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Application Rate Adjustments for Seal Coats in Texas

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16. Abstract

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. This 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 equipment used to place the asphalt or aggregate.

With little to no changes in design and construction methods, Texas continues to see the same problems, such as rock loss, flushing, and bleeding reoccurring. New technologies are being developed that could potentially reduce these types of problems. There have been recent new developments for asphalt distributors due to the performance-based warranty specification being used by the New Zealand Transport Agency. The asphalt distributor improvements include the ability to use up to eight different transversely varying application rates at normal operating speed. This is extremely useful to apply the optimal shot rate when surface conditions change. In addition to this, high definition video systems and scanners can map and document existing texture conditions to define the required spray bar pattern.

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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 the 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 C. 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. INTRODUCTION AND BACKGROUND

Seal coats are an 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. This 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 equipment used to place the asphalt and aggregate.

With little to no changes in design and construction methods, Texas continues to see the same types of problems. These problems include rock loss, flushing, and bleeding. New technologies are being developed that could potentially reduce these types of problems. There have been recent developments for asphalt distributors due to the performance-based warranty specification being used by the New Zealand Transport Agency. The asphalt distributor improvements include the ability to use up to eight different transversely varying application rates at normal operating speed. This is extremely useful to apply the optimal shot rate when surface conditions change. In addition to this, high definition video systems and scanners can map and document existing texture conditions to define the required spray bar pattern.

New technologies for improvements to seal coat construction are investigated in this project. The project addressed the following goals:

- Investigate the current state of practice in innovative agencies around the United States and internationally. This includes New Zealand, Australia, and South Africa, who have very similar roadway conditions to Texas. Focus on spray bar technology and other implementable practices including but not limited to the use of fiber ribbon in seal coat.
- Survey local distributor and spray bar manufacturers to determine what is currently available and what enhancements can be made.
- Construct a prototype spray bar control system or develop detailed plans for what it would take to construct an appropriate system to accommodate Texas conditions.
- Evaluate new approaches for documenting up-front pavement texture conditions, with the idea of using automated texture measurements to help determine shot rates. Identify optimal shot rates for the most common conditions found in Texas; for example, the different severity levels of bleeding wheel paths and limestone rock asphalt patches.
- Develop an approach where the technologies can be merged together and implemented in future studies.

In summary, the goals of this project are to provide implementable guidelines and procedures to document pavement conditions; guidelines and details for equipment improvements; and guidelines for asphalt application rate adjustments and include recommendations for future developments in these areas.

CHAPTER 2. LITERATURE REVIEW

This chapter summarizes the literature review in which researchers determined the current state-of-the practice and emerging research technology for the following:

- Seal coat equipment.
- Methods of determining asphalt application rate adjustments.
- Construction.

OVERVIEW

A successful seal coat is one that provides over the design life, adequate surface texture and seals the pavement structure from water intrusion. One of the common distresses that leads to premature end of service life is loss of texture. Generally, the loss of texture occurs due to flushing, bleeding, aggregate loss, and/or wear of aggregate. There are several factors that influence the constructability and performance of the seal coat, as well as the determination of optimal application rates. Some of those factors include traffic, weather, existing pavement conditions, roadway geometrics, and materials selected for the seal coat. In order to obtain a uniform seal coat when the conditions vary transversely, the use of variable transverse asphalt application rates should be considered as a method used to improve service life of the seal coat.

Strain Alleviating Membrane (SAM), Strain Alleviating Membrane Interlayer (SAMI), Fibre Reinforced Sprayed Seal (FRSS), and Geotextile Reinforced Seal (GRS) are specialty use seal coats. All the specialty seals are designed to reduce reflective cracking. Traditional SAM and SAMI seals use rubber to absorb strains that occur, thereby reducing reflection cracking. SAMI is similar to SAM except that it typically has an asphalt overlay. Both the FRSS and GRS can be used as a surface or interlayer. The FRSS seal uses chopped glass fibers (fiberglass) and a polymer modified emulsion. The GRS uses a layer of geotextile fabric and two applications of binder.

APPLICATION RATES

Two commonly used design methods in the United States and Canada are the McLeod's Method and the Kearby Design Method (*1*). The Texas Department of Transportation (TxDOT) has historically used the Modified Kearby Design Method or experience to set the application rates. The Modified Kearby Design Method includes design values for synthetic aggregate that were not included in the original design method. TxDOT relies heavily on experienced personnel for application rates and adjustments. Australia and New Zealand use the Austroads Sprayed Seal Design method (*2*). South Africa's design method was not found in the review.

The following discussion is based on the review of TxDOT's, "Seal Coat and Surface Treatment Manual" (*3*) and Austroad's "Update of the Austroads Sprayed Seal Design Method" (*2*). In general, application rates are determined based on optimal embedment depth for the aggregate size and shape. The embedment depth should provide adequate texture while providing enough binder to prevent aggregate loss. One of the main differences in TxDOT and Austroads methods are determination of voids needed. TxDOT designs for 20 percent voids while Austroads uses a method based on traffic levels to determine the voids needed. There are several factors that influence the determination of the optimal application rates, shown in Table 1.

In general, application rates should be adjusted for the factors shown in Table 1. Several sources have different adjustments for these factors. For example, for material selection, care should be taken to balance the performance as the climatic conditions change. When specifying a hard binder that may prevent flushing in the summer, it could become very stiff and brittle in the winter leading to aggregate loss. It will be critical for TxDOT to determine regional factors based on the weather, traffic, aggregate, and binder sources.

Table 1. Application Rate Adjustment Factors.

Factors	**Description**	**Description**
Traffic	Overall traffic volume	Truck volume (Heavy Vehicles)
Weather	Humidity	Temperature
	Wind Speed	Cloud Cover
Asphalt Material Properties	Polymer or Tire Rubber modified	Crumb Rubber modified
	Emulsion	Cut-Back
	Unmodified Asphalt	
Aggregate Material Properties	Size and Shape	Flakiness Index
	Average least dimension (ALD)	Gradation
	Precoated with asphalt	Absorption properties
Existing Pavement Condition	Macro-texture depth of existing roadway	Surface hardness
	Cracking	Flushing
	Bleeding	Patches, fresh or Fog Sealed
	Primed surface	Finished granular base
	Oxidized hot mix	New hot mix
	Ball Penetration test, AG:PT/T251, this test measures the penetration depth and testing temperature that will then be used in the Australian design method.	
Geometry of Roadway	Steep grades	Curves
	Narrow Lanes	Non-through lanes
	shoulders	continuous two way turn lanes
	crossovers	turn lanes
	climbing lanes	

Variable rates are needed to minimize flushing/bleeding in the wheel paths and to help prevent aggregate loss outside the wheel paths. Determining whether to use variable rates is a function of the existing pavement type and traffic loading. There are also conditions that variable rates are not recommended (*3*) those are as follows:

- When a Grade 5 aggregate is being used.
- When shooting emulsions on full super-elevated curves, as it may increase asphalt migration prior to rock placement.

- On new construction because the degree of potential benefit is small compared to potential loss of performance due to smaller amounts of asphalt sealing the pavement where stresses are the greatest.
- On shoulders and other non-traffic locations.
- In continuous left-hand turn lanes where traffic patterns are random.
- In intersections where the side street also carries considerable traffic volume.
- On flushed or bleeding hot mix pavements that may have stripping or an otherwise unstable pavement layer below.

The Austroads Sprayed Seal Design method includes the design of seals with Geotextile Reinforcement and Fiber Reinforcement (*2*). The Geotextile reinforcement is intended to be used to help waterproofing over cracked pavements. It can also be used as an asphalt interlayer. The use of a double seal is preferred over geotextile since a single seal may have a tendency to lose aggregate. The basic rate design method is the same, but the binder rate is adjusted based on the geotextiles binder retention. Fiber reinforcement seals in Australia are a proprietary process. The proprietary process includes the specific emulsion, glass fiber, and fiber spreading equipment used. This process has a layer of fiberglass fibers between two coats of polymer modified emulsion. The basic rate design method is the same, but the binder rate is adjusted based on the amount of binder needed to coat the fibers. The design manual does not list the intended use for the fiber reinforcement as it does for the geotextile reinforcement.

SEAL COAT EQUIPMENT

The asphalt distributor is the equipment used to apply binder material to the pavement. The distributor has a spreader bar usually 12 ft to 14 ft wide with spray nozzles spaced at 4-inch intervals. The travel speed and nozzle size affect the application rate. The height of the spray bar above the pavement is usually set so that a triple overlap of asphalt is achieved. The correct spray pattern is critical to a successful seal coat, so selecting the correct nozzle angle, size, and height above the pavement are essential to performance. Since nozzles can wear over time, it is critical to maintain the nozzles and calibrate the system to ensure the application rates are within acceptable tolerances. TxDOT’s current acceptable deviation between nozzles is 10 percent, unless variable rates are specified, and in that case, the plan note states the acceptable percentage (*4*).

Attempts have been made to use equipment to help determine the shot rate adjustments. Measurement of pavement macrotexture can be performed using the sand patch method, Tex-436-A. In New Zealand, lasers are used to measure macrotexture both in and between wheel paths, but this method is not currently used for chip seal design (*5*).

Current Variable Rate Spray Bar Background

For purposes of this section, variable rate implies variation transversely across the pavement section width. Longitudinal variation is usually controllable by vehicle speed and pump operation.

The fundamentals of liquid binder spray operations begin with a bar through which asphalt is pumped under pressure to a series of orifices, generally orifices designed to result in a flat spray pattern. Simple variable rates could be applied by changing something about the orifices (e.g., angle, orifice size, pump operation, orifice open or shut). The nozzles on the bar, in the simple case, are opened or closed by a single actuator (i.e., the valves are not individually controllable). As the next step in advancement of variable rate spray bar (VRSB) systems, smaller sections were set up for individual control of the valves; for example, 1-ft sections and two-pump, two-bar systems became more common as the need to vary the application rate across the wheel path and non-wheel path areas of the road became more widely recognized. Figure 1 illustrates an example of a simple binary on/off gang valve system.

Main In-Cab Control Panel

Figure 5-2

1 - Master Control
2 - Burner Control
3 - Manual Pump Speed Control
4 - Spraybar Master Switch
5 - 1 ft. Spray Nozzle Activation - Left Bar
6 - 1 ft. Spray Nozzle Activation - Right Bar
7 - Left Spraybar Extend / Retract
8 - Right Spraybar Extend / Retract
9 - Left 4 ft. Spray Nozzle Activation Switch
10 - Right 4 ft. Spray Nozzle Activation Switch
11 - Spraybar Raise / Lower Switch
12 - Soft Keys
13 - ESC Button
14 - OK Button
15 - Navigation Buttons (Left / Right)
16 - Navigation Buttons (Up / Down)

Figure 1. Rosco LeeBoy Maximizer Controls (*6*).

In 1996, Fulton Hogan in New Zealand built a Transverse Variable Application Sprayer called Multispray^{tm} (*7*). Figure 2 illustrates the setup to execute variable application rate spraying.

