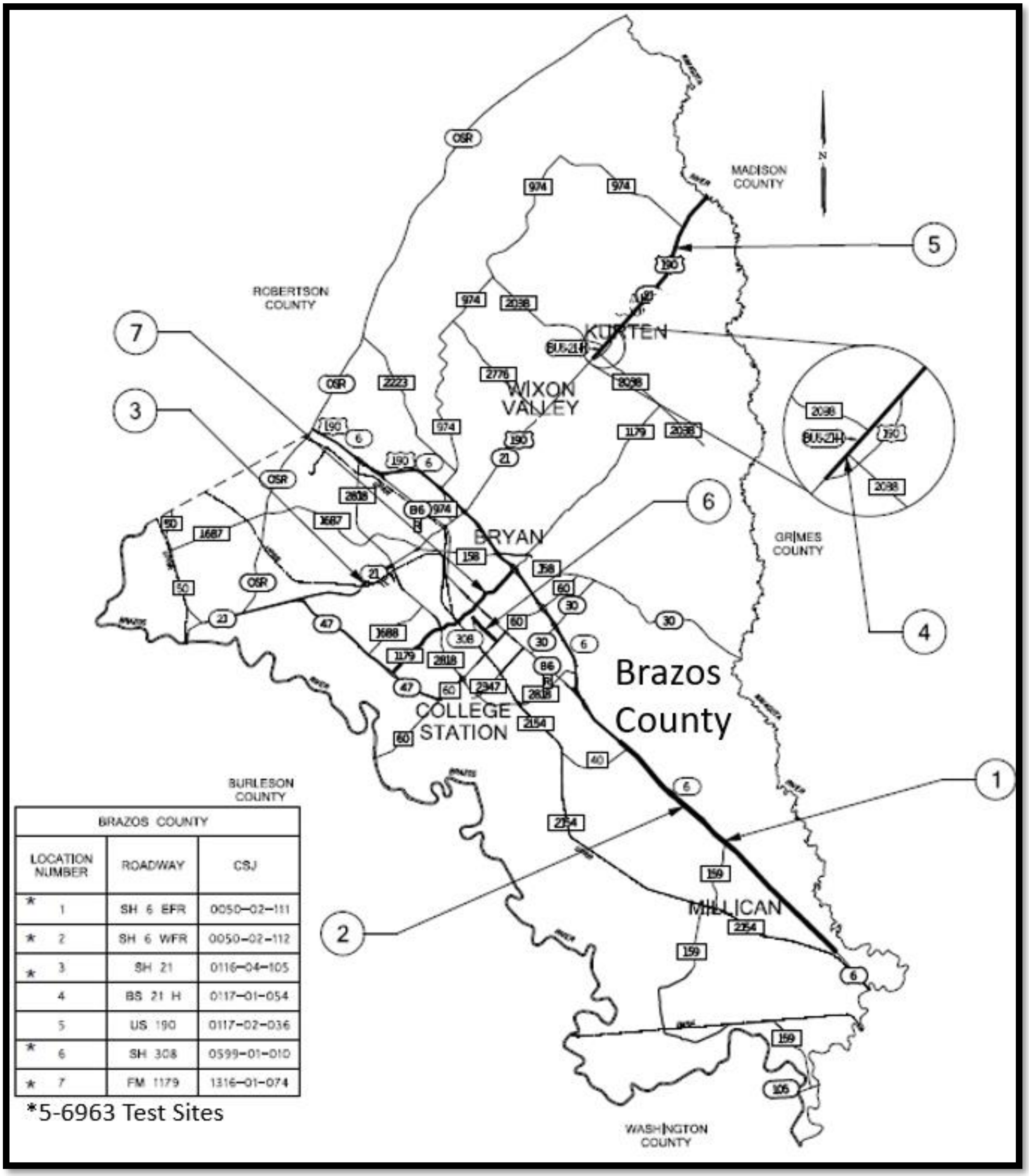
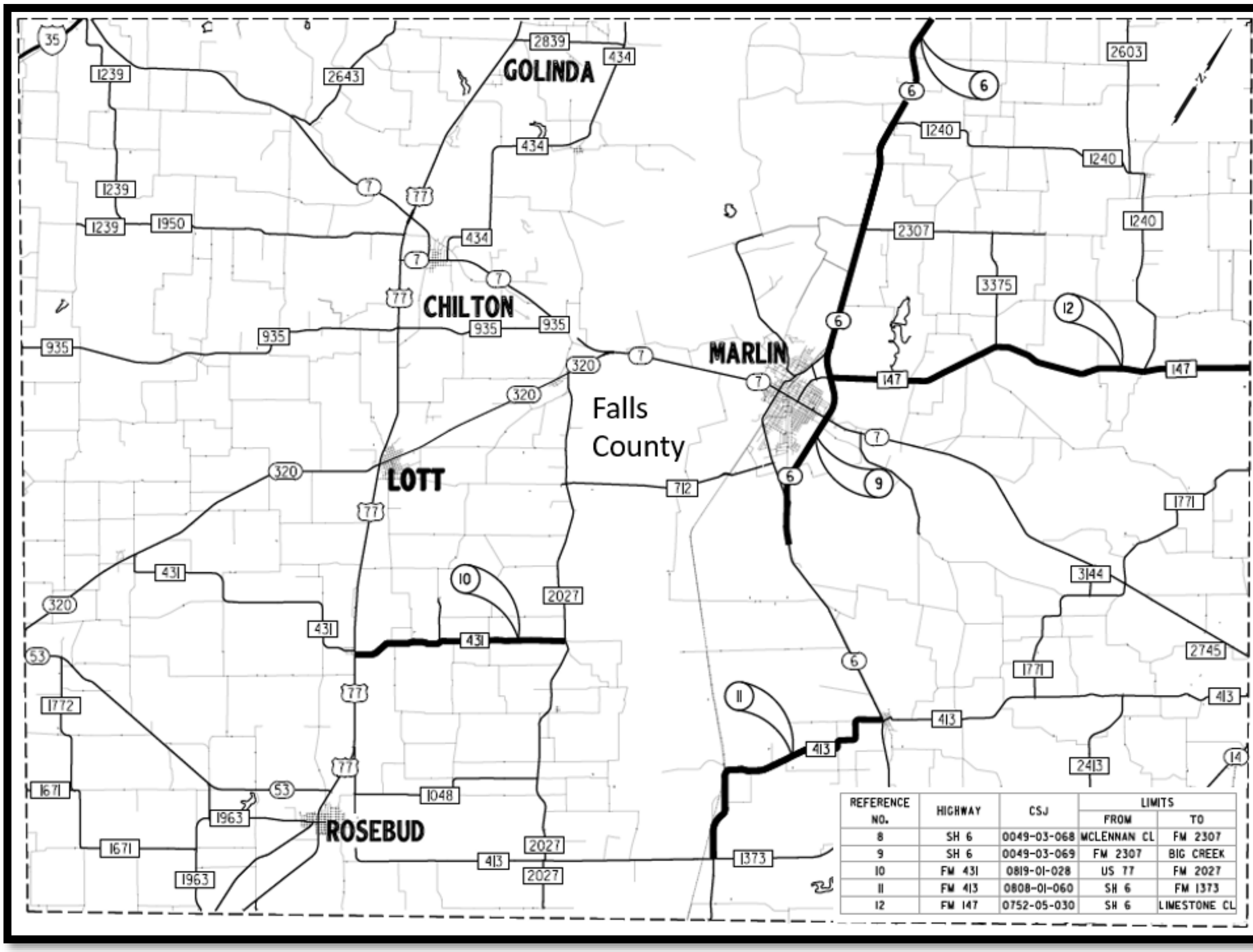


Figure 15. 2020 Bryan District Test Sites.



REFERENCE NO.	HIGHWAY	CSJ	LIMITS	
			FROM	TO
8	SH 6	0049-03-068	MCLENNAN CL	FM 2307
9	SH 6	0049-03-069	FM 2307	BIG CREEK
10	FM 431	0819-01-028	US 77	FM 2027
11	FM 413	0808-01-060	SH 6	FM 1373
12	FM 147	0752-05-030	SH 6	LIMESTONE CL

Figure 16. 2020 Waco District Test Sites.

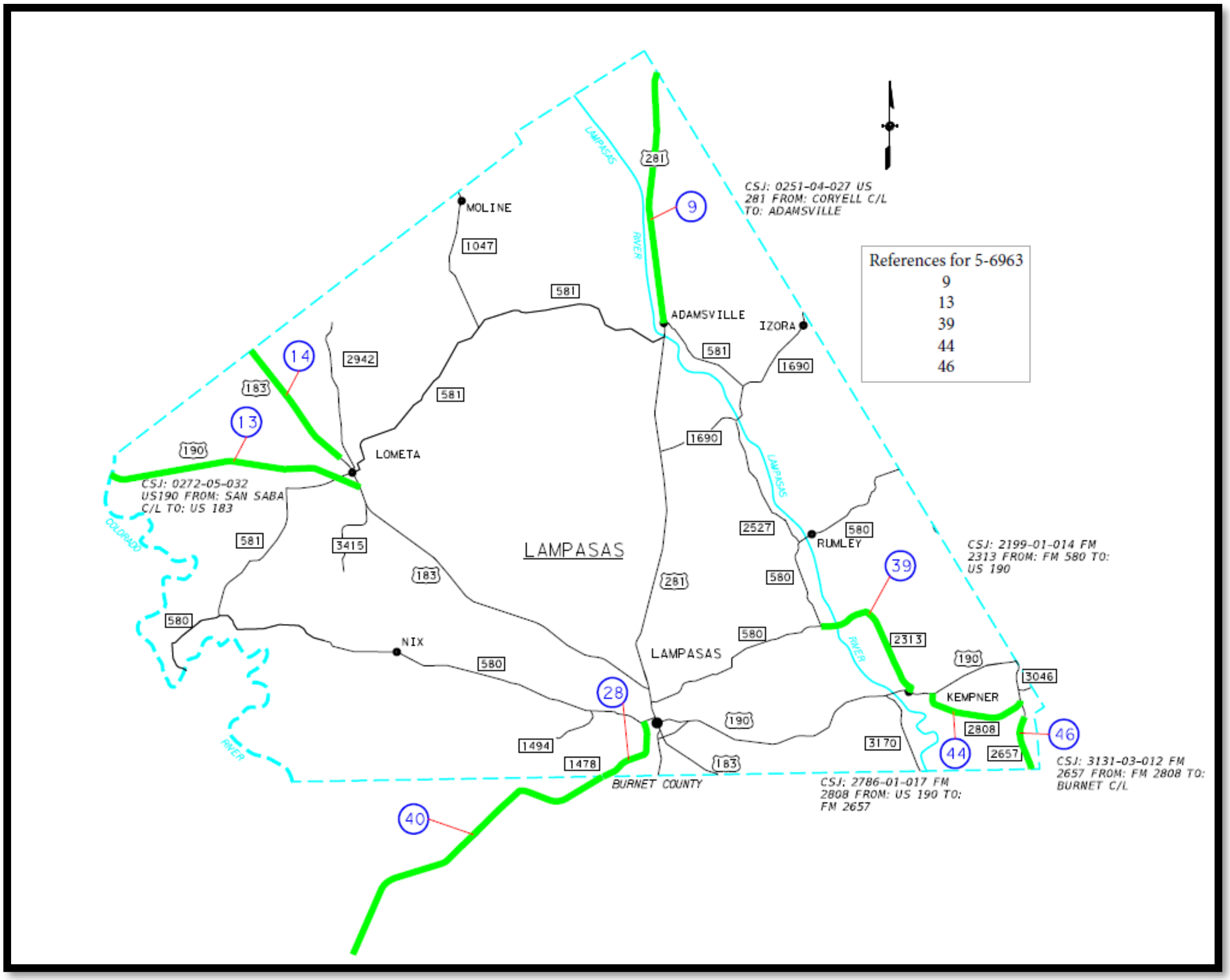


Figure 17. 2020 Brownwood District Test Sites.

BINDER APPLICATION RATE ADJUSTMENT

The LiDAR data were collected one to two months before construction in order to have time to analyze the data. Researchers worked with the districts before and during construction to estimate shot rates. All projects were completed. The design method developed in TxDOT research project 0-6989 was used to establish the starting rates based on the aggregate size (note: not all aggregate was tested; some sections were estimated based on previous testing of similar aggregate) and the traffic data. Once these initial rates were determined based on the aggregate properties and traffic, the LiDAR data analysis was used to estimate pavement condition adjustments.

The reflectivity data generated by the LiDAR are a measure of the signal power returned to the laser after bouncing off the target surface. Three areas of interest (i.e., LTWP, BTWP, and RTWP) 3 ft wide were generated by processing the data from the data collection lane. Grids with 1-ft longitudinal and 4-inch transverse spacing were formed for the collected reflectivity data.

The data were then grouped into 100-ft lengths to match with the length of a reference unit (as expected condition). The returned signal intensity was converted to a 0–255 red, green, blue (RGB) scale in postprocessing software (Road Doctor 3). A less reflective surface returns a lower value. In order to reduce the RGB scale, a k-means clustering algorithm was applied, and then the data were structured into a directed acyclic graph for the systematic description of the pavement surface condition. Finally, binder rate adjustments were generated by comparing the existing surface and the as-expected condition. If the existing surface was a seal coat, a reference unit of 300 ft (3 stations) of a seal coat was chosen to provide reflective values of the desired surface. Because the existing roadway contained a hot mix asphalt (HMA) surface, a reference unit of 300-ft HMA was chosen as the desired surface.

Bryan District

The aggregate used on the Bryan District project was lightweight and had been previously tested in TxDOT research project 0-6989. Since the properties were similar to the material tested, further aggregate tests were not performed. All projects used asphalt rubber (AR) binder and lightweight Grade 4 precoated aggregate. The aggregate spread rate was estimated at 1 cy per 124 sy. Table 15 through Table 19 contain a summary of the overall estimated binder rates with the proposed adjustments.

Table 15. Bryan District SH 6 WFR Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.61	0.48	
2	WFR SB Outside Lane (OL)	0–1	0.53	-0.03	-0.01	0.49	no	okay	okay	0.49
		1–2	0.57	0.01	-0.01	0.57	no	okay	okay	0.57
		2–3	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		3–4	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		4–5	0.57	0.01	0.01	0.59	no	okay	okay	0.59
		5–6	0.57	0.01	0.01	0.59	no	okay	okay	0.59
		6–7	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		7–8	0.57	0.01	0.04	0.62	no	use Max.	okay	0.61
		8–9	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		9–10	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		10–11	0.57	0.01	0.05	0.63	no	use Max.	okay	0.61
		11–12	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		12–end	0.57	0.01	0	0.58	no	okay	okay	0.58
	WFR SB Inside Lane (IL)	0–1	0.53	-0.03	0.01	0.51	no	okay	okay	0.51
		1–2	0.57	0.01	0	0.58	no	okay	okay	0.58
		2–3	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		3–4	0.57	0.01	0.01	0.59	no	okay	okay	0.59
		4–5	0.57	0.01	0.01	0.59	no	okay	okay	0.59
		5–6	0.57	0.01	0.01	0.59	no	okay	okay	0.59
		6–7	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		7–8	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		8–9	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		9–10	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		10–11	0.57	0.01	0.05	0.63	no	use Max.	okay	0.61
		11–12	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		12–end	0.57	0.01	0	0.58	no	okay	okay	0.58

[a] Consider Transverse Variable Asphalt Rates (TVAR).

Table 16. Bryan District SH 6 EFR Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.61	0.48	
1	EFR NB OL	0–1	0.57	0.01	0.01	0.59	no	okay	okay	0.59
		1–2	0.57	0.01	0.01	0.59	no	okay	okay	0.59
		2–3	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		3–4	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		4–5	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		5–6	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		6–7	0.57	0.01	0.05	0.63	no	use Max.	okay	0.61
		7–8	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		8–9	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		9–10	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		10–11	0.57	0.01	0.01	0.59	no	okay	okay	0.59
		11–12	0.57	0.01	-0.01	0.57	no	okay	okay	0.57
		12–13	0.57	0.01	-0.01	0.57	no	okay	okay	0.57
		13–end	0.53	-0.03	-0.02	0.48	no	okay	okay	0.48
	EFR NB IL	0–1	0.57	0.01	0	0.58	no	okay	okay	0.58
		1–2	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		2–3	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		3–4	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		4–5	0.57	0.01	0.03	0.61	no	okay	okay	0.61
		5–6	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		6–7	0.57	0.01	0.04	0.62	no	use Max.	okay	0.61
		7–8	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		8–9	0.57	0.01	0.04	0.62	no	use Max.	okay	0.61
		9–10	0.57	0.01	0.02	0.60	no	okay	okay	0.60
		10–11	0.57	0.01	0.01	0.59	no	okay	okay	0.59
		11–12	0.57	0.01	0	0.58	no	okay	okay	0.58
		12–13	0.57	0.01	0	0.58	no	okay	okay	0.58
		13–end	0.53	-0.03	-0.01	0.49	no	okay	okay	0.49

[a] Consider TVAR.

Table 17. Bryan District SH 21 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.61	0.48	
3	EB OL	0–1	0.53	-0.03	0.04	0.54	no	okay	okay	0.54
		1–end	0.53	-0.03	0.04	0.50	no	okay	okay	0.50
	EB IL	0–1	0.53	-0.03	0.06	0.56	no	okay	okay	0.56
		1–end	0.53	-0.03	0.05	0.55	no	okay	okay	0.55
	WB OL	0–1	0.53	-0.03	0.01	0.51	no	okay	okay	0.51
		1–end	0.53	-0.03	0.01	0.50	no	okay	okay	0.50
	WB IL	0–1	0.53	-0.03	0.04	0.54	no	okay	okay	0.54
		1–end	0.53	-0.03	0.05	0.50	no	okay	okay	0.50
	Center Turn Lane (CTL)	0–1	0.58	0.01	0.05	0.64	no	use Max.	okay	0.61
		1–end	0.58	0.01	0.06	0.65	no	use Max.	okay	0.61

[a] Consider TVAR.

Table 18. Bryan District SH 308 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.61	0.48	
6	SB OL	0–1	0.53	-0.03	-0.03	0.47	no	okay	Use Min.	0.48
		1–end	0.53	-0.03	-0.02	0.50	no	okay	okay	0.50
	SB IL	0–1	0.53	-0.03	-0.04	0.46	yes	okay	Use Min.	0.48
		1–end	0.53	-0.03	-0.05	0.45	yes	okay	Use Min.	0.48
	NB OL	0–1	0.53	-0.03	-0.03	0.47	no	okay	Use Min.	0.48
		1–end	0.53	-0.03	-0.04	0.46	yes	okay	Use Min.	0.48
	NB IL	0–1	0.53	-0.03	-0.04	0.46	yes	okay	Use Min.	0.48
		1–end	0.53	-0.03	-0.06	0.44	yes	okay	Use Min.	0.48

[a] Consider TVAR.