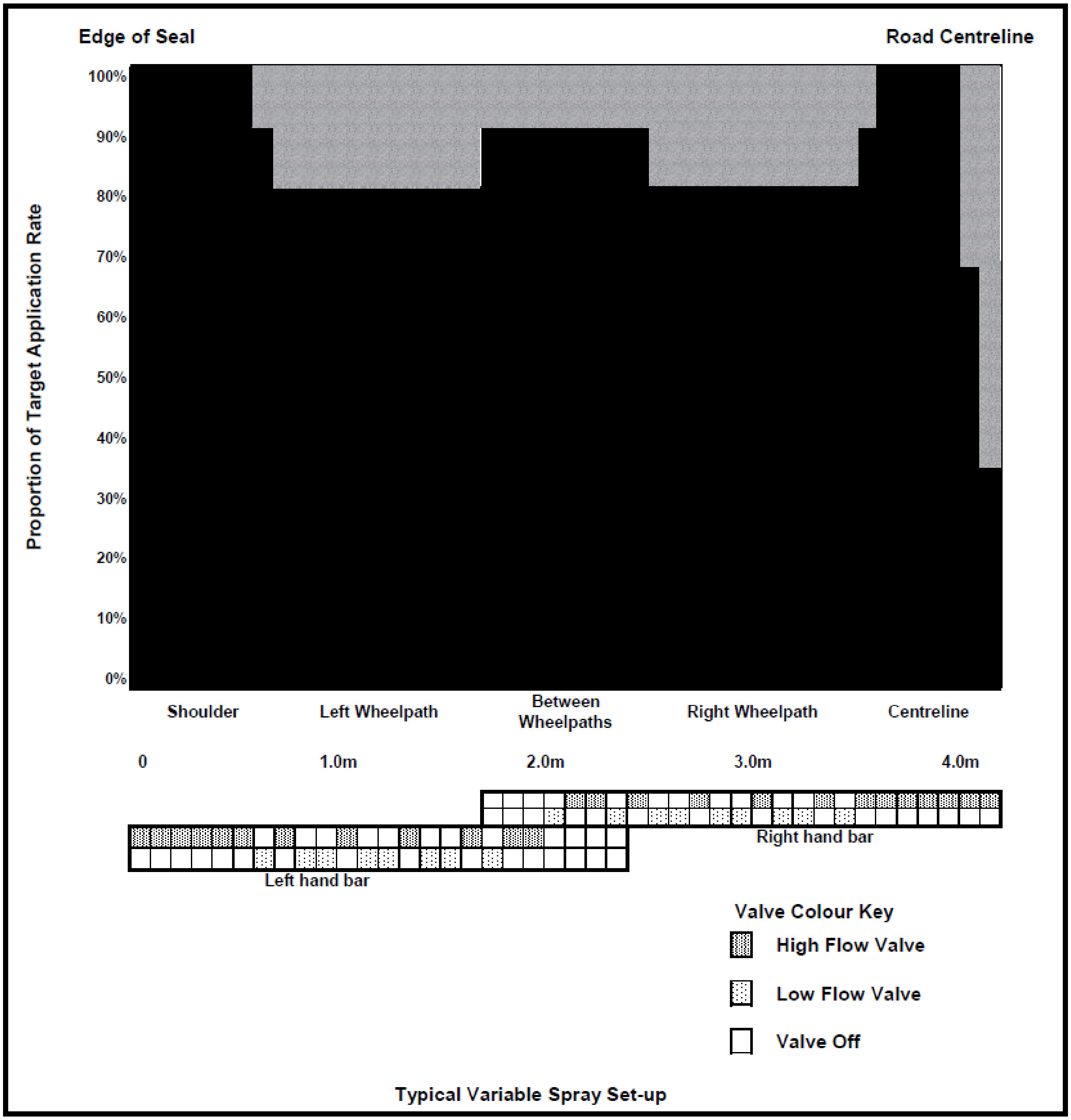


Figure 2. Transverse Variable Application Sprayer Bar Setup (from *7*).

In 1999, letters patent were granted to Albert Clark and Eddy Clark of San Antonio, Texas (*8*). The Objects and Claims of the invention may be concisely described as an apparatus and method to vary the application rate of liquid asphalt without changing spray nozzles so that two areas receive different application rates essentially simultaneously through two delivery systems on one truck. Basically, the system was two spray bars with two pumps and associated controls, used in such a way as to apply a different rate in the wheel path versus outside the wheel path. Since two pumps were used, flow rate and/or pressure delivered at the bars could be different for each bar, and the rate could be further adjusted by nozzle size distribution and placement on the bar. Rizzutto et al. suggest that Clark Construction was working with Bearcat Manufacturing on this project (*1*); however, the patent does not indicate that it was assigned to Bearcat, so it appears the Clarks retained all rights associated with the patent. A patent search that references the Clark and Clark patent yielded 54 results, which include not only the variable spray system devices themselves, but also methods for sensing surface conditions and devices for agricultural, snowplow, pavement paint striping, and concrete paver applications. Table 2 lists the companies and individuals represented by these 54 patents. The Clark and Clark patent references 15 prior art patents granted to various individuals and companies, including well-known names in the industry such as E.D. Etnyre and Colas SA.

Table 2. Sampling of Patents Relevant to VRSB.

Applicant	***Title***
Albert Hedegaard	Sprayer boom
Cmi Terex Corporation	Concrete curing machine
E. D. Etnyre & Co.	Directional control valve and valve assembly in an asphalt distributor
John A. Doherty	Vehicle mounted travel surface and weather condition monitoring system
John A. Doherty	Apparatus and system for synchronized application of one or more materials to a surface from a vehicle and control of a vehicle mounted variable position snow removal device
Agri-Inject, Inc.	System for uniform dispersal of agricultural chemicals
James Laddie L	Tack spraying apparatus
Western Strategic Products, Llc	Methods for determining need for treating a vehicle travel surface
Bearcat Manufacturing, Inc.	Spray assembly for paving machine
Brian George Knight	Spray apparatus
Joseph Voegele Ag	Paving convoy
Hall David R	Method for depositing pavement rejuvenation material into a layer of aggregate
Iwapi Inc.	Maintenance decision support system and method
Western Strategic Products, Llc	Surface condition sensing and treatment systems, and associated methods
Western Strategic Products, Llc	Systems and method for monitoring and controlling a vehicle travel surface
Terex Usa, Llc	Trackless tack pre-coating system and method for hot mix asphalt paving
Concaten, Inc.	Smart modem device for vehicular and roadside applications
Concaten, Inc.	Integrated rail efficiency and safety support system
Concaten, Inc.	Information delivery and maintenance system for dynamically generated and updated data pertaining to road maintenance vehicles and other related information
Concaten, Inc.	Maintenance decision support system and method for vehicular and roadside applications
Cmi Terex Corporation	Integrated carriage fogging system for concrete pavers
Concaten, Inc.	Distributed maintenance decision and support system and method
Dbi Holding, Llc	Systems and methods for automating the application of friction-modifying coatings
Terex Usa, Llc	Integrated carriage fogging system for concrete pavers
Crown Beds, Inc.	Spray assembly for surface treatment
Northeast Asphalt, Inc.	Paving machine

Applicant	Title
Heritage Research Group	Void reducing asphalt membrane composition, method and apparatus for asphalt paving applications
Newton Gary D	System for uniform dispersal of agricultural chemicals
Doherty John A	Surface condition sensing and treatment systems, and associated methods
Building Materials Investment Corporation	Procedure for blocked drain line on asphalt trailer
Anderson Paul M	Traffic stripe lay-out device
Knight Brian G	Spray apparatus
Bergkamp, Inc.	Pavement coating system having shiftable spray bar
Bergkamp, Inc.	Control system for applying a pavement coating emulsion
长安大学	Road maintenance agent spraying device and method

Rizzutto et al. note that a "… (3 ft) wheel path area is the standard recognized area that a driver can normally maintain the vehicle alignment within." Further, they suggest that nozzle size, manufacturing tolerances, orifice wear rates and "… nozzle angle and the height of the distributor spray bar are critical to obtaining the correct spray pattern" (*1*). Because of the range of variables involved in getting a good spray result on the surface, these authors suggest that methods and frequency of calibration such as those found in Tex-922-K are not as robust as the Modified Caltrans CTM-339 2000 method, so they recommend the use of the Caltrans method to address variance issues.

The basic pavement seal design used in New Zealand resulted in too much binder being applied in the wheel path (*7*). Pidwerbesky and Waters note that one of the simple methods for adjusting the rate is to reduce the wheel path rate by 10 percent, 20 percent, or 30 percent from the basic seal design recommendation (*7*). This has been refined to some degree with site specific texture measurements. Further refinement in the New Zealand approach involves taking textures at nine locations across a two-lane pavement, which includes shoulders, wheel paths, between wheel paths, and centerline.

Apparently, Etnyre bought out Bearcat, so two of the major U.S. players in asphalt distributor system offerings are now effectively one. Etnyre has three types of bars, two with one-foot controls and one with individual nozzle controls, although there may be sporadic availability of some of the special configurations (*9*). A simple approach to altering the delivery in the wheel paths is to simply to change the nozzle design/size in the wheel path, as was done to address some procedures used in the Brownwood District.

Cooper notes that nozzle on/off controls also affect the pump rate through a computer system to keep the delivery consistent. Some systems control binary on/off valves at a relatively high frequency in some precision applications. In the individual nozzle system, "the plumbing gets very tight …" (*9*).

The entire process of interest comprises not only a liquid binder distributor, but also an aggregate chip spreader. Etnyre shows gate arrangements that include both 6 in. and 12 in. gates, and a two-section variable hopper system that could be used to place two different types/sizes of aggregate (*10*). Cooper suggests this capability might be a first step toward evaluating a trade-off approach to, for example, management of ruts (i.e., could a different size rock in the ruts be traded for lower shot rates?) (*9*).

Relevant Advanced Systems

An interesting 2017 patent to Texas and California inventors (*11*) and assigned to a Pennsylvania company combines the functions of a liquid binder distributor truck with a form of chip spreader (i.e., “The systems and methods enable the precise and uniform application of the coating by mechanically controlling and metering both the binder and filler”). While this patent is directly applicable to surface friction enhancement using polymer binders and relatively small size fillers, the potential extension to pavement seal coating and next generation systems is obvious. The production rate of this system is claimed to be over 10,000 sy per day with epoxy binders. Because this patent deals with multi-part epoxy binders and production of accurate binder component ratios, it is not a particularly difficult stretch of the imagination to see that, if desired, the system could be used to blend liquid asphalts with different viscosities and/or to meter variable amounts of polymer modifiers to vary the binder properties both transversely and longitudinally along the roadway. Emphasis is placed on obtaining even distribution of the coating system, but the capability to perform multiple zone control of the binder and filler is described. The system provides various options for dealing with binders. For example, a means of heating the binder for thermoplastic materials and using heat, microwaves, or light on a liquid binder placed on the surface is suggested as another option. This system optionally includes an air curtain (or air knife), the purpose of which is to smooth “… the polymer resin to prepare it for receiving aggregate from dispensers 1820 and 1822.” It may be that some permutation of the air curtain idea could be used to help conform the desired thickness of the liquid asphalt better in areas in which rut basin shapes become a factor for seal coat applications. Device(s) to accelerate break/cure of the placed material could become part of the system. Figure 3 and Figure 4 show drawings of a single aggregate and multipart epoxy delivery machine.

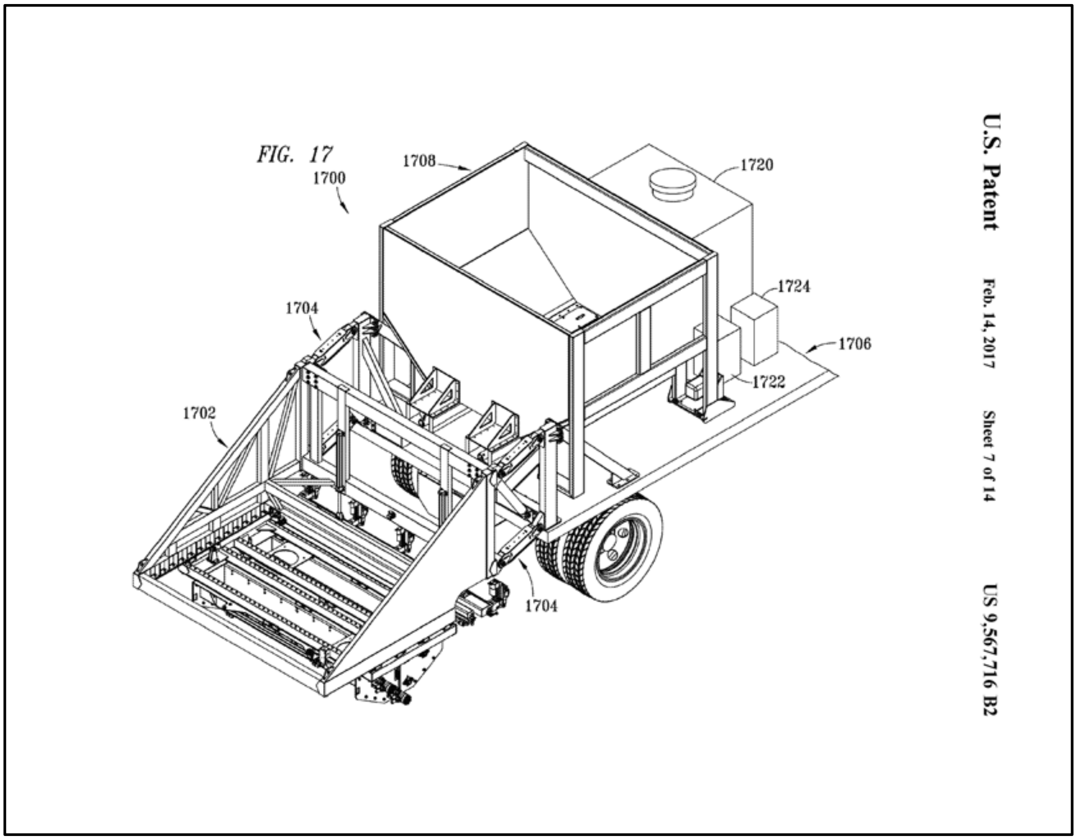


Figure 3. Integrated Platform with Aggregate Bin 1708, Multipart Epoxy Tanks 1720, 1722, 1724, and Delivery Components 1702 (*11*).

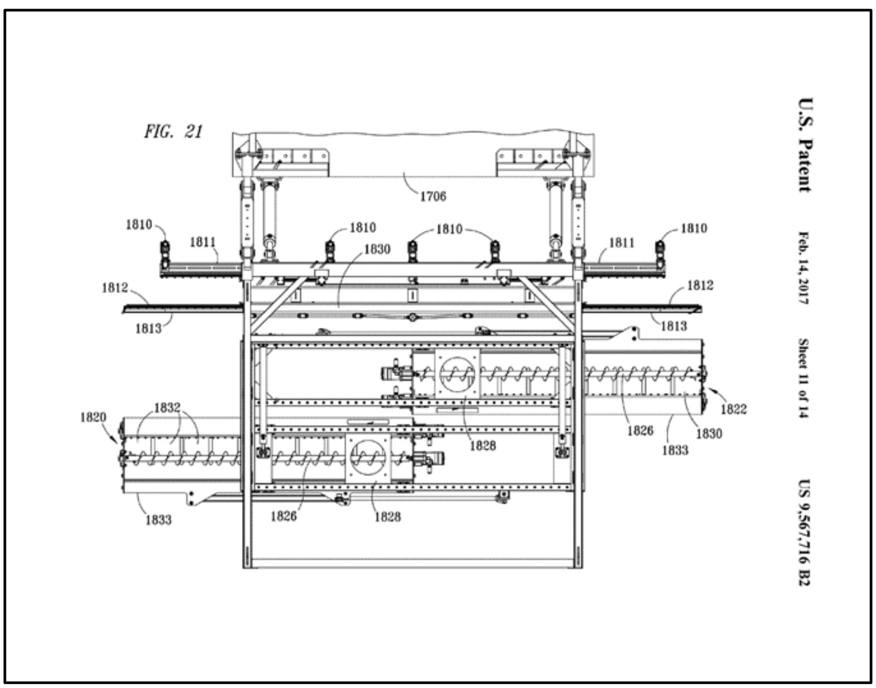


Figure 4. Delivery Package including Extendable Bars: Spray Bar 1811, Air Curtain Bar 1813, and Aggregate Dispensers 1820 and 1822 (*11*).

Doherty et al. developed a system to deliver snow and ice mitigating materials to pavement surfaces based on surface condition sensing on the fly (Figure 5 and Figure 6) (*12*). The surface condition sensing system and the variable delivery system are the features relevant to next generation seal coating systems. In Figure 6, the electromagnetic radiation sensor is an active remote sensor as opposed to a passive sensor like a video camera. The electromagnetic radiation device may be "… an ultra wide band Doppler radar or any other suitable electromagnetic radiation (EMR) emission and detection technique as well as Laser Induced Breakdown Spectroscopy (LIBS) may be used to remotely ascertain chemical and physical characteristics of the material on the roadway surface" (*12*).

Figure 7 illustrates one of the various control panel configurations shown in the patent. As shown, the control is similar to that of asphalt distributors and chip spreaders that have only one binder, one aggregate and use open loop control (i.e., the operator effectively provides the loop closure, so it is not an automatic machine control). However, in the abstract and detailed description sections of the patent, the inventors have covered the extension to automatic and remote command and extension of the embodiments to those that "… may also be used to control … more than two materials, whether they be liquids or granular material and in any combination" (*12*). This patent uses the concept of a trigger material and a ratiometric distribution (e.g., the Width K knob in Figure 7) of a slave material, which is claimed to "… allow a uniform or non-uniform pattern of deposition on the roadway surface, as desired" (*12*).

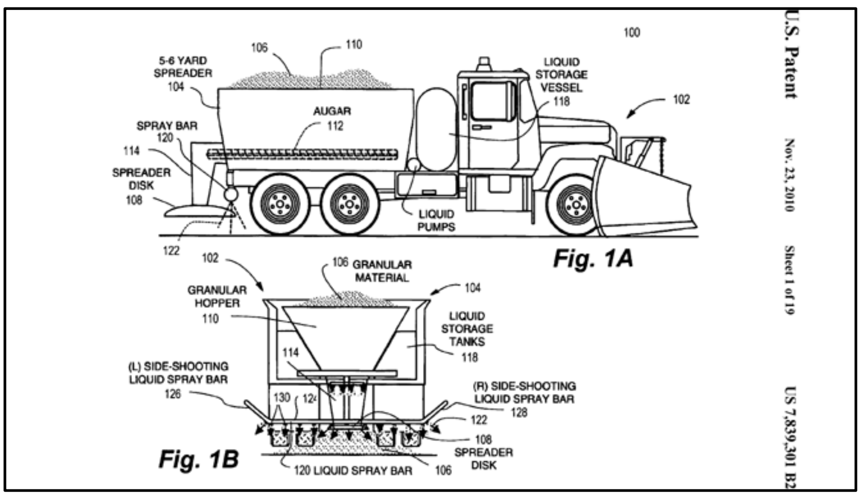


Figure 5. Basic Snowplow Configuration (*12*).

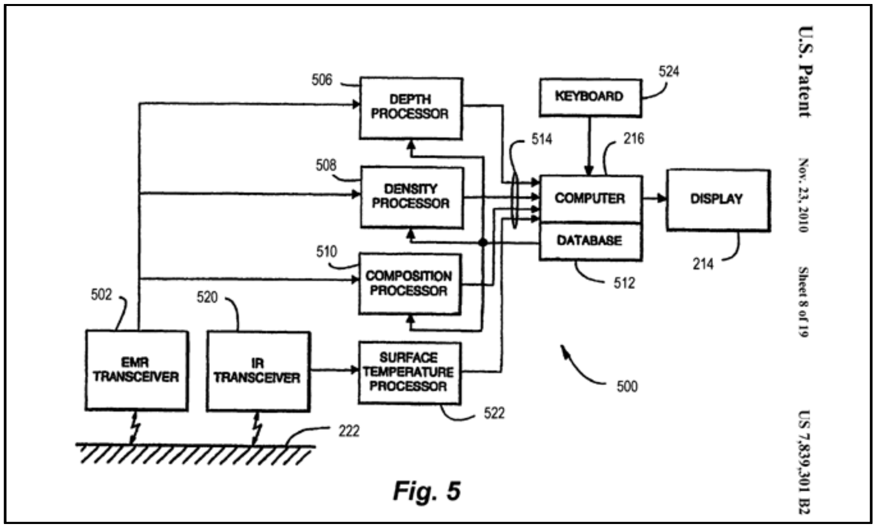


Figure 6. Sensing and Computer System (*12*).

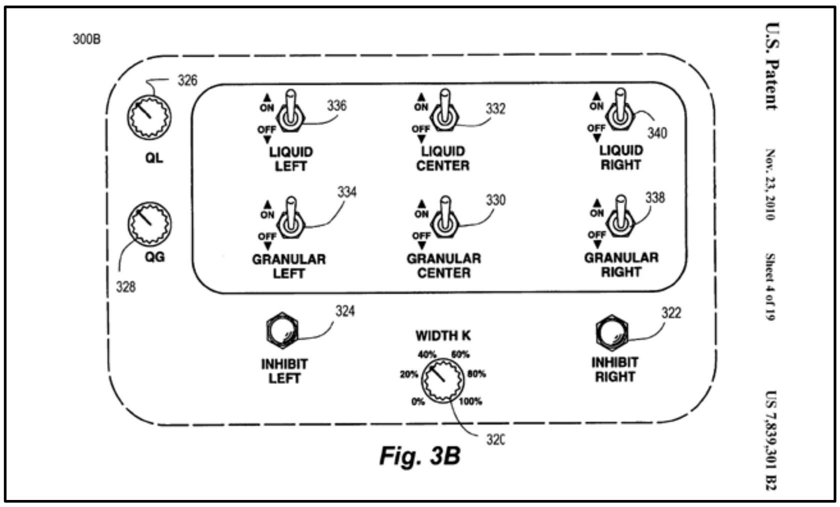


Figure 7. Example Operator Control Panel (*12*).

Potential Integration Components for Next Generation Equipment

This section describes some approaches and components that are currently available for some materials but are not currently readily available for very high temperature and/or high viscosity liquid asphalts or binders with some degree of particulates being carried in the fluid. Most of these items come from the field of hydraulics.

Several manufacturers' approaches to VRSB involve two pumps, two bars, and several binary on/off valves. There is a way to have different flows without having two pumps. The device used for this is called a flow divider/combiner. In the simplest configuration, it is two pressure-compensated flow control valves in a single housing. The flow controls enable constant flow regardless of pressure and the divider/combiner "… divides or combines the flow in a specific proportion regardless of changes in system load or pressure" (*13*). So, for the simple case of reducing the shot rate in the wheel paths, a flow divider could theoretically be used in place of two pumps, two bars, and/or individually controllable nozzles.

There is some precedent for controlling shot rate using cyclic opening and closing of binary (e.g., solenoid, of/off) valves. This is similar to pulse width modulation (PWM) typically used to make the result of a digital signal look like an analog result (e.g., to make a stepper motor operation look like servo motor behavior). A simple conceptualization of PWM versus analog is your stove top at home. If you have a gas stove top burner system, your cooking process control is basically analog, while if you have a newer electric range, you are likely operating more in the realm of PWM because the simulation of the analog process may be done by varying the length of time the burner is on versus off and how many times per minute those transitions happen. Either PWM binary or analog servo approaches could be used to achieve the intended effect of VRSBs. For instance, if a binary valve response time is fast enough, PWM could be used to achieve different spray rates at each valve.

Alternatively, many hydraulic systems use servovalves in high precision closed loop automation applications, and a wide range of valve designs exist. One servovalve design of interest is the Woodward R-DDV valve (*14*). While this valve is not designed for very high temperature fluids (160°F maximum standard with some higher temperature options available) and does require that a fluid cleanliness standard be observed and has a maximum chip shear capacity of 83 lb, the technological approach would be advantageous in asphalt binder metering applications if it were designed for that application. Multiple feedback signals can be used with this device.