Table 19. Bryan District FM 1179 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	[1]TVAR	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.61	0.48	gal/sy
7	EB 2 Lane Section	0–1	0.53	-0.03	-0.01	0.49	no	okay	okay	0.49
		1–end	0.53	-0.03	-0.04	0.50	yes	okay	okay	0.50
	WB 2 Lane Section	0–1	0.53	-0.03	-0.03	0.47	no	okay	Use Min.	0.48
		1–end	0.53	-0.03	-0.02	0.50	no	okay	okay	0.50
	EB OL Seal Coat Surface (SCS)	0–1	0.53	-0.03	-0.02	0.48	no	okay	okay	0.48
		1–end	0.53	-0.03	-0.05	0.50	yes	okay	okay	0.50
	EB IL SCS	0–1	0.53	-0.03	-0.02	0.48	no	okay	okay	0.48
		1–end	0.53	-0.03	-0.03	0.47	no	okay	Use Min.	0.48
	WB OL SCS	0–1	0.53	-0.03	-0.03	0.47	no	okay	Use Min.	0.48
		1–end	0.53	-0.03	-0.02	0.50	no	okay	okay	0.50
	WB IL SCS	0–1	0.53	-0.03	-0.04	0.46	yes	okay	Use Min.	0.48
		1–end	0.53	-0.03	-0.03	0.47	no	okay	Use Min.	0.48
	EB OL Hot Mix Asphalt (HMA) Surface	0–1	0.53	-0.03	0.03	0.53	no	okay	okay	0.53
		1–2	0.53	-0.03	0.04	0.54	no	okay	okay	0.54
		2–3	0.53	-0.03	0.03	0.53	no	okay	okay	0.53
		3–end	0.53	-0.03	0.04	0.54	no	okay	okay	0.54
	EB IL HMA Surface	0–1	0.53	-0.03	0.02	0.52	no	okay	okay	0.52
		1–2	0.53	-0.03	0.05	0.55	no	okay	okay	0.55
		2–3	0.53	-0.03	0.04	0.54	no	okay	okay	0.54
		3–end	0.53	-0.03	0.04	0.54	no	okay	okay	0.54
	WB OL HMA Surface	0–1	0.53	-0.03	0.04	0.54	no	okay	okay	0.54
		1–2	0.53	-0.03	0.05	0.55	no	okay	okay	0.55
		2–3	0.53	-0.03	0.05	0.55	no	okay	okay	0.55
		3–end	0.53	-0.03	0.02	0.52	no	okay	okay	0.52
	WB IL HMA Surface	0–1	0.53	-0.03	0.03	0.53	no	okay	okay	0.53
		1–2	0.53	-0.03	0.05	0.55	no	okay	okay	0.55
		2–3	0.53	-0.03	0.05	0.55	no	okay	okay	0.55
		3–end	0.53	-0.03	0.01	0.51	no	okay	okay	0.51

[a] Consider TVAR.

Waco District

The aggregate used on the Waco District project was from two suppliers, and the material was not tested; therefore, the rates were estimated based on a similar aggregate. All projects used hot applied asphalt, such as AC15P or AC20-5TR, and a Grade 3 or Grade 4 precoated aggregate. Table 20 through Table 24 contain a summary of the overall estimated binder rates with the proposed adjustments.

Table 20. Waco District FM 413 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.47	0.38	
11	EB	0–1	0.39	0.04	-0.03	0.40	no	okay	okay	0.40
		1–2	0.39	0.04	-0.05	0.38	yes	okay	okay	0.38
		2–3	0.39	0.04	-0.04	0.39	yes	okay	okay	0.39
		3–4	0.39	0.04	-0.04	0.39	yes	okay	okay	0.39
		4–5	0.39	0.04	-0.05	0.38	yes	okay	okay	0.38
		5–6	0.39	0.04	-0.03	0.40	no	okay	okay	0.40
		6–end	0.39	0.04	-0.05	0.38	yes	okay	okay	0.38
	WB	0–1	0.39	0.04	-0.07	0.36	yes	okay	Use Min.	0.38
		1–2	0.39	0.04	-0.05	0.38	yes	okay	okay	0.38
		2–3	0.39	0.04	-0.03	0.40	no	okay	okay	0.40
		3–4	0.39	0.04	-0.04	0.39	yes	okay	okay	0.39
		4–5.5	0.39	0.04	-0.02	0.41	no	okay	okay	0.41
		5.5–6.5	0.39	0.04	-0.04	0.39	yes	okay	okay	0.39
		6.5–end	0.39	0.04	-0.05	0.38	yes	okay	okay	0.38
Aggregate Grade		3	Aggregate Spread Rate			108	sy:cy	Binder		AC

[a] Consider TVAR.

Table 21. Waco District SH 6 SB Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.38	0.29	
8 & 9	SB OL	0–1	0.32	-0.03	0.04	0.33	no	okay	okay	0.33
		1–2	0.32	-0.03	0.07	0.36	no	okay	okay	0.36
		2–3	0.32	-0.03	0.04	0.33	no	okay	okay	0.33
		3–4	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		4–5	0.32	-0.03	0.03	0.32	no	okay	okay	0.32
		5–6	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
		6–7	0.32	-0.03	0.04	0.33	no	okay	okay	0.33
		7–8	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
		8–9	0.32	-0.03	0.04	0.33	no	okay	okay	0.33
		9–10.5	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
		10.5–11.5	0.32	-0.03	0.04	0.33	no	okay	okay	0.33
		11.5–12.5	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		12.5–13.5	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
		13.5–14.5	0.32	-0.03	0.04	0.33	no	okay	okay	0.33
		14.5–15.5	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
		15.5–end	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
	SB IL	0–1	0.33	-0.01	-0.02	0.30	no	okay	okay	0.30
		1–2	0.33	-0.01	-0.02	0.30	no	okay	okay	0.30
		2–3	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		3–4	0.33	-0.01	-0.02	0.30	no	okay	okay	0.30
		4–5	0.33	-0.01	-0.05	0.27	yes	okay	Use Min.	0.29
		5–6	0.33	-0.01	-0.05	0.27	yes	okay	Use Min.	0.29
		6–7	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		7–8	0.33	-0.01	-0.05	0.27	yes	okay	Use Min.	0.29
		8–9	0.33	-0.01	-0.03	0.29	no	okay	okay	0.29
		9–10.5	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		10.5–11.5	0.33	-0.01	-0.03	0.29	no	okay	okay	0.29
		11.5–12.5	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		12.5–13.5	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		13.5–14.5	0.33	-0.01	-0.03	0.29	no	okay	okay	0.29
		14.5–15.5	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		15.5–end	0.33	-0.01	-0.02	0.30	no	okay	okay	0.30
	Outside Shoulder (SHLD)		0.38	0.05		0.43	no	use Max.	okay	0.38
Grade		4	Aggregate Spread Rate			124	sy:cy	Binder		AC

[a] Consider TVAR.

Table 22. Waco District SH 6 NB Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.38	0.29	
8 & 9	NB OL	0–1	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		1–2	0.32	-0.03	0.07	0.36	no	okay	okay	0.36
		2–3	0.32	-0.03	0.07	0.36	no	okay	okay	0.36
		3–4	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
		4–5	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		5–6	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		6–7	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		7–8	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		8–9	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		9–10	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		10–11	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		11–12	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
		12–13	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		13–14	0.32	-0.03	0.06	0.35	no	okay	okay	0.35
		14–15	0.32	-0.03	0.07	0.36	no	okay	okay	0.36
		15–16	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
		16–end	0.32	-0.03	0.05	0.34	no	okay	okay	0.34
	NB IL	0–1	0.33	-0.01	-0.02	0.30	no	okay	okay	0.30
		1–2	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		2–3	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		3–4	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		4–5	0.33	-0.01	-0.05	0.27	yes	okay	Use Min.	0.29
		5–6	0.33	-0.01	-0.06	0.26	yes	okay	Use Min.	0.29
		6–7	0.33	-0.01	-0.05	0.27	yes	okay	Use Min.	0.29
		7–8	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		8–9	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		9–10	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		10–11	0.33	-0.01	-0.05	0.27	yes	okay	Use Min.	0.29
		11–12	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		12–13	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		13–14	0.33	-0.01	-0.04	0.28	yes	okay	Use Min.	0.29
		14–15	0.33	-0.01	-0.06	0.26	yes	okay	Use Min.	0.29
		15–16	0.33	-0.01	-0.06	0.26	yes	okay	Use Min.	0.29
		16–end	0.33	-0.01	-0.05	0.27	yes	okay	Use Min.	0.29
	Outside SHLD		0.38	0.05		0.43	no	use Max.	okay	0.38
Grade		4	Aggregate Spread Rate			124	sy:cy	Binder		AC

[a] Consider TVAR.

Table 23. Waco District FM 147 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.4	0.32	
12	EB	0–1	0.38	0.03	-0.05	0.36	yes	okay	okay	0.36
		1–2	0.38	0.03	-0.04	0.37	yes	okay	okay	0.37
		2–3	0.38	0.03	-0.04	0.37	yes	okay	okay	0.37
		3–4	0.38	0.03	-0.04	0.37	yes	okay	okay	0.37
		4–5	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		5–6	0.38	0.03	-0.02	0.39	no	okay	okay	0.39
		6–7	0.38	0.03	-0.02	0.39	no	okay	okay	0.39
		7–8	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		8–9	0.38	0.03	-0.02	0.39	no	okay	okay	0.39
		9–10.5	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		10.5–11.5	0.38	0.03	-0.05	0.36	yes	okay	okay	0.36
		11.5–end	0.38	0.03	-0.04	0.37	yes	okay	okay	0.37
	WB	0–1	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		1–2	0.38	0.03	-0.05	0.36	yes	okay	okay	0.36
		2–3	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		3–4	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		4–5.5	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		5.5–6.5	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		6.5–7.5	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		7.5–8.5	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		8.5–9.5	0.38	0.03	-0.03	0.38	no	okay	okay	0.38
		9.5–10.5	0.38	0.03	-0.04	0.37	yes	okay	okay	0.37
		10.5–11.5	0.38	0.03	-0.04	0.37	yes	okay	okay	0.37
		11.5–end	0.38	0.03	-0.05	0.36	yes	okay	okay	0.36
Aggregate Grade		4	Aggregate Spread Rate			124	sy:cy	Binder		AC

[a] Consider TVAR.

Table 24. Waco District FM 431 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.41	0.3	
10	EB	0–1	0.39	0.04	-0.02	0.41	no	okay	okay	0.41
		1–2	0.39	0.04	-0.03	0.40	no	okay	okay	0.40
		2–3	0.39	0.04	-0.03	0.40	no	okay	okay	0.40
		3–4	0.39	0.04	-0.03	0.40	no	okay	okay	0.40
		4–5	0.39	0.04	-0.04	0.39	yes	okay	okay	0.39
		5–end	0.39	0.04	-0.05	0.38	yes	okay	okay	0.38
	WB	0–1	0.39	0.04	-0.04	0.39	yes	okay	okay	0.39
		1–2	0.39	0.04	-0.03	0.40	no	okay	okay	0.40
		2–3	0.39	0.04	-0.05	0.38	yes	okay	okay	0.38
		3–4	0.39	0.04	-0.03	0.40	no	okay	okay	0.40
		4–5	0.39	0.04	-0.03	0.40	no	okay	okay	0.40
		5–end	0.39	0.04	-0.04	0.39	yes	okay	okay	0.39
Aggregate Grade		3	Aggregate Spread Rate			124	sy:cy	Binder		AC

[a] Consider TVAR.

Brownwood District

The researchers provided additional assistance by performing aggregate testing to establish the initial binder and aggregate application rates. Both Grade 3 and 4 precoated aggregate were used on the project. The testing results are shown in Table 25. Once these initial rates were determined based on the aggregate properties, the LiDAR data analysis was used to estimate pavement condition adjustments. Table 26 through Table 30 contain a summary of the overall estimated binder rates with the proposed adjustments.

Table 25. Aggregate Test Results.

	Aggregate	
Test Description	**Grade 3**	**Grade 4**
Dry Loose Unit Weight, lb/ft^3	89.83	91.45
Spec Gravity	2.584	2.674
Matt Thickness, inch	0.315	0.249
Flakiness Index, %	8	10

Table 26. Brownwood District FM 2313 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.31	0.21	
46	NB	0–1	0.28	-0.01	0.01	0.28	no	okay	okay	0.28
	NB	1–2	0.28	-0.01	0	0.27	no	okay	okay	0.27
	NB	2–3	0.28	-0.01	0.01	0.28	no	okay	okay	0.28
	NB	3–4	0.28	-0.01	0	0.27	no	okay	okay	0.27
	NB	4–5	0.28	-0.01	0	0.27	no	okay	okay	0.27
	NB	5–6	0.28	-0.01	0.01	0.28	no	okay	okay	0.28
	NB	6–end	0.28	-0.01	0.02	0.29	no	okay	okay	0.29
	SB	0–1	0.28	-0.01	-0.01	0.26	no	okay	okay	0.26
	SB	1–2	0.28	-0.01	0.01	0.28	no	okay	okay	0.28
	SB	2–3	0.28	-0.01	0	0.27	no	okay	okay	0.27
	SB	3–4	0.28	-0.01	0	0.27	no	okay	okay	0.27
	SB	4–5	0.28	-0.01	0.02	0.29	no	okay	okay	0.29
	SB	5–6	0.28	-0.01	0	0.27	no	okay	okay	0.27
	SB	6–end	0.28	-0.01	0.02	0.29	no	okay	okay	0.29
	Wide SHLD		0.31	0.05	n/a	0.36	no	Use Max.	okay	0.31
Aggregate Grade		4	Aggregate Spread Rate			145	sy:cy	Binder		AC

[a] Consider TVAR.

Table 27. Brownwood District FM 2657 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.31	0.21	
46	SB OL	0–1	0.26	-0.03	-0.04	0.19	yes	okay	Use Min.	0.21
	SB OL	1–2	0.26	-0.03	-0.02	0.21	no	okay	okay	0.21
	SB OL	2–end	0.26	-0.03	0.03	0.26	no	okay	okay	0.26
	SB IL	0–end	0.27	-0.01	-0.05	0.21	yes	okay	okay	0.21
	NB OL	0–1	0.26	-0.03	0.04	0.27	no	okay	okay	0.27
	NB OL	1–2	0.26	-0.03	-0.01	0.22	no	okay	okay	0.22
	NB OL	2–end	0.26	-0.03	-0.03	0.20	no	okay	Use Min.	0.21
	NB IL	0–end	0.27	-0.01	-0.01	0.25	no	okay	okay	0.25
Grade		4	Aggregate Spread Rate			145	sy:cy	Binder		AC

[a] Consider TVAR.

Table 28. Brownwood District FM 2808 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.31	0.21	
44	EB	0–1	0.28	-0.01	-0.01	0.26	no	okay	okay	0.26
	EB	1–2	0.28	-0.01	-0.01	0.27	no	okay	okay	0.27
	EB	2–3	0.28	-0.01	0.01	0.28	no	okay	okay	0.28
	EB	3–4	0.28	-0.01	0	0.27	no	okay	okay	0.27
	EB	4–end	0.28	-0.01	0.01	0.28	no	okay	okay	0.28
	WB	0–1	0.28	-0.01	-0.03	0.24	no	okay	okay	0.24
	WB	1–2	0.28	-0.01	-0.02	0.25	no	okay	okay	0.25
	WB	2–3	0.28	-0.01	0.01	0.28	no	okay	okay	0.28
	WB	3–4	0.28	-0.01	0.01	0.28	no	okay	okay	0.28
	WB	4–end	0.28	-0.01	0.01	0.28	no	okay	okay	0.28
	Wide SHLD		0.31	0.04	n/a	0.35	no	Use Max.	okay	0.31
Grade		4	Aggregate Spread Rate			145	sy:cy	Binder		AC

[a] Consider TVAR.

Table 29. Brownwood District US 281 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.40	0.27	
9	SB	0–1	0.35	-0.03	0.03	0.35	no	okay	okay	0.35
		1–2	0.35	-0.03	-0.02	0.32	no	okay	okay	0.32
		2–3	0.35	-0.03	0.02	0.34	no	okay	okay	0.34
		3–4	0.35	-0.03	0.02	0.34	no	okay	okay	0.34
		4–5	0.35	-0.03	0	0.32	no	okay	okay	0.32
		5–6	0.35	-0.03	0.02	0.34	no	okay	okay	0.34
		6–7	0.35	-0.03	0.05	0.37	no	okay	okay	0.37
		7–8	0.35	-0.03	-0.02	0.30	no	okay	okay	0.30
		8–9	0.35	-0.03	0	0.32	no	okay	okay	0.32
		9–10	0.35	-0.03	-0.03	0.29	no	okay	okay	0.29
		10–end	0.35	-0.03	0.01	0.33	no	okay	okay	0.33
	NB	0–1	0.35	-0.03	0.03	0.35	no	okay	okay	0.35
		1–2	0.35	-0.03	0.01	0.33	no	okay	okay	0.33
		2–3	0.35	-0.03	-0.01	0.31	no	okay	okay	0.31
		3–4	0.35	-0.03	-0.05	0.27	yes	okay	Use Min.	0.27
		4–5	0.35	-0.03	0.04	0.36	no	okay	okay	0.36
		5–6	0.35	-0.03	0.03	0.35	no	okay	okay	0.35
		6–7	0.35	-0.03	-0.02	0.30	no	okay	okay	0.30
		7–8	0.35	-0.03	0.01	0.33	no	okay	okay	0.33
		8–9	0.35	-0.03	0	0.32	no	okay	okay	0.32
		9–10	0.35	-0.03	-0.03	0.29	no	okay	okay	0.29
		10–end	0.35	-0.03	0.05	0.37	no	okay	okay	0.37
	Wide SHLD		0.40	0.04	n/a	0.44		no	okay	0.40
	SB Pass Lane	0–1	0.37	0.00	0.02	0.39	no	okay	okay	0.39
		1–2	0.37	0.00	0.02	0.39	no	okay	okay	0.39
		2–end	0.37	0.00	0.01	0.38	no	okay	okay	0.38
	NB Pass Lane	0–1	0.37	0.00	0.02	0.39	no	okay	okay	0.39
		1–2	0.37	0.00	0	0.37	no	okay	okay	0.37
		2–3	0.37	0.00	-0.01	0.36	no	okay	okay	0.36
		3–4	0.37	0.00	0	0.37	no	okay	okay	0.37
		4–end	0.37	0.00	-0.02	0.35	no	okay	okay	0.35
Grade		3	Aggregate Spread Rate			114	sy:cy	Binder		AC

[a] Consider TVAR.

Table 30. Brownwood District US 190 Rate Summary.