Implications for Current Project and Next Generation Equipment

The technology reviewed here is in various states of technology readiness. For instance, servovalves and flow dividers are mature technologies at very high levels of readiness for hydraulic power applications but are at much lower levels of readiness for asphalt binder metering applications. Specialty servovalves and research and development (R&D) on these valves are expensive, so hands-on work with these components and activities was not feasible within the scope of this project.

The next generation of equipment could conceivably be a blend of the Rainwater et al. and Doherty et al. patents along with new valve and/or flow control technology (*11*, *12*).

CONSTRUCTION

TxDOT currently uses transverse variable rates, but the designer must include plan notes requiring this type of application. TxDOT standard specifications, Item 316, “Seal Coat,” section 3, “Equipment” discusses the use of transverse variable rates and requires the equipment to output a predetermined percentage more asphalt material by volume outside the wheel paths than over the wheel paths (*15*). TxDOT’s recommended plan note is: “In addition to other asphalt distributor requirements, the asphalt distributor shall be capable of providing a transversely varied asphalt rate. The Contractor shall demonstrate that the distributor can apply an asphalt rate outside of the wheel path locations between 22 and 32 percent higher than the asphalt rate being applied in the wheel paths. The contractor’s calibration of the distributor will include verification of this capability and a description of the spray bar(s) and nozzles to be used. The percentage difference in asphalt rate provided by each tested spray bar and nozzle arrangement shall be provided to the Engineer. The Engineer will select the pavements where the transversely varied asphalt rate is to be provided” (*3*).

To achieve variable rates, there are currently two options. The first is to use a single bar and change nozzle sizes. The second is to use a dual bar distributor.

The Texas Asphalt Paving Association (TXAPA) does not have easily accessible online information concerning seal coat construction. For the last several years they have included a 4-hr training workshop along with their annual meeting. Australian Asphalt Pavement Association (AAPA) has extensive online information. AAPA has a series of documents called "Work Tips," and these documents are a great resource. They are short descriptions of specific topics and give an overview of the main points. For example, Pavement Work Tips – No. 21, "Spraying Sealing – Uniformity and Neatness" describes the best practices for uniform binder application and neatness of joints. This document provides a table for adjustments to binder rates on curves (Figure 8). Another example is Pavement Work Tips – No. 32, "Sprayed Seals-a brief description" describes the different types of seals, Prime, Primeseal, Number and Sequence of binder and aggregate, and special uses and materials. One of the special uses is FRSS, which it describes as being similar to a SAM or a SAMI treatment. SAM or SAMI are designed to absorb strains that occur in the pavement and thereby reduce reflection cracking (*16*).

Table 3: Indicative binder application rates on curves

Radius of curve (centre of sprayer) m	Spray width m	Variation in application rate %		Examples of binder application rate variation L/m²		
		Outside curve	Inside curve	Design	Outside of curve	Inside of curve
7.5	2	- 13	+ 18	1.5	1.32	1.73
7.5	4	- 26	+ 36	1.5	1.18	2.05
15	2	- 6.7	+ 7.1	1.5	1.41	1.61
15	4	- 13	+ 15	1.5	1.32	1.73
15	8	- 26	+ 36	1.5	1.18	2.05
30	4	- 6.7	+ 7.1	1.5	1.41	1.61
30	8	- 13	+ 15	1.5	1.32	1.73
60	4	- 3.3	+ 3.4	1.5	1.45	1.55
60	8	- 6.7	+ 7.1	1.5	1.41	1.61
120	4	- 1.7	+ 1.7	1.5	1.48	1.53
120	8	- 3.3	+ 3.3	1.5	1.45	1.55

Figure 8. Rate Adjustments in Curves (*17*).

Australia and New Zealand do not specifically discuss the use of variable transverse rates in the design guide or specifications, but quality of the constructed seal is based on measuring texture and rock retention both in and outside the wheelpaths. The only way to effectively achieve the needed texture depth and rock retention over time across the lane width is to use variable transverse rates.

SPECIFICATIONS

TxDOT

TxDOT specifications that are relevant to seal coat construction are as follows (*15*):

- Item 210, "Rolling."
- Item 300, "Asphalts, Oils, and Emulsions."

- Item 302, “Aggregates for Surface Treatments.”
- Item 316, “Seal Coat.”
- Item 520, “Weighing and Measuring Equipment.”

Item 316 is the main specification for seal coat construction. This specification describes and references the materials, equipment, and construction methods. The designer designates on the plans, specific materials, combinations of materials and application rates, including transverse variable rates. The specification states the rates shown on the plans are for estimating purposes only and to adjust the rates for existing conditions or as directed. For the asphalt distributor, the equipment is calibrated with test method, Tex-922-K and dual spray bars are allowed. Test strips can be required when there is non-uniform application of rates. The tolerances are 0.03 gal/sy on three consecutive shots or 0.05 gal/sy on any shot.

FHWA

United States National Specifications that are relevant to seal coat construction are (*18*):

- Section 409, “Asphalt Surface Treatment.”
- Section 702, “Asphalt Material.”
- Section 703, “Aggregate.”

Section 409 is the main specification for seal coat construction. The significant differences in specifications compared to the TxDOT specifications are:

- Application rate tolerance is 0.02 gallons per square yard.
- A 500-ft test strip is required.
- There is no discussion about transverse variable rates.
- Figure 9, Figure 10, and Figure 11 show Tables 409-1, 409-2, and 409-3, which list application rates; however the exact application rates and adjustments for field conditions have to be approved by the contracting officer. (FHWA)

Table 409-1
Approximate Quantities of Material for
Single-Course Surface Treatment

Designation	Nominal Maximum Size of Aggregate	Aggregate Gradation (1)	Estimated Quantity of Aggregate (2) pounds/yd²	Estimated Quantity of Emulsified Asphalt (3) gallons/yd²	Estimated Quantity of Asphalt Binder (3) gallons/yd²
1A	3/4 inch	B	40 – 49	0.33 – 0.46	0.22 – 0.31
1B	1/2 inch	C	26 – 29	0.26 – 0.37	0.16 – 0.26
1C	3/8 inch	D	20 – 26	0.16 – 0.29	0.11 – 0.20
1D	No. 4	E	15 – 20	0.13 – 0.18	0.09 – 0.15
1E	Sand	F	9 – 15	0.09 – 0.15	0.07 – 0.13

(1) See Table 703-7 for aggregate gradations.
(2) Aggregate masses are for aggregates having a bulk specific gravity of 2.65, as determined by AASHTO T 84 and T 85. Make proportionate corrections when the aggregate furnished has a bulk specific gravity above 2.75 or below 2.55.
(3) Adjust the asphalt content for the condition of the road.

Figure 9. Table 409-1.

Table 409-2
Approximate Quantities of Material for
Double Course Surface Treatments

Designation (Thickness)	Nominal Maximum Size of Aggregate	Aggregate Gradation(1)	Estimated Quantity of Aggregate(2) pounds/yd²	Estimated Quantity of Emulsified Asphalt (3) gallons/yd²	Estimated Quantity of Asphalt Binder (3) gallons/yd²
2A (1/2 inch)					
1st Application	3/8 inch	D	26 – 35	0.16 – 0.26	0.09 – 0.18
2nd Application	No. 4	E	9 – 15	0.26 – 0.33	0.15 – 0.24
2B (5/8 inch)					
1st Application	1/2 inch	C	29 – 40	0.26 – 0.33	0.15 – 0.24
2nd Application	No. 4	E	14 – 20	0.33 – 0.42	0.20 – 0.27
2C (3/4 inch)					
1st Application	3/4 inch	B	40 – 49	0.29 – 0.42	0.18 – 0.27
2nd Application	3/8 inch	D	20 – 26	0.42 – 0.49	0.27 – 0.35

(1) See Table 703-7 for aggregate gradations.
(2) Aggregate masses are for aggregates having a bulk specific gravity of 2.65, as determined by AASHTO T 84 and T 85. Make proportionate corrections when the aggregate furnished has a bulk specific gravity above 2.75 or below 2.55.
(3) Adjust the asphalt content of the first application for the condition of the road.

Figure 10. Table 409-2.

Table 409-3
Approximate Quantities of Material for
Triple Course Surface Treatments

Designation (Thickness)	Nominal Maximum Size of Aggregate	Aggregate Gradation(1)	Estimated Quantity of Aggregate(2) pounds/yd²	Estimated Quantity of Emulsified Asphalt (3) gallons/yd²	Estimated Quantity of Asphalt Binder(3) gallons/yd²
3A (1/2 inch)					
1st Application	3/8 inch	D	26 – 35	0.16 – 0.26	0.09 – 0.18
2nd Application	No. 4	E	9 – 15	0.20 – 0.29	0.13 – 0.22
3rd Application	Sand	F	9 – 15	0.16 – 0.26	0.09 – 0.18
3B (5/8 inch)					
1st Application	1/2 inch	C	29 – 40	0.16 – 0.26	0.09 – 0.18
2nd Application	3/8 inch	D	15 – 20	0.26 – 0.33	0.15 – 0.24
3rd Application	No. 4	E	9 – 15	0.16 – 0.26	0.09 – 0.18
3C (3/4 inch)					
1st Application	3/4 inch	B	35 – 46	0.20 – 0.29	0.13 – 0.22
2nd Application	3/8 inch	D	20 – 26	0.26 – 0.33	0.15 – 0.24
3rd Application	No. 4	E	9 – 15	0.20 – 0.29	0.13 – 0.22

(1) See Table 703-7 for aggregate gradations.
(2) Aggregate masses are for aggregates having a bulk specific gravity of 2.65 as determined by AASHTO T 84 and T 85. Make proportionate corrections when the aggregate furnished has a bulk specific gravity above 2.75 or below 2.55.
(3) Adjust the asphalt content of the first application for the condition of the road.

Figure 11. Table 409.

Australia

Australian specifications are state or territory specific and the specifications reviewed are summarized below.

Access Canberra Territory specifications can be found online (*19*). The significant differences in specifications compared to the TxDOT specifications are as follows:

- Requires the contractor to verify the actual ALD for aggregate being used instead of the nominal aggregate size and use RTA 395 design form.
- Requires a 50 mm overlap for adjacent runs.

New South Wales Roads and Maritime Services (RMS) specifications can be found online (*20*). The RMS relevant specifications are:

- QA specifications R106, Sprayed Bituminous Surfacing (With Cutback Bitumen).
- QA specifications R107, Sprayed Bituminous Surfacing (With Polymer Modified Binder).
- QA specifications R111, Sprayed Bituminous Surfacing (With Bitumen Emulsion).
- QA specifications R1113, Sprayed Bituminous Surfacing (With Fibre Reinforcement).

The significant differences in specifications compared to the TxDOT specifications are as follows:

- Requires the contractor to verify the actual ALD for aggregate being used instead of the nominal aggregate size and use RTA 395 design form.
- Requires precoated aggregate
- For Cutback binders, requires a process control chart for application rates and requires corrective action if any point is between 2 percent and 5 percent above or below the target on 5 successive runs or any point is greater than 5 percent above or below the target binder application rate.
- For Polymer modified binders(PMB), the specified tolerance is ± 10 percent where the PMB contains scrap rubber and ± 5 percent otherwise.
- For Emulsion requires:
  - Shot tolerance of 5 percent.
  - Aggregate must be applied within 15 minutes of spraying binder.
- Discusses overlap and nozzle configuration requirements.
- Has a section for the use of Geotextiles.
- Pay reduction for difference from target spray rate.
- Fibre reinforcement:
  - Design is guided by Section 4 and the Annexure of the RMS Sprayed Sealing Guide.
  - Used with an Emulsion binder and requires the application rate to include coating the fibres.

Northern Territory specifications can be found online (*21*). “Standard Specification for Roadworks 2017, 8. Spray Sealing” is the relevant specification. The significant differences in specifications compared to the TxDOT specifications are as follows:

- Includes a geofabric requirement.
- Asphalt and aggregate material requirements are contained within the specification.
- Requires contractor to repair bleeding or flushing at their cost during a defined defects period.
- Discusses the use of end nozzles.
- Has specific inspection requirements for nozzles and spray bar.
- The project Superintendent sets the application rates using Austroads design methods and requires the following information be supplied at least three days before application:
  - Particle Size Distribution (1 per 250 tonne -minimum 3 tests).
  - ALD (1 per 250 tonne - minimum 3 tests).
  - Flakiness Index of the aggregate, (1 per 250 tonne - minimum 3 tests).
  - Ball Penetration testing (for new seal work).
  - Dryback results (for new seal work).
- Asphalt spray rate tolerances are between 95 percent and 105 percent of the target rate.
- Figure 12 shows the aggregate application rates are listed in table 8.6 and are based on aggregate size, binder type, and traffic volume.
  - Placed with a mechanical sprayer certified by RMS.

Table 8.6 – Aggregate Spread Rates		
STRAIGHT RUN BINDER COATS		
Aggregate Size	**Traffic Volume**	**Application Rate m²/m³**
10 mm and greater	>200 vehicles/day	900/ALD
10 mm and greater	< 200 vehicles/day	850/ALD
7 mm and less		900/ALD
POLYMER MODIFIED BINDER COATS		
Aggregate Size	**Traffic Volume**	**Application Rate m²/m³**
10 mm and greater	< 300 vehicles/day	750/ALD
10 mm and greater	> 300 vehicles/day	800/ALD
7 mm and less		160 – 200
TWO COAT SEALS		
First coat		
Aggregate Size	**Traffic Volume**	**Application Rate m²/m³**
10 mm and greater	>200 vehicles/day	950/ALD
10 mm and greater	< 200 vehicles/day	900/ALD
Second Coat		
Aggregate Size	**Number of Thicknesses**	**Application Rate m²/m³**
10	1	1050 – 1100 / ALD
7 (ALD known)	1	1100 – 1150 / ALD
5 or 7 (no ALD)	1	250 - 300
5 or 7 (no ALD)	2	175 - 225

Figure 12. Table 8.6, Aggregate Spread Rates.

Queensland specifications can be found online (*22*). The relevant specifications are from the Transport and Main Roads Specifications:

- MRS11, Sprayed Bituminous Surfacing (Excluding Emulsion).
- MRS12, Sprayed Bituminous Emulsion Surfacing.
- MRTS11, Sprayed Bituminous Surfacing (Excluding Emulsion).
- MRST12, Sprayed Bituminous Emulsion Surfacing.

The significant differences in specifications compared to the TxDOT specifications are as follows:

- Non-Emulsion Seal designs application rates are determined in accordance with the requirements of Austroads Technical Report AP T68/06 Update of the *Austroads Sprayed Seal Design Method.*
    - The designer of seal rates should be trained and has attained the AAPA *Statement of Attainment* (prior to 2008 *Certification of Attainment*) for the course titled *Sprayed Sealing Selection and Design.*

    - Additionally, the person on site must also be trained from the same course and be under the supervision of the seal designer. Rates should be adjusted by this trained person based on field conditions.
- Emulsion seal designs are in accordance with Austroads publication Design of Sprayed Seals.
- Require testing to be provided to determine application rates. The Contractor provides the testing, which includes Texture Depth (Sand Patch), Aggregate Particle Size Distribution, Flakiness Index, and ALD. Additionally, a Ball Penetration test is required in and outside the wheelpaths.
- Specification allows either Agency or Contractor to design the application rates.
- Do not accept spray rate outside plus or minus 10 percent of design rate or plus or minus 20 percent of the aggregate design rate.
- Pay reduction schedule tables for spray rate and aggregate rate being outside the design rates.
- The specification has opening to traffic requirements and in some cases restricts opening to traffic to 24 hours. Requires a surface texture test before opening to traffic.
- Specification discusses a defect liability period with defined measurements when defects occur in more than 10 percent of the wheel path length. Stripping is defined as areas where more than 10 percent cover aggregate has been lost from the seal's aggregate matrix. Flushing is defined as where surface texture depth is < 0.5 mm when tested by AGPT/T250. Debonding is defined as separation of the seal from the underlying layer.

Tasmania specifications can be found online (*23*). Victoria specifications can be found online (*24*). The relevant specification for both Tasmania and Victoria is "Section 408, Sprayed Bituminous Surfacings."

The significant differences in specifications compared to the TxDOT specifications are as follows:

- Allow geotextile and/or fiberglass reinforcement.
- Contractor is required to determine the application rates in accordance with Austroads Sprayed Seal Design Method
- Includes a table for timing to sweep loose aggregate based on traffic volume.
- Tolerances for spray rate include pay deductions.
- For acceptability of the seal, visual assessments are made for surface texture and aggregate retention. If there are concerns, then tests are performed.
- Discusses a defect liability period.

Western Australia specifications can be found online (*25*). The relevant Mainroads Western Australia specifications are as follows:

- Specification 503, Bituminous Surfacing.
- Specification 509, Polymer Modified Bituminous Surfacing.

The significant differences in specifications compared to the TxDOT specifications are as follows:

- Requires precoated aggregate except for use with Emulsion.
- Design can be by agency or contractor except required to be by contractor for polymer modified specification. The design method is in accordance with Austroads Provisional Sprayed Seal Design Method, Revision 2000 (AP-T09).
- Requires a test for ALD, surface texture, and/or ball embedment test.
- Equipment spray tolerances for calibration are listed in the specification.
- Discusses the use of end nozzles.
- Geotextile fabric is included.
- Specification 503 includes base course finish and moisture requirements.
- Spraying tolerances are included for both rate and area covered.
- Specification 503 includes information about aggregate rates for double seals.
- 60 days after completion timeframe for defects that must be repaired by the contractor.
- Pay reduction, including no pay and corrective action, for binder application rates that deviate from the design rate.

New Zealand

New Zealand specifications can be found online (*26*). The relevant New Zealand specifications are as follows:

- TNZ P/4:1995, Specification for Resealing.
- TNZ P/3:1995, Specification for First Coat Sealing.
- NZTA P17: October 2012, Performance Based Specification for Reseals.

The significant differences in specifications compared to the TxDOT specifications are as follows:

- Non-performance based specifications:
    - Separate specifications for sealing on base (i.e., the first seal and seals that are placed on previous seals or primed surfaces). There is also a performance-based specification for reseals.
    - Binder and aggregate quality requirements are included in the specifications.
    - Binder application rate tolerances are 50 litres plus 4 percent of the design rate.
    - Longitudinal joint overlap is discussed.
    - Rolling time is determined by the following formula: $T = V_t/(450xSxn)$, where T = Total roller requirement (hours), Vt = Total volume of binder sprayed (litres) measured at spraying temperature, S = Average overall rolling speed (kph) employed in uninterrupted rolling for an average speed of up to 8 kph. For average overall speeds of 8 kph or greater S = 8 kph, and n = number of rollers employed in uninterrupted rolling.
    - For Reseal, a dry grit locking coat is discussed. This is similar to TxDOT's Racked in Seal specification.
- Performance-based specification.

- Requires a quality control plan.
- Contractor checks site to be sealed to determine if pre-seal repairs completed and conditions to seal area satisfactory. The conditions that the contractor investigates are surface hardness, texture variation, traffic, and contract timing.
- Defines defects and expected results.
- Assessment period is defined as between 10 and 12 months after construction for surface texture and chip retention. The criteria to measure texture and chip retention is included.
- Contractor response time for repairs during the performance period are defined.

SUMMARY

New technologies are needed to improve the design and construction techniques for the seal coat. A review of design methods used statewide, nationally, and internationally indicates that all rely heavily on experienced personnel to set rates, adjust rates, and construct a well performing seal coat. Researchers have tried to help remove subjectivity from the procedures in certain areas such as determining the existing pavement hardness and texture. However, more improvements in this area are needed since the methods are point specific and require working on the pavement under traffic control. Most specifications do not discuss how to construct transverse variable rates and TxDOT has the most descriptive specification for transverse variable rates. The Australian and New Zealand specifications require texture measurements outside and in wheel paths that can only be achieved using transverse variable rates, but they are not prescriptive in how to construct the seal coat.

CHAPTER 3. FIELD SITES

OVERVIEW

Researchers worked with TxDOT districts to evaluate the pavement conditions for fiscal year 2018 (FY18) seal coat projects. The work included using two new approaches for documenting up-front pavement texture conditions. These methods included using the following systems, which are both discussed further in Chapter 4 and Chapter 5:

1. High-definition video (HDV) system.
2. Mobile Light Detecting and Ranging (LiDAR) system.

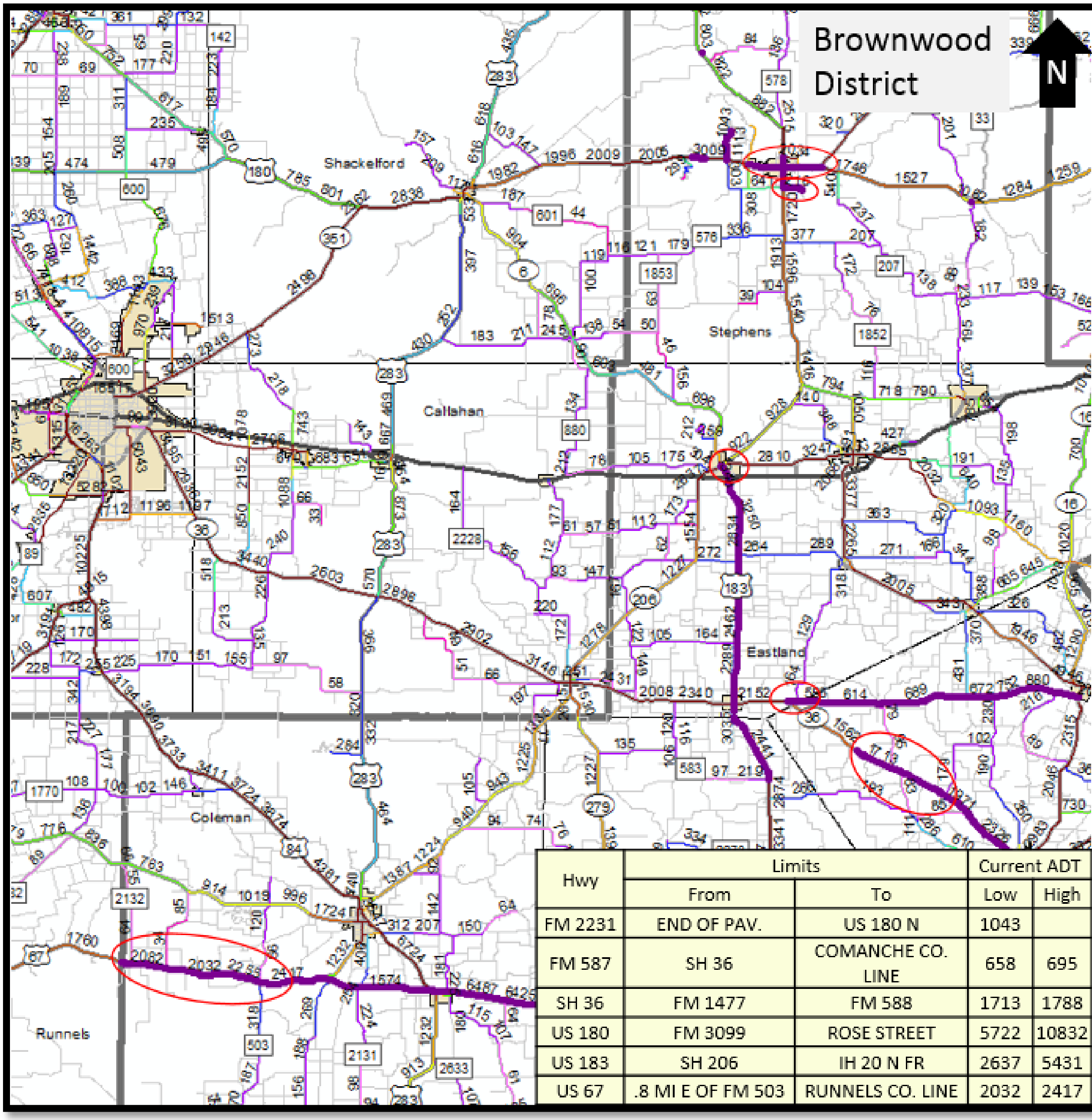
The most common surface conditions in Texas were documented using both methods of data collection. The description of the pavement condition includes both transverse changes and changes as you travel down the roadway. The information was then used to determine recommendations for binder rate adjustments to obtain the optimal binder application rates.