Ref No.	Lane	Section	Design Rate Temp Adj.	Traffic Adj.	Est. LiDAR Data Adj.	Total Rate w/ Adj.	TVAR[a]	Max. Rate (gal/sy)	Min. Rate (gal/sy)	Proposed Rate (gal/sy)
		mile	gal/sy	gal/sy	gal/sy	gal/sy		0.31	0.21	
13	NB	0–1	0.27	-0.02	0.01	0.26	no	okay	okay	0.26
		1–2	0.27	-0.02	0.01	0.25	no	okay	okay	0.25
		2–3	0.27	-0.02	0	0.25	no	okay	okay	0.25
		3–4	0.27	-0.02	0.03	0.28	no	okay	okay	0.28
		4–5	0.27	-0.02	-0.01	0.24	no	okay	okay	0.24
		5–6	0.27	-0.02	-0.03	0.22	no	okay	okay	0.22
		6–7	0.27	-0.02	-0.02	0.23	no	okay	okay	0.23
		7–8	0.27	-0.02	-0.03	0.22	no	okay	okay	0.22
		8–9	0.27	-0.02	-0.02	0.23	no	okay	okay	0.23
		9–10	0.27	-0.02	-0.04	0.21	yes	okay	okay	0.21
		10–11	0.27	-0.02	0.03	0.28	no	okay	okay	0.28
		11–end	0.27	-0.02	0.04	0.29	no	okay	okay	0.29
	WB	0–1	0.27	-0.02	0.03	0.28	no	okay	okay	0.28
		1–2	0.27	-0.02	0.01	0.26	no	okay	okay	0.26
		2–3	0.27	-0.02	-0.02	0.23	no	okay	okay	0.23
		3–4	0.27	-0.02	-0.03	0.22	no	okay	okay	0.22
		4–5	0.27	-0.02	-0.04	0.21	yes	okay	okay	0.21
		5–6	0.27	-0.02	-0.03	0.22	no	okay	okay	0.22
		6–7	0.27	-0.02	-0.02	0.23	no	okay	okay	0.23
		7–8	0.27	-0.02	0.03	0.28	no	okay	okay	0.28
		8–9	0.27	-0.02	0.03	0.28	no	okay	okay	0.28
		9–10	0.27	-0.02	0.02	0.27	no	okay	okay	0.27
		10–11	0.27	-0.02	0.02	0.27	no	okay	okay	0.27
		11–end	0.27	-0.02	0.04	0.29	no	okay	okay	0.29
	Wide SHLD		0.31	0.04	n/a	0.35	no	no	okay	0.31
	EB Pass Lane	0–1	0.30	0.02	0.02	0.34	no	Use Max.	okay	0.31
		1–end	0.30	0.02	-0.03	0.29	no	okay	okay	0.29
Grade		4	Aggregate Spread Rate			145	sy:cy	Binder		AC

[a] Consider TVAR.

CONSTRUCTION SUPPORT AND ANALYSIS

Researchers collected the available actual shot rates and compared the rates with the proposed rates that were determined based on the aggregates' properties and LiDAR data analysis for predicting the post-construction conditions for 2020 case studies.

The researchers estimated a 1-mile shot length. This measurement was close to the actual shot length; however, since the shot lengths varied, the adjustment recommendations may have also been different if the actual shot length was used.

APPLICATION RATE ADJUSTMENT

Bryan District

All projects in the Bryan District used AR binder and lightweight Grade 4 precoated aggregate. Table 31 through Table 35 contain a summary of the overall proposed rates, actual shot rates, and predictions of the post-construction conditions.

Table 31. Bryan District SH 6 WFR Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
2	WFR SB OL	0–1	-0.01	0.49	0.6	Flushed/Bleeding
		1–2	-0.01	0.57	0.6	Flushed
		2–3	0.03	0.61	0.6	Good
		3–4	0.02	0.60	0.6	Good
		4–5	0.01	0.59	0.6	Good
		5–6	0.01	0.59	0.6	Good
		6–7	0.02	0.60	0.6	Good
		7–8	0.04	0.61	0.6	Good
		8–9	0.02	0.60	0.6	Good
		9–10	0.03	0.61	0.6	Good
		10–11	0.05	0.61	0.6	Good
		11–12	0.02	0.60	0.6	Good
		12–end	0	0.58	0.6	Good
	WFR SB IL	0–1	0.01	0.51	0.6	Flushed/Bleeding
		1–2	0	0.58	0.6	Good
		2–3	0.03	0.61	0.6	Good
		3–4	0.01	0.59	0.6	Good
		4–5	0.01	0.59	0.6	Good
		5–6	0.01	0.59	0.6	Good
		6–7	0.02	0.60	0.6	Good
		7–8	0.02	0.60	0.6	Good
		8–9	0.03	0.61	0.6	Good
		9–10	0.03	0.61	0.6	Good
		10–11	0.05	0.61	0.6	Good
		11–12	0.03	0.61	0.6	Good
		12–end	0	0.58	0.6	Good

Table 32. Bryan District SH 6 EFR Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
1	EFR NB OL	0–1	0.01	0.59	0.6	Good
		1–2	0.01	0.59	0.6	Good
		2–3	0.03	0.61	0.6	Good
		3–4	0.03	0.61	0.6	Good
		4–5	0.03	0.61	0.6	Good
		5–6	0.03	0.61	0.6	Good
		6–7	0.05	0.61	0.6	Good
		7–8	0.02	0.60	0.6	Good
		8–9	0.03	0.61	0.6	Good
		9–10	0.02	0.60	0.6	Good
		10–11	0.01	0.59	0.6	Good
		11–12	-0.01	0.57	0.6	Flushed
		12–13	-0.01	0.57	0.6	Flushed
		13–end	-0.02	0.48	0.6	Flushed/Bleeding
	EFR NB IL	0–1	0	0.58	0.6	Good
		1–2	0.02	0.60	0.6	Good
		2–3	0.03	0.61	0.6	Good
		3–4	0.03	0.61	0.6	Good
		4–5	0.03	0.61	0.6	Good
		5–6	0.02	0.60	0.6	Good
		6–7	0.04	0.61	0.6	Good
		7–8	0.02	0.60	0.6	Good
		8–9	0.04	0.61	0.6	Good
		9–10	0.02	0.60	0.6	Good
		10–11	0.01	0.59	0.6	Good
		11–12	0	0.58	0.6	Good
		12–13	0	0.58	0.6	Good
		13–end	-0.01	0.49	0.6	Flushed/Bleeding

Table 33. Bryan District SH 21 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
3	EB OL	0–1	0.04	0.54	0.6	Flushed/Bleeding
		1–end	0.04	0.50	0.6	Flushed/Bleeding
	EB IL	0–1	0.06	0.56	0.6	Flushed/Bleeding
		1–end	0.05	0.55	0.6	Flushed/Bleeding
	WB OL	0–1	0.01	0.51	0.6	Flushed/Bleeding
		1–end	0.01	0.50	0.6	Flushed/Bleeding
	WB IL	0–1	0.04	0.54	0.6	Flushed/Bleeding
		1–end	0.05	0.50	0.6	Flushed/Bleeding
	CTL	0–1	0.05	0.61	0.6	Good
		1–end	0.06	0.61	0.6	Good

Table 34. Bryan District SH 308 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
6	SB OL	0–1	-0.03	0.48	0.6	Flushed/Bleeding
		1–end	-0.02	0.50	0.6	Flushed/Bleeding
	SB IL	0–1	-0.04	0.48	0.6	Flushed/Bleeding
		1–end	-0.05	0.48	0.6	Flushed/Bleeding
	NB OL	0–1	-0.03	0.48	0.6	Flushed/Bleeding
		1–end	-0.04	0.48	0.6	Flushed/Bleeding
	NB IL	0–1	-0.04	0.48	0.6	Flushed/Bleeding
		1–end	-0.06	0.48	0.6	Flushed/Bleeding

Table 35. Bryan District FM 1179 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
7	EB 2 Lane	0–1	-0.01	0.49	0.6	Flushed/Bleeding
		1–end	-0.04	0.50	0.6	Flushed/Bleeding
	WB 2 Lane	0–1	-0.03	0.48	0.6	Flushed/Bleeding
		1–end	-0.02	0.50	0.6	Flushed/Bleeding
	EB OL SCS	0–1	-0.02	0.48	0.6	Flushed/Bleeding
		1–end	-0.05	0.50	0.6	Flushed/Bleeding
	EB IL SCS	0–1	-0.02	0.48	0.6	Flushed/Bleeding
		1–end	-0.03	0.48	0.6	Flushed/Bleeding
	WB OL SCS	0–1	-0.03	0.48	0.6	Flushed/Bleeding
		1–end	-0.02	0.50	0.6	Flushed/Bleeding
	WB IL SCS	0–1	-0.04	0.48	0.6	Flushed/Bleeding
		1–end	-0.03	0.48	0.6	Flushed/Bleeding
	EB OL HMA Surface	0–1	0.03	0.53	0.6	Flushed/Bleeding
		1–2	0.04	0.54	0.6	Flushed/Bleeding
		2–3	0.03	0.53	0.6	Flushed/Bleeding
		3–end	0.04	0.54	0.6	Flushed/Bleeding
	EB IL HMA Surface	0–1	0.02	0.52	0.6	Flushed/Bleeding
		1–2	0.05	0.55	0.6	Flushed/Bleeding
		2–3	0.04	0.54	0.6	Flushed/Bleeding
		3–end	0.04	0.54	0.6	Flushed/Bleeding
	WB OL HMA Surface	0–1	0.04	0.54	0.6	Flushed/Bleeding
		1–2	0.05	0.55	0.6	Flushed/Bleeding
		2–3	0.05	0.55	0.6	Flushed/Bleeding
		3–end	0.02	0.52	0.6	Flushed/Bleeding
	WB IL HMA Surface	0–1	0.03	0.53	0.6	Flushed/Bleeding
		1–2	0.05	0.55	0.6	Flushed/Bleeding
		2–3	0.05	0.55	0.6	Flushed/Bleeding
		3–end	0.01	0.51	0.6	Flushed/Bleeding

Waco District

All projects in the Waco District used hot applied asphalt and a Grade 3 or Grade 4 precoated aggregate. Table 36 through Table 40 contain a summary of the overall proposed rates, actual shot rates, and predictions of the post-construction conditions.

The researchers estimated the proposed rate based on aggregate testing from the previous year’s Grade 4 limestone seal coat aggregate. The large difference in the proposed and actual rate may be from the assumption of the aggregate size to estimate the proposed rate; therefore, the condition prediction may not be accurate.