TEST SECTIONS

During the kickoff meeting, candidate projects were requested from the project team. Researchers evaluated projects in the Waco, Bryan, and Brownwood Districts that were scheduled for seal coat construction in FY18. Each district provided information about the upcoming seal coat projects to be considered as candidates for the HDV and LiDAR evaluation. Six projects from each district were selected to represent various surface conditions expected in Texas and with different traffic levels. Table 3 contains the test sections selected along with the traffic conditions on those sections. Figure 15 through Figure 14 show the locations of the test sites for each district and the current annual daily traffic (ADT).

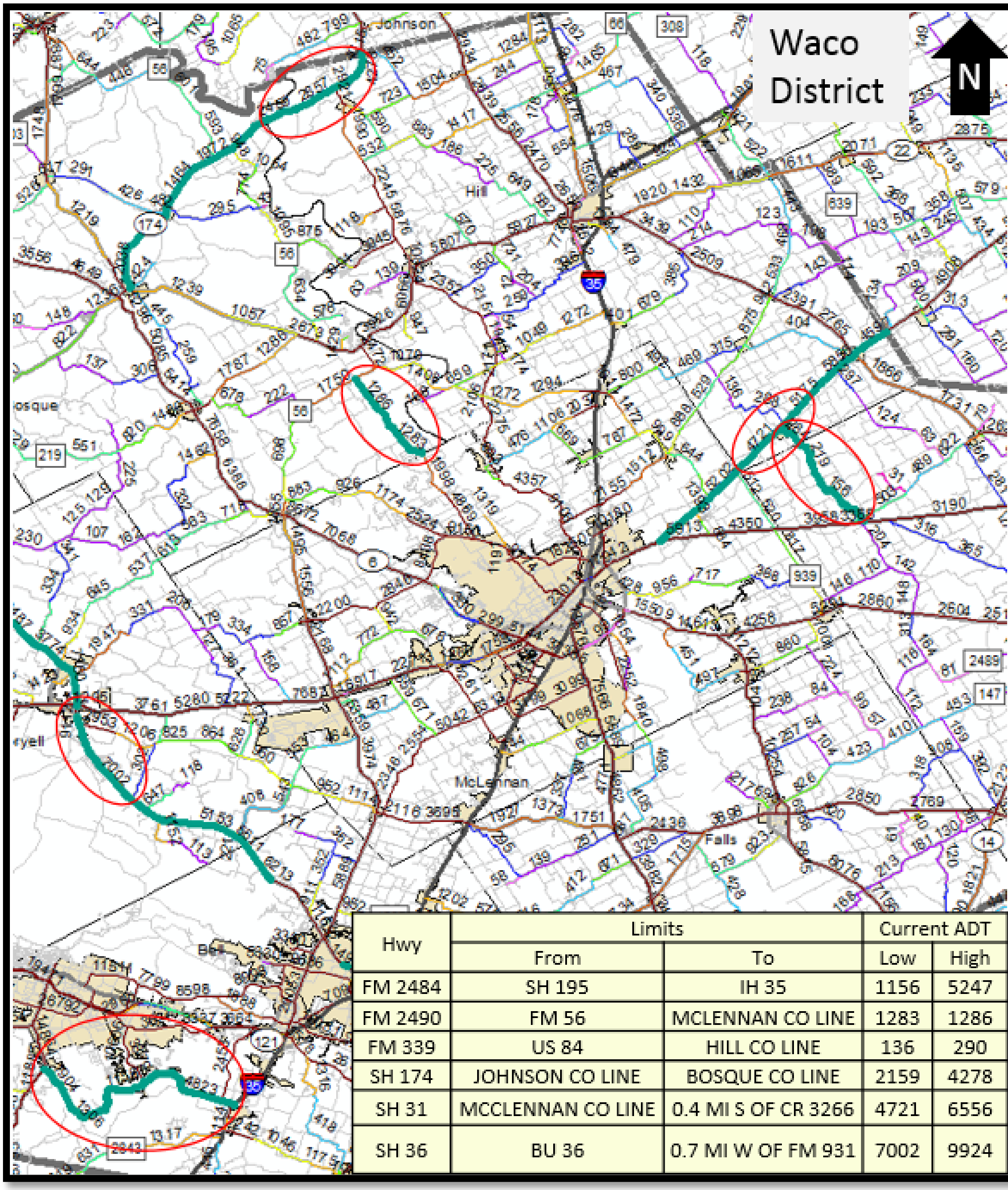
Table 3. Project 0-6369 Test Sections.

District	CSJ	Hwy	Limits		Current ADT		Main Surface Type
			From	To	Low	High	
Bryan		FM 158	SH 6	SH 30	12979	21298	Asphaltic Conc.
	169102013, etc.	FM 974	FM 2038	SH 21	834	1383	Seal Coat
	172301016	FM 1452	FM 39	US 190	822	817	Seal Coat
	057802046	FM 247	MADISON CO. LINE	FM 980	1153	3214	Seal Coat
	140001031	FM 1774	SH 90	SH 105	1299	2098	Seal Coat
		FM 60	SH 36	FM 2155	4987	7259	Seal Coat
Brownwood	209501016	FM 2231	END OF PAVEMENT	US 180 N	1043		Seal Coat
	103602007, etc.	FM 587	SH 36	COMANCHE CO. LINE	658	695	Seal Coat
	018202042	SH 36	FM 1477	FM 588	1713	1788	Seal Coat
	001107050, etc.	US 180	FM 3099	ROSE STREET	5722	10832	Seal Coat
	012701033	US 183	SH 206	IH 20 N FR	2637	5431	Asphaltic Conc.
	007802021, etc.	US 67	.8 MI E OF FM 503	RUNNELS CO. LINE	2032	2417	Seal Coat
Waco	230403014, etc.	FM 2484	SH 195	IH 35	1156	5247	Seal Coat
	239601007	FM 2490	FM 56	MCCLENNAN CO LINE	1283	1286	Seal Coat
	166203014, etc.	FM 339	US 84	HILL CO LINE	136	290	Seal Coat
	051902023	SH 174	JOHNSON CO LINE	BOSQUE CO LINE	2159	4278	Seal Coat/AC
	016202040	SH 31	MCCLENNAN CO LINE	0.4 MI S OF CR 3266	4721	6556	Asphaltic Conc.
	018401064	SH 36	BU 36	0.7 MI W OF FM 931	7002	9924	Seal Coat



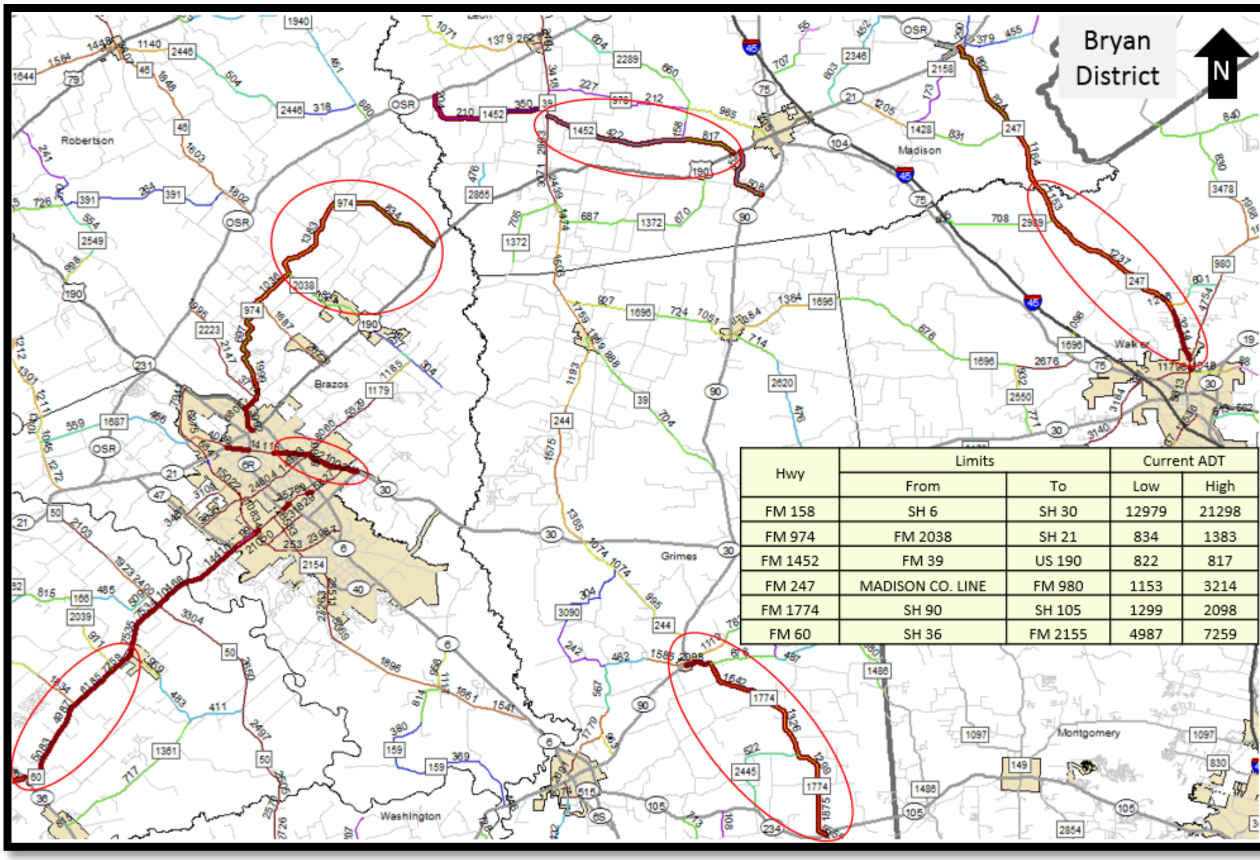
Hwy	Limits		Current ADT	
	From	To	Low	High
FM 2231	END OF PAV.	US 180 N	1043	
FM 587	SH 36	COMANCHE CO. LINE	658	695
SH 36	FM 1477	FM 588	1713	1788
US 180	FM 3099	ROSE STREET	5722	10832
US 183	SH 206	IH 20 N FR	2637	5431
US 67	.8 MI E OF FM 503	RUNNELS CO. LINE	2032	2417

Figure 13. Brownwood District 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 14. Waco District 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 15. Bryan District Test Sites with Current ADT.

PAVEMENT CONDITION REVIEW

These field test sites were selected to determine the typical pavement surface conditions found in Texas. Chapters 4 through 6 discuss the methods used to evaluate the pavement condition and how that information can be used to effectively adjust binder application rates.

For clarification, some of the terminology used for the description of the surface conditions are as follows:

- "Level-up" is typically material placed by maintenance forces. The material may be hot mixed asphaltic concrete, cold mixed patch material, hot mixed-cold laid patch material, or limestone rock asphalt patch material; however, all are typically considered for rate adjustment as an asphaltic concrete type material or patch.
  - "Dry" refers to a surface that has been in place and is showing effects of oxidation.
  - "Fresh" is a recently placed material that has not had sufficient time to cure.
- "Spot Repairs" are localized repairs by maintenance forces that may have a seal coat or asphaltic concrete surface. The default surface will be asphaltic concrete; however, if a seal coat is the surface, it will be noted in the discussion.
- "Severe Cracking" will not have sealed cracks and the crack will be easily visible.

CHAPTER 4. HIGH DEFINITION VIDEO

BACKGROUND AND OVERVIEW

The Texas A&M Transportation Institute's (TTI's) video logging system shown in Figure 16 was developed to provide TxDOT personnel with a low cost methodology for collecting and processing high definition right-of-way images of the pavement. It consists of:

- A high definition camera located in a weather proof box attached by magnets to the top of the vehicle (mounting brackets for aluminum vehicles will need to be developed).
- A GPS system (attached to the camera box).
- Laptop computer and associated cables.
- Video collection software (PaveScan).
- Video processing software (PaveView).

The system can be attached to any vehicle as the distance information is obtained from the GPS signals. Video data are collected at highway speeds, and examples of the images collected are described in this chapter. The Austin District has six operating video data collecting systems. The Fort Worth, Dallas, El Paso, and Laredo Districts each have a single system.

The system is designed to be low cost and easy to use. There are numerous applications being explored by districts including up-front maintenance needs estimate prior to overlaying, damage estimates in very high ADT locations, use in preconstruction meetings to finalize construction scheduling, and estimating percentage completion in construction projects. The innovative part of the system is the PaveView software allowing estimation and the exporting of results in Excel®.

Figure 16. HDV Logging System.

The benefits of the HDV system for evaluating surface conditions on the test sections from each district will be included in this chapter. Analysis of the video was performed manually using the PaveView software, which was developed by TTI. The software allows the user to quantify the approximate limits of the pavement changes. The limits noted in the software can be exported and then imported into another program, such as Excel, where additional analysis can be performed. Figure 17 is a screenshot of the PaveView Software with the dialog box open. In this screenshot, there are three different pavement conditions, fresh level-up, flushed wheel paths, and dry level-up. It was documented in the software that the fresh level-up was 680 ft in length, then 1093 ft of flushed wheel paths followed by 227 ft of dry level-up. This is just a portion of the roadway, but the full length collected can be quantified in this manner.

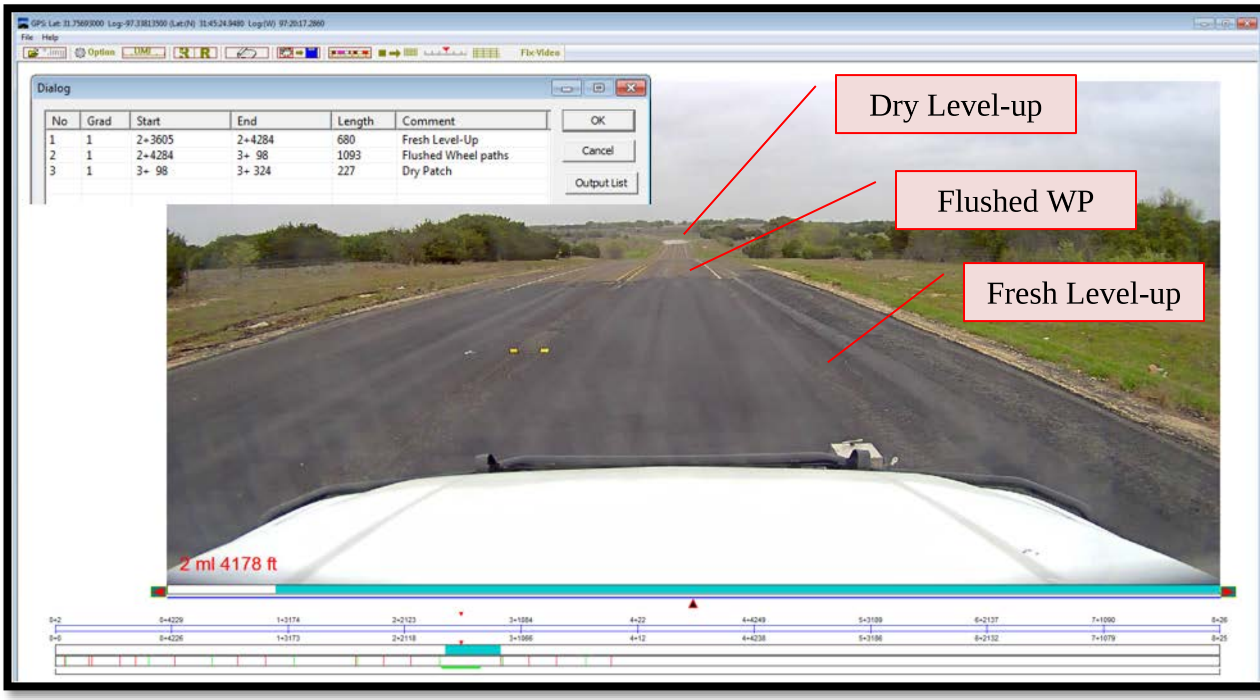


Figure 17. PaveView Software.

FIELD TEST SITE EVALUATIONS

The field test site evaluation portion of this chapter summarizes the analysis performed using the HDV system and PaveView Software for each of the field test sites. The following basic procedure was used for each project:

1. Collect High Definition Video of the roadway.
2. Use PaveView Software to manually visually analyze the video.
    a. Document Conditions in the Crack dialog box.
    b. Output the Crack dialog file.
    c. Load Crack dialog file into Excel.
    d. Calculate area and locations of different pavement conditions.
3. Provide the information to construction personnel to assist with rate adjustments.

Bryan District

FM 158 Eastbound from SH 6 to SH 30

This is an urban four-lane highway with a high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 18:

- Short section of new hot mix inlay.
- Concrete pavement in intersections.
- Number of intersections.

The pavement changes in the eastbound outside lane were sections with newer hot mix and concrete intersections. Based on the analysis, only 2.4 percent of this section has different surface conditions.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.04 gal/sy for traffic, and surface adjustments would range from +0.04 gal/sy to +0.06 gal/sy. This would result in a rate of 0.36 gal/sy over the majority of the section and 0.38 gal/sy over the area with more cracking. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, no additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. It is anticipated that the concrete intersections would not be sealed. This section will be very challenging to construct since there is a high ADT and several intersections. Based on the equipment currently available, the suggestion for this roadway would be to not use variable rate nozzles and increase the application rate slightly over the areas with more cracking.

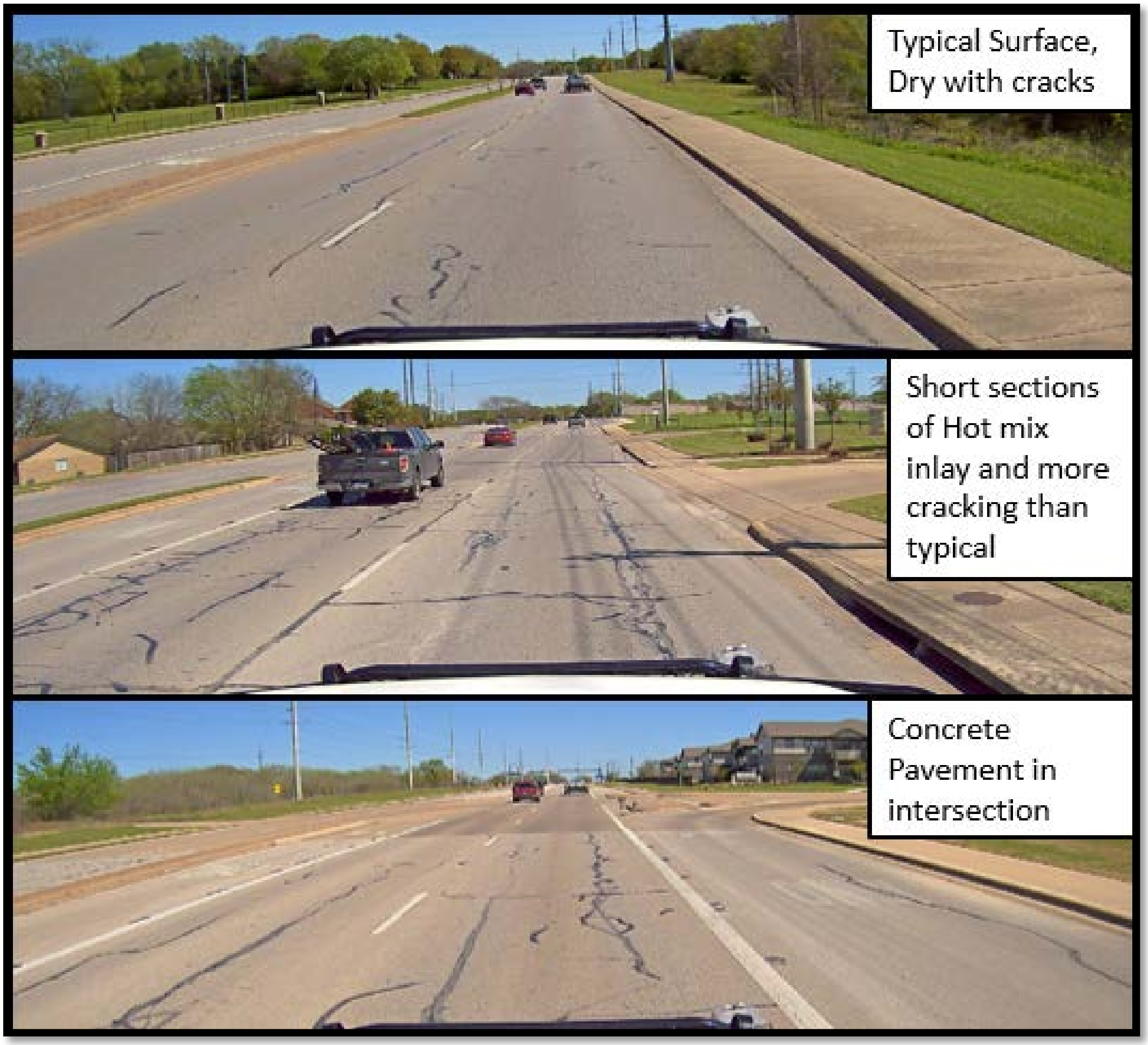


Figure 18. FM 158 Surface Conditions.

FM 974 Westbound from SH 21 to FM 2038

This roadway is a rural two-lane highway with a low ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 19:

- Slight flushing in the wheel paths.
- Short sections of spot repairs, both with seal coat surface or level-up.
- Long sections of level-up, both fresh and dry.
- Loss of aggregate at intersections.
- Severe failures, which will need to be repaired before placing the seal coat.

The pavement changes in the westbound lane were sections with slight flushing (53 percent), level-up [dry (1.6 percent) and fresh (10.7 percent)], patches (16 percent), and severe failures (1.6 percent). The remaining 17 percent would not require adjustments due to surface conditions.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would range from no adjustment to −0.01 gal/sy for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.33 gal/sy over the flushed wheel paths and 0.38 gal/sy over the level-up patches. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, additional binder may be needed outside the wheel paths in the flushed areas with the higher traffic to prevent rock loss. This section will be very challenging to construct since 53 percent of the section may need variable rates. Based on the equipment currently available, the suggestion for this roadway would be to not use variable rate nozzles (since many of the areas are only slightly flushed) and increase the application rate over the level-up patches as they are crossed.