Table 36. Waco District FM 413 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
11	EB	0–1	-0.03	0.40	0.42	Slightly Flushed/Bleeding
		1–2	-0.05	0.38	0.4	Slightly Flushed/Bleeding
		2–3	-0.04	0.39	0.41	Slightly Flushed/Bleeding
		3–4	-0.04	0.39	0.41	Slightly Flushed/Bleeding
		4–5	-0.05	0.38	0.4	Slightly Flushed/Bleeding
		5–6	-0.03	0.40	0.42	Slightly Flushed/Bleeding
		6–end	-0.05	0.38	0.4	Slightly Flushed/Bleeding
	WB	0–1	-0.07	0.38	0.38	Good
		1–2	-0.05	0.38	0.4	Slightly Flushed/Bleeding
		2–3	-0.03	0.40	0.42	Slightly Flushed/Bleeding
		3–4	-0.04	0.39	0.41	Slightly Flushed/Bleeding
		4–5.5	-0.02	0.41	0.43	Slightly Flushed/Bleeding
		5.5–6.5	-0.04	0.39	0.41	Slightly Flushed/Bleeding
		6.5–end	-0.05	0.38	0.4	Slightly Flushed/Bleeding
	Aggregate			Proposed Rate (sy/cy)	Actual Rate (sy/cy)	Binder Type
	Arcosa—PL GR 3			121	120	AC-15P

Table 37. Waco District SH 6 SB Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
8 & 9	SB OL	0–1	0.04	0.33	0.32	Good
		1–2	0.07	0.36	0.32/0.33	Dry
		2–3	0.04	0.33	0.33	Good
		3–4	0.06	0.35	0.33/0.31	Slightly Dry/Dry
		4–5	0.03	0.32	0.31/0.33	Good
		5–6	0.05	0.34	0.33	Good
		6–7	0.04	0.33	0.33	Good
		7–8	0.05	0.34	0.31	Dry
		8–9	0.04	0.33	0.31/0.32	Slightly Dry/Good
		9–10.5	0.05	0.34	0.32/0.31	Slightly Dry/Dry
		10.5–11.5	0.04	0.33	0.32	Good
		11.5–12.5	0.06	0.35	0.32	Dry
		12.5–13.5	0.05	0.34	0.32/0.33	Slightly Dry/Good
		13.5–14.5	0.04	0.33	0.33	Good
		14.5–15.5	0.05	0.34	0.28	Dry
		15.5–end	0.05	0.34	0.28	Dry
	SB IL	0–1	-0.02	0.30	0.31	Good
		1–2	-0.02	0.30	0.35	Flushed/Bleeding
		2–3	-0.04	0.29	0.32	Flushed/Bleeding
		3–4	-0.02	0.30	0.34	Flushed/Bleeding
		4–5	-0.05	0.29	0.33	Flushed/Bleeding
		5–6	-0.05	0.29	0.34	Flushed/Bleeding
		6–7	-0.04	0.29	0.33	Flushed/Bleeding
		7–8	-0.05	0.29	0.31	Slightly Flushed/Bleeding
		8–9	-0.03	0.29	0.34	Flushed/Bleeding
		9–10.5	-0.04	0.29	0.33	Flushed/Bleeding
		10.5–11.5	-0.03	0.29	0.34	Flushed/Bleeding
		11.5–12.5	-0.04	0.29	0.33	Flushed/Bleeding
		12.5–13.5	-0.04	0.29	0.35	Flushed/Bleeding
		13.5–14.5	-0.03	0.29	0.35	Flushed/Bleeding
		14.5–15.5	-0.04	0.29	0.34	Flushed/Bleeding
		15.5–end	-0.02	0.30	0.34	Flushed/Bleeding
	Outside SHLD			0.38	0.38	Good
			Aggregate	Proposed Rate (sy/cy)	Actual Rate (sy/cy)	Binder Type
			Capital—PD GR3	133	133	AC-15P

Table 38. Waco District SH 6 NB Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
8 & 9	NB OL	0–1	0.06	0.35	0.31	Dry
		1–2	0.07	0.36	0.31/0.32	Dry
		2–3	0.07	0.36	0.32	Dry
		3–4	0.05	0.34	0.32/0.33	Slightly Dry/Good
		4–5	0.06	0.35	0.33	Slightly Dry
		5–6	0.06	0.35	0.33/0.3	Slight Dry/Dry
		6–7	0.06	0.35	0.3	Slightly Dry
		7–8	0.06	0.35	0.34	Good
		8–9	0.06	0.35	0.34	Good
		9–10	0.06	0.35	0.34	Good
		10–11	0.06	0.35	0.29	Dry
		11–12	0.05	0.34	0.32/0.34	Slightly Dry/Good
		12–13	0.06	0.35	0.34	Good
		13–14	0.06	0.35	0.34	Good
		14–15	0.07	0.36	0.34	Slightly Dry
		15–16	0.05	0.34	0.34/0.33	Good
		16–end	0.05	0.34	0.33	Good
	NB IL	0–1	-0.02	0.30	0.31	Good
		1–2	-0.04	0.29	0.34	Flushed/Bleeding
		2–3	-0.04	0.29	0.32	Flushed/Bleeding
		3–4	-0.04	0.29	0.34	Flushed/Bleeding
		4–5	-0.05	0.29	0.35	Flushed/Bleeding
		5–6	-0.06	0.29	0.34	Flushed/Bleeding
		6–7	-0.05	0.29	0.36	Flushed/Bleeding
		7–8	-0.04	0.29	0.36	Flushed/Bleeding
		8–9	-0.04	0.29	0.35	Flushed/Bleeding
		9–10	-0.04	0.29	0.36	Flushed/Bleeding
		10–11	-0.05	0.29	0.34	Flushed/Bleeding
		11–12	-0.04	0.29	0.35	Flushed/Bleeding
		12–13	-0.04	0.29	0.34	Flushed/Bleeding
		13–14	-0.04	0.29	0.33	Flushed/Bleeding
		14–15	-0.06	0.29	0.31	Slightly Flushed/Bleeding
		15–16	-0.06	0.29	0.34	Flushed/Bleeding
		16–end	-0.05	0.29	0.33	Flushed/Bleeding
	Outside SHLD			0.38	0.36	Slightly Dry
			Aggregate	Proposed Rate (sy/cy)	Actual Rate (sy/cy)	Binder Type
			Capital—PD GR3	133	133	AC-15P

Table 39. Waco District FM 147 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
12	EB	0–1	-0.05	0.36	0.36	Good
		1–2	-0.04	0.37	0.41	Flushed/Bleeding
		2–3	-0.04	0.37	0.40	Flushed/Bleeding
		3–4	-0.04	0.37	0.41	Flushed/Bleeding
		4–5	-0.03	0.38	0.37	Good
		5–6	-0.02	0.39	0.36	Dry
		6–7	-0.02	0.39	0.42	Flushed/Bleeding
		7–8	-0.03	0.38	0.42	Flushed/Bleeding
		8–9	-0.02	0.39	0.41	Slightly Flushed/Bleeding
		9–10.5	-0.03	0.38	0.41	Flushed/Bleeding
		10.5–11.5	-0.05	0.36	0.42	Flushed/Bleeding
		11.5–end	-0.04	0.37	0.42	Flushed/Bleeding
	WB	0–1	-0.03	0.38	0.40	Slightly Flushed/Bleeding
		1–2	-0.05	0.36	0.41	Flushed/Bleeding
		2–3	-0.03	0.38	0.38	Good
		3–4	-0.03	0.38	0.41	Flushed/Bleeding
		4–5.5	-0.03	0.38	0.40	Slightly Flushed/Bleeding
		5.5–6.5	-0.03	0.38	0.40	Slightly Flushed/Bleeding
		6.5–7.5	-0.03	0.38	0.41	Flushed/Bleeding
		7.5–8.5	-0.03	0.38	0.39	Good
		8.5–9.5	-0.03	0.38	0.41	Flushed/Bleeding
		9.5–10.5	-0.04	0.37	0.41	Flushed/Bleeding
		10.5–11.5	-0.04	0.37	0.40	Flushed/Bleeding
		11.5–end	-0.05	0.36	0.42	Flushed/Bleeding
		Aggregate		Proposed Rate (sy/cy)	Actual Rate (sy/cy)	Binder Type
		Capital—PD GR4		133	133	AC-15P

Table 40. Waco District FM 431 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
10	EB	0–1	-0.02	0.41	0.49	Flushed/Bleeding
		1–2	-0.03	0.40	0.51	Flushed/Bleeding
		2–3	-0.03	0.40	0.49	Flushed/Bleeding
		3–4	-0.03	0.40	0.49	Flushed/Bleeding
		4–5	-0.04	0.39	0.54	Flushed/Bleeding
		5–end	-0.05	0.38	0.52	Flushed/Bleeding
	WB	0–1	-0.04	0.39	0.50	Flushed/Bleeding
		1–2	-0.03	0.40	0.48	Flushed/Bleeding
		2–3	-0.05	0.38	0.48	Flushed/Bleeding
		3–4	-0.03	0.40	0.48	Flushed/Bleeding
		4–5	-0.03	0.40	0.46	Flushed/Bleeding
		5–end	-0.04	0.39	0.51	Flushed/Bleeding
		Aggregate		Proposed Rate (sy/cy)	Actual Rate (sy/cy)	Binder Type
		Capital—PD GR3		97	97	AC-15P

Brownwood District

All projects in the Brownwood District used both Grade 3 and 4 precoated aggregate. Table 41 through Table 45 contain a summary of the overall proposed rates, actual shot rates, and predictions of the post-construction conditions.

Table 41. Brownwood District FM 2313 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
46	NB	0–1	0.01	0.28	0.34	Flushed/Bleeding
	NB	1–2	0	0.27	0.34	Flushed/Bleeding
	NB	2–3	0.01	0.28	0.34	Flushed/Bleeding
	NB	3–4	0	0.27	0.34	Flushed/Bleeding
	NB	4–5	0	0.27	0.36	Flushed/Bleeding
	NB	5–6	0.01	0.28	0.32	Flushed/Bleeding
	NB	6–end	0.02	0.29	0.29	Good
	SB	0–1	-0.01	0.26	0.29	Flushed/Bleeding
	SB	1–2	0.01	0.28	0.36	Flushed/Bleeding
	SB	2–3	0	0.27	0.36	Flushed/Bleeding
	SB	3–4	0	0.27	0.34	Flushed/Bleeding
	SB	4–5	0.02	0.29	0.34	Flushed/Bleeding
	SB	5–6	0	0.27	0.33	Flushed/Bleeding
	SB	6–end	0.02	0.29	0.33	Flushed/Bleeding
	Wide SHLD		n/a			
			Aggregate	Proposed Rate (sy/cy)	Actual Rate (sy/cy)	Binder Type
			TX Materials—PB GR4	145	139	AC20-5TR

Table 42. Brownwood District FM 2657 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
46	SB OL	0–1	-0.04	0.21	0.36	Flushed/Bleeding
	SB OL	1–2	-0.02	0.21	0.36/0.35	Flushed/Bleeding
	SB OL	2–end	0.03	0.26	0.35	Flushed/Bleeding
	SB IL	0–end	-0.05	0.21	n/a	
	NB OL	0–1	0.04	0.27	0.34	Flushed/Bleeding
	NB OL	1–2	-0.01	0.22	0.34	Flushed/Bleeding
	NB OL	2–end	-0.03	0.21	0.34	Flushed/Bleeding
	NB IL	0–end	-0.01	0.25	n/a	
			Aggregate	Proposed Rate (sy/cy)	Actual Rate (sy/cy)	Binder Type
			TX Materials—PB GR4	145	138	AC20-5TR

Table 43. Brownwood District FM 2808 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
44	EB	0–1	-0.01	0.26	0.37	Flushed/Bleeding
	EB	1–2	-0.01	0.27	0.37	Flushed/Bleeding
	EB	2–3	0.01	0.28	0.40	Flushed/Bleeding
	EB	3–4	0	0.27	0.40	Flushed/Bleeding
	EB	4–end	0.01	0.28	0.40	Flushed/Bleeding
	WB	0–1	-0.03	0.24	0.35	Flushed/Bleeding
	WB	1–2	-0.02	0.25	0.35	Flushed/Bleeding
	WB	2–3	0.01	0.28	0.39	Flushed/Bleeding
	WB	3–4	0.01	0.28	0.39	Flushed/Bleeding
	WB	4–end	0.01	0.28	0.39	Flushed/Bleeding
	Wide SHLD		n/a	0.31	n/a	
			Aggregate	Proposed Rate (sy/cy)	Actual Rate (sy/cy)	Binder Type
			Vulcan—PB GR4	145	134	AC20-5TR

Table 44. Brownwood District US 281 Rate Summary.

Ref No.	Lane	Section (mile)	Est. LiDAR Data Adj. (gal/sy)	Proposed Rate (gal/sy)	Actual Rate (gal/sy)	Condition Prediction
9	SB	0–1	0.03	0.35	0.44	Flushed/Bleeding
		1–2	-0.02	0.32	0.49	Flushed/Bleeding
		2–3	0.02	0.34	0.44	Flushed/Bleeding
		3–4	0.02	0.34	0.48	Flushed/Bleeding
		4–5	0	0.32	0.47	Flushed/Bleeding
		5–6	0.02	0.34	0.45	Flushed/Bleeding
		6–7	0.05	0.37	0.46	Flushed/Bleeding
		7–8	-0.02	0.30	0.43	Flushed/Bleeding
		8–9	0	0.32	0.44	Flushed/Bleeding
		9–10	-0.03	0.29	0.44	Flushed/Bleeding
		10–end	0.01	0.33	0.43	Flushed/Bleeding
	NB	0–1	0.03	0.35	0.42	Flushed/Bleeding
		1–2	0.01	0.33	0.45	Flushed/Bleeding
		2–3	-0.01	0.31	0.46	Flushed/Bleeding
		3–4	-0.05	0.27	0.42	Flushed/Bleeding
		4–5	0.04	0.36	0.41	Flushed/Bleeding
		5–6	0.03	0.35	0.43	Flushed/Bleeding
		6–7	-0.02	0.30	0.45	Flushed/Bleeding
		7–8	0.01	0.33	0.41	Flushed/Bleeding
		8–9	0	0.32	0.45	Flushed/Bleeding
		9–10	-0.03	0.29	0.43	Flushed/Bleeding
		10–end	0.05	0.37	0.45	Flushed/Bleeding
	Wide SHLD		n/a	0.40	0.48	Flushed/Bleeding
	SB Pass Lane	0–1	0.02	0.39	0.43	Flushed/Bleeding
		1–2	0.02	0.39	0.44	Flushed/Bleeding
		2–end	0.01	0.38	0.45	Flushed/Bleeding
	NB Pass Lane	0–1	0.02	0.39	0.45	Flushed/Bleeding
		1–2	0	0.37	0.42	Flushed/Bleeding
		2–3	-0.01	0.36	0.42	Flushed/Bleeding
		3–4	0	0.37	0.43	Flushed/Bleeding
		4–end	-0.02	0.35	0.43	Flushed/Bleeding
			Aggregate	Proposed Rate (sy/cy)	Actual Rate (sy/cy)	Binder Type
			TX Mat.—PB GR3	114	100	AC20-5TR

Table 45. Brownwood District US 190 Rate Summary.

<table>
<tr><th>Ref No.</th><th>Lane</th><th>Section</th><th>Est. LiDAR Data Adj.</th><th>Proposed Rate</th><th>Actual Rate</th><th>Condition Prediction</th></tr>
<tr><td></td><td></td><td>mile</td><td>gal/sy</td><td>gal/sy</td><td>gal/sy</td><td></td></tr>
<tr><td rowspan="27">13</td><td rowspan="12">EB</td><td>0–1</td><td>0.01</td><td>0.26</td><td>0.3</td><td>Flushed/Bleeding</td></tr>
<tr><td>1–2</td><td>0.01</td><td>0.25</td><td>0.3</td><td>Flushed/Bleeding</td></tr>
<tr><td>2–3</td><td>0</td><td>0.25</td><td>0.3/0.31</td><td>Flushed/Bleeding</td></tr>
<tr><td>3–4</td><td>0.03</td><td>0.28</td><td>0.31</td><td>Flushed/Bleeding</td></tr>
<tr><td>4–5</td><td>-0.01</td><td>0.24</td><td>0.31/0.29</td><td>Flushed/Bleeding</td></tr>
<tr><td>5–6</td><td>-0.03</td><td>0.22</td><td>0.29/0.27</td><td>Flushed/Bleeding</td></tr>
<tr><td>6–7</td><td>-0.02</td><td>0.23</td><td>0.27</td><td>Flushed/Bleeding</td></tr>
<tr><td>7–8</td><td>-0.03</td><td>0.22</td><td>0.28</td><td>Flushed/Bleeding</td></tr>
<tr><td>8–9</td><td>-0.02</td><td>0.23</td><td>0.26</td><td>Flushed/Bleeding</td></tr>
<tr><td>9–10</td><td>-0.04</td><td>0.21</td><td>0.26/0.3</td><td>Flushed/Bleeding</td></tr>
<tr><td>10–11</td><td>0.03</td><td>0.28</td><td>0.3</td><td>Slightly Flushed/Bleeding</td></tr>
<tr><td>11–end</td><td>0.04</td><td>0.29</td><td>0.3</td><td>Good</td></tr>
<tr><td rowspan="12">WB</td><td>0–1</td><td>0.03</td><td>0.28</td><td>0.34</td><td>Flushed/Bleeding</td></tr>
<tr><td>1–2</td><td>0.01</td><td>0.26</td><td>0.34/0.3</td><td>Flushed/Bleeding</td></tr>
<tr><td>2–3</td><td>-0.02</td><td>0.23</td><td>0.29</td><td>Flushed/Bleeding</td></tr>
<tr><td>3–4</td><td>-0.03</td><td>0.22</td><td>0.29/0.3</td><td>Flushed/Bleeding</td></tr>
<tr><td>4–5</td><td>-0.04</td><td>0.21</td><td>0.3</td><td>Flushed/Bleeding</td></tr>
<tr><td>5–6</td><td>-0.03</td><td>0.22</td><td>0.3</td><td>Flushed/Bleeding</td></tr>
<tr><td>6–7</td><td>-0.02</td><td>0.23</td><td>0.34</td><td>Flushed/Bleeding</td></tr>
<tr><td>7–8</td><td>0.03</td><td>0.28</td><td>0.34</td><td>Flushed/Bleeding</td></tr>
<tr><td>8–9</td><td>0.03</td><td>0.28</td><td>0.34/0.32</td><td>Flushed/Bleeding</td></tr>
<tr><td>9–10</td><td>0.02</td><td>0.27</td><td>0.32</td><td>Flushed/Bleeding</td></tr>
<tr><td>10–11</td><td>0.02</td><td>0.27</td><td>0.32/0.33</td><td>Flushed/Bleeding</td></tr>
<tr><td>11–end</td><td>0.04</td><td>0.29</td><td>0.33</td><td>Flushed/Bleeding</td></tr>
<tr><td colspan="2">Wide SHLD</td><td>n/a</td><td>0.31</td><td>n/a</td><td></td></tr>
<tr><td rowspan="2">EB Pass Lane</td><td>0–1</td><td>0.02</td><td>0.31</td><td>n/a</td><td></td></tr>
<tr><td>1–end</td><td>-0.03</td><td>0.29</td><td>n/a</td><td></td></tr>
<tr><td rowspan="2"></td><td colspan="3">Aggregate</td><td>Proposed Rate (sy/cy)</td><td>Actual Rate (sy/cy)</td><td>Binder Type</td></tr>
<tr><td colspan="3">TX Mat. - PB GR4</td><td>145</td><td>139</td><td>AC20-5TR</td></tr>
</table>

2020 CASE STUDY SUMMARY

The LiDAR data were collected for 5 projects in 3 districts (15 total projects). An algorithm was applied to estimate pavement adjustments for the binder application rate. Some of the challenges included the following:

- Applying the correct reference section for the algorithm:
    - The person performing the analysis needs to be able to identify the existing pavement surface as either a seal coat or hot mix.
    - The limits of existing pavement surface type changes need to be identified.
- Determining the reasonable starting rate to adjust:
    - It is important that the starting rate to adjust from is known. The researchers recommend following the design procedure, including aggregate testing (developed in TxDOT research 0-6989), to determine the starting rate.

For the Brownwood and Waco Districts, the majority of the adjustment trends (up or down) were comparable for the proposed and actual rates. The key is to estimate the starting rate to adjust from correctly. Adjustment trends can be seen in Figure 18 and Figure 19.

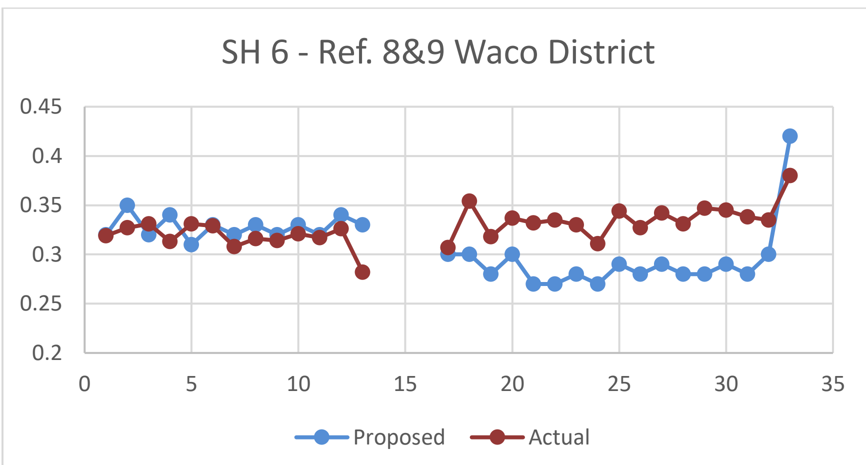


Figure 18. SH 6 Rates—Waco District.

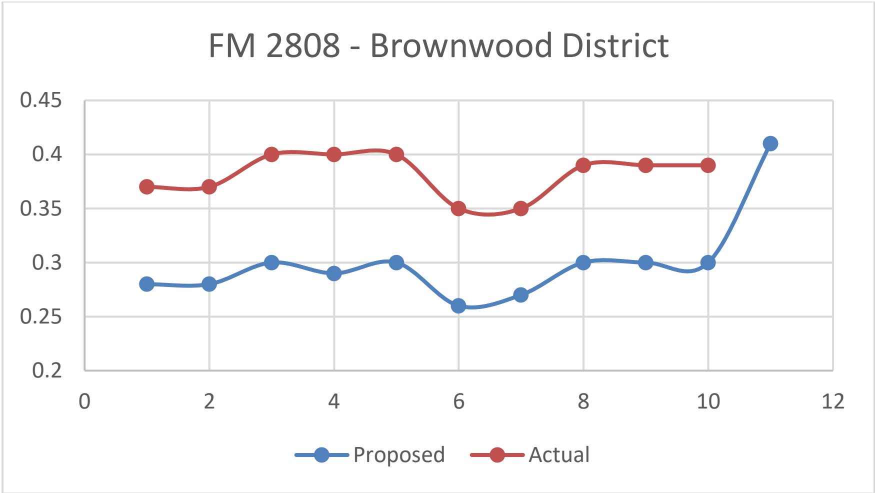


Figure 19. FM 2808 Rates—Brownwood District.

Although the adjustments followed the same trends as the actual shot rates, improvements to the proposed application rates can be made based on the following:

- It is highly recommended that the starting rate be determined from the design procedure developed in TxDOT research 0-6989; then, the binder rate adjustments should be determined from LiDAR data analysis. This process can help field engineers make real-time decisions and can lead to better seal coat performance.
- After working with the contractor to determine the shot length, field engineers should use the LiDAR data to summarize adjustments based on the proposed shot length instead of a typical length.
- It is critical that the person analyzing the LiDAR data understand the existing pavement surface type. There is a control section for a seal coat surface and one for a hot mix surface. If the wrong control section is used, the adjustment algorithm will not produce accurate results. The potential for inaccurate adjustments exists when long sections of level-up occur on a typical seal coat roadway due to the algorithm.

CHAPTER 5: CONCLUSIONS, RECOMMENDATIONS, AND ADDITIONAL IMPLEMENTATION

CONCLUSIONS

New technologies are being developed that can potentially reduce the typical types of problems—such as rock loss, flushing, and bleeding—that occur with seal coat construction. Recently completed research projects 0-6963 (Planning the Next Generation of Seal Coat Equipment) and 0-6989 (Update Seal Coat Application Rate Design Method) provide the most recent new tools and technologies for seal coat application rate design.

This study validated the finding in project 0-6963 that the mobile LiDAR system shows much promise to remove a significant amount of subjectivity when determining variations in surface conditions. Identification of the surface conditions is needed to adjust the seal coat binder rates during construction as conditions change. The LiDAR data method of rate adjustment along with the new design method developed in project 0-6989 are the initial steps in implementing the newest technologies for seal coat rate design.

Based on the results obtained in this study, the following conclusions can be made:

- The laser-reflected signal intensity of a pavement surface collected using a LiDAR unit can be processed and analyzed to generate binder rate adjustments for seal coat projects without subjectivity. The HDV system can be used to document and evaluate the surface condition without traffic control.
- The expected surface conditions based on the comparisons between actual and predicted binder rates were validated and matched up well with the observations from the HDV system. Thus, LiDAR can improve seal coat construction by collecting surface information in a safe manner and analyzing it in an automated fashion to describe actual surface characteristics. It can also be deployed shortly before actual construction and offers managing agencies the ability to provide detailed binder rates that more accurately address the existing surface conditions, leading to better performance.
- The LiDAR information can identify when there is a change in rates across the width of a lane and along the roadway. A significant amount of data is collected at close intervals; however, changing nozzle rates at every 100-ft station is not operational from a construction standpoint:

RECOMMENDATIONS

The following recommendations are based on the findings of this study:

- Determine the starting rate from the design procedure developed in TxDOT research project 0-6989, and then determine the binder rate adjustments from LiDAR data analysis. This process can help field engineers make real-time decisions and can lead to better seal coat performance.

- Work with the contractor to determine the shot length, and then use the LiDAR data to summarize adjustments based on the proposed shot length instead of a typical length.
    - Since the typical shot length of a distributor is approximately 1 mile, the researchers recommend using an average binder adjustment in the LTWP and RTWP every 1 mile:
        - Coordination with the contractor will help fine-tune the shot length to coincide with actual estimated shot lengths for construction. When the actual shot length is known, the researchers recommend using an average of the actual shot length.
    - When the difference in the median rate between wheel paths or between the wheel paths and outside the wheel paths is greater than 0.03 gal/sy, the use of a variable-rate nozzle is highly recommended.
- When analyzing the LiDAR data, determine if the existing pavement surface type is either a seal coat or hot mix. There is a control section for a seal coat surface and one for a hot mix surface. If the wrong control section is used, the adjustment algorithm will not produce accurate results. There is potential for inaccurate adjustments when long sections of level-up exist on a typical seal coat roadway due to the algorithm if the reference control section is not changed.
- When the difference between the actual shot rate and the proposed rate is more than 0.02 gal/sy, monitor those projects and document the condition using the HDV system. Evaluations of as-built projects will help designers and inspectors understand field adjustments.

ADDITIONAL IMPLEMENTATION

The researchers have been working on developing a user-friendly interface to combine most of this process into a one-click technology to minimize the complexity and recommend that TxDOT consider further development of the automated analysis system to document pavement changes and provide binder adjustment rates right before applying seat coats in the field.

Seal coat binder rate adjustments heavily depend on traffic (e.g., ADT) and pavement condition (e.g., surface type, surface condition, etc.), as well as the initial application rate at the time of construction. Depending on local materials and conditions, the adjustment rate might need modifications as well. Researchers recommend additional implementation using the developed adjustment factor along with LiDAR measurements to test different surface type conditions and ADT with locally available materials under various weather conditions in Texas.

Based on the results, the following may limit implementation:

- While this is a valid procedure, TxDOT does not currently have the LiDAR equipment available for large-scale implementation of this technology. Additional equipment and training would be needed for large-scale implementation:
    - Training:
        - Analysis: Although the algorithm predicts the applied binder rate reductions based on the differences identified through LiDAR reflectivity data and mathematical analysis of the pavement surface characteristics, the whole process requires training for the person performing the analysis:
            - Conversion of LiDAR reflectivity data using Road Doctor.
            - Modification of the converted data for mathematical analysis and more.
        - Data Collection: Training is required to properly set up the system and collect data.
    - Equipment: TxDOT owns one LiDAR system capable of collecting the data needed for the analysis. LiDAR systems are expensive.
        - The researchers recommend investigating other types of equipment that can collect reflectivity data. For example, the modification of profile lasers (i.e., those that collect ride quality) to output reflectivity rather than elevation could be used. Using an existing profile vehicle with lasers in each wheel path and modifying the equipment to mount an additional laser between wheel paths might be a feasible option.
        - Evaluating other imaging-based algorithms might make the use of images more feasible as well.
        - Each of the possibilities above requires analyzing and/or building software applications.