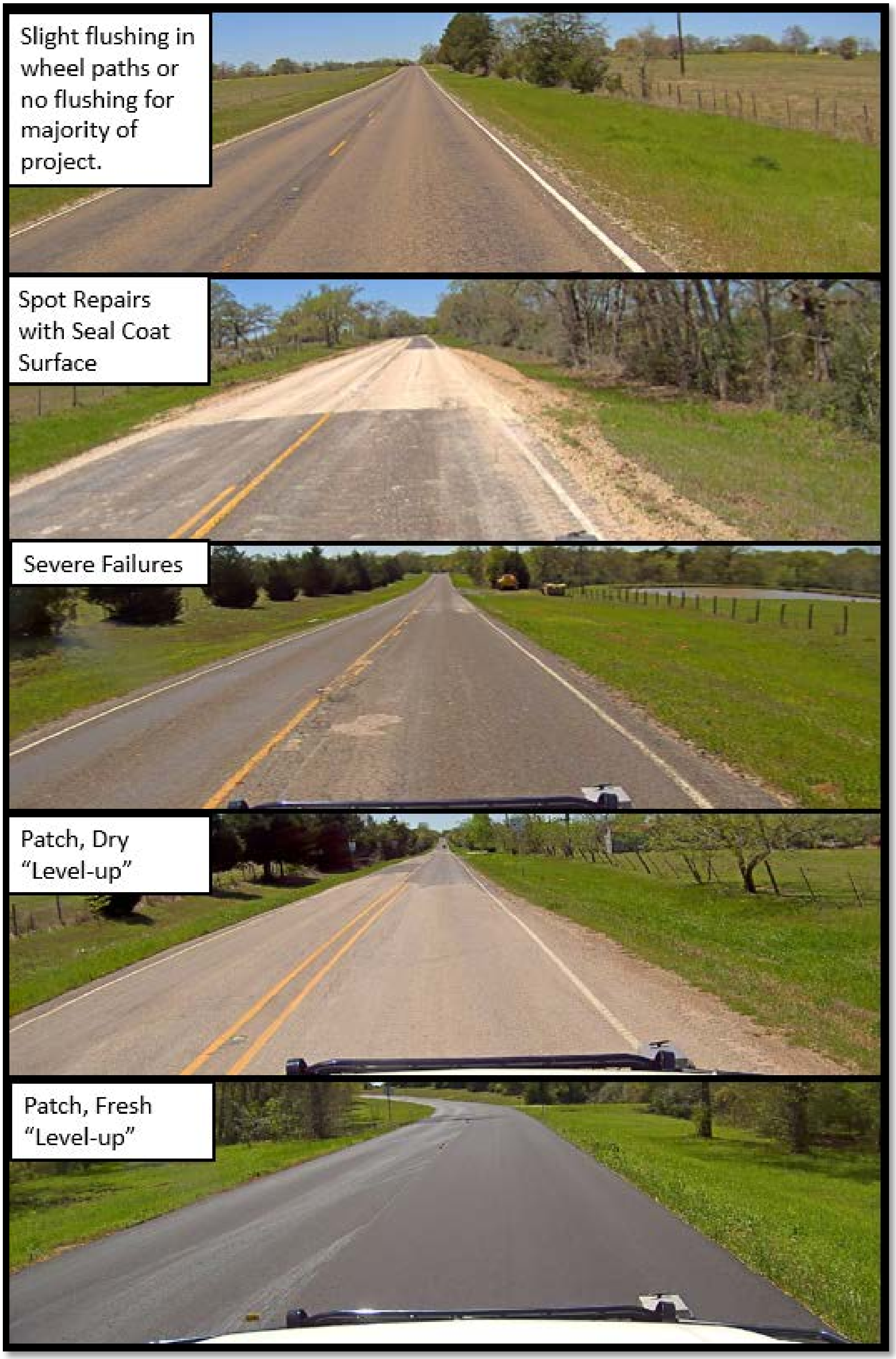


Figure 19. FM 974 Surface Condition.

FM 1452 Westbound from FM 39 to US 190

This roadway is a rural two-lane highway with a low ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 20:

- Slight flushing in the wheel paths.
- Long sections of level-up, dry.
- Loss of aggregate outside wheel paths

The pavement changes in the westbound lane were sections with flushing (78 percent), level-up (dry), patches (22 percent), and rock loss outside wheel paths. The rock loss outside the wheel paths would indicate additional binder is needed to help retain the aggregate.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. No adjustments needed for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.34 gal/sy over the flushed wheel paths and 0.39 gal/sy over the level-up patches. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, additional binder may be needed outside the wheel paths in the flushed areas to prevent rock loss. This section will be challenging to construct since 78 percent of the section may need variable rates. Based on the equipment currently available, the suggestion for this roadway would be to not use variable rate nozzles (since many of the areas are only slightly flushed) and increase the application rate over the level-up patches as they are crossed.

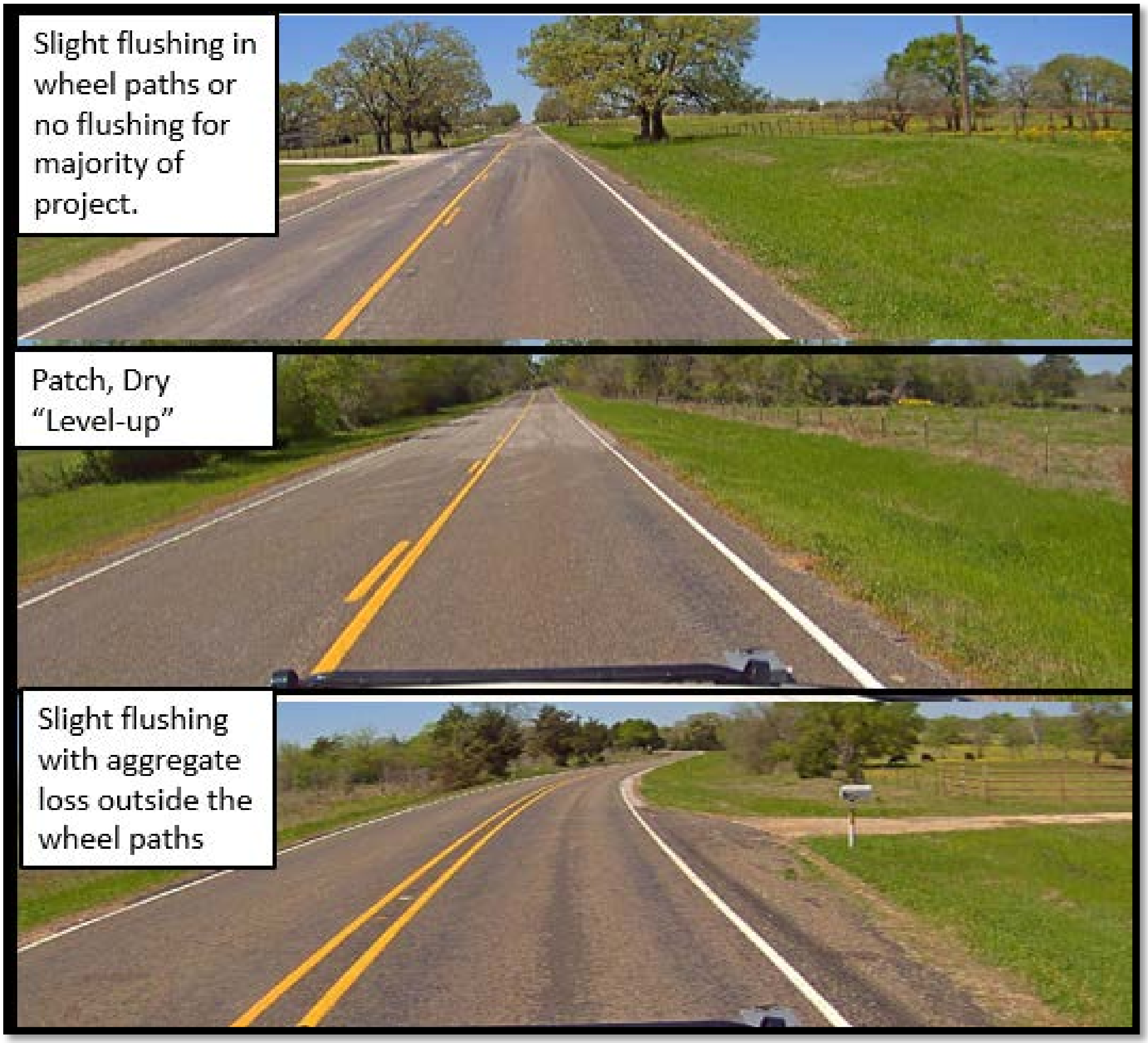


Figure 20. FM 1452 Surface Conditions.

FM 247 Southbound from Madison Co. Line to FM 980

This roadway is a rural two-lane highway with a high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 21:

- Flushing in the wheel paths.
- Long sections of level-up, dry.
- Long sections of spot repairs with seal coat surface and with flushing in spot locations.

The pavement changes in the southbound lane were sections with flushing (85 percent), level-up (dry, 2 percent), and spot repairs with seal coat surfaces (13 percent).

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would range from −0.04 gal/sy to −0.02 gal/sy for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.30 gal/sy to 0.32 gal/sy over the flushed wheel paths and 0.35 gal/sy to 0.37 gal/sy over the level-up patches. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, additional binder may be needed outside the wheel paths in the flushed areas with the higher traffic to prevent rock loss. Based on the equipment currently available, the suggestion for this roadway would be to use variable rate nozzles and fog seal the level-up patches before the seal coat is placed.

Figure 21. FM 247 Surface Conditions.

FM 1774 Northbound from SH 105 to SH 90

This roadway is a rural two-lane highway with a high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 22:

- Slight flushing in the wheel paths.
- Long sections of level-up, dry.

The pavement changes in the northbound lane were sections with flushing (73 percent) and level-up (dry) patches (27 percent).

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would range from −0.04 gal/sy to −0.02 gal/sy for traffic and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate ranging from 0.30 gal/sy to 0.32 gal/sy over the flushed wheel paths and 0.35 gal/sy to 0.37 gal/sy over the level-up patches. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, additional binder may be needed outside the wheel paths in the flushed areas to prevent rock loss. This section will be very challenging to construct since 73 percent of the section may need variable rates. Based on the equipment currently available, the suggestion for this roadway would be to use variable rate nozzles and fog seal the level-up patches before the seal coat is placed.

Figure 22. FM 1774 Surface Conditions.

FM 60 Eastbound from SH 36 to the Beginning of the Overlay in Snook

This roadway is a rural two-lane highway with a high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 23:

- Short sections of spot level-up at culverts.
- Flushed wheel paths.
- Loss of aggregate at intersections.

The pavement changes identified in the eastbound lane were sections with flushing (70 percent), level-up (12 percent), and severe cracking (1 percent). The remaining 17 percent would not require adjustments due to surface conditions.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.04 gal/sy for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.3 gal/sy over the flushed wheel paths and 0.35 gal/sy over the level-up patches. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. This section will be challenging to construct since 70 percent of the section needs variable rates. Based on the equipment currently available, the suggestion for this roadway would be to use variable rate nozzles and fog seal the level-up patches before the seal coat is placed.

Figure 23. FM 60 Eastbound Surface Conditions.

Brownwood District

FM 2231 Westbound from End of Pavement to US 180 N

This is rural two-lane highway with a moderate ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 24:

- Seal coat surface that is dry and cracked.
- Spot locations of rock loss.
- Spot locations of flushing and bleeding.

The pavement changes in the westbound lane were sections with flushing (21 percent) and rock loss (11 percent).

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.33 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.01 gal/sy for traffic, and surface adjustments would range from −0.04 gal/sy to +0.03 gal/sy. This would result in a rate ranging from 0.29 gal/sy to 0.36 gal/sy. Since the original rate needed for proper embedment of the aggregate was 0.33 gal/sy, additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. This section will be very challenging to construct since there is a large variation in rates needed. Based on the equipment currently available, the suggestion for this roadway would be to use variable rate nozzles and adjust the rates over spot locations with flushing.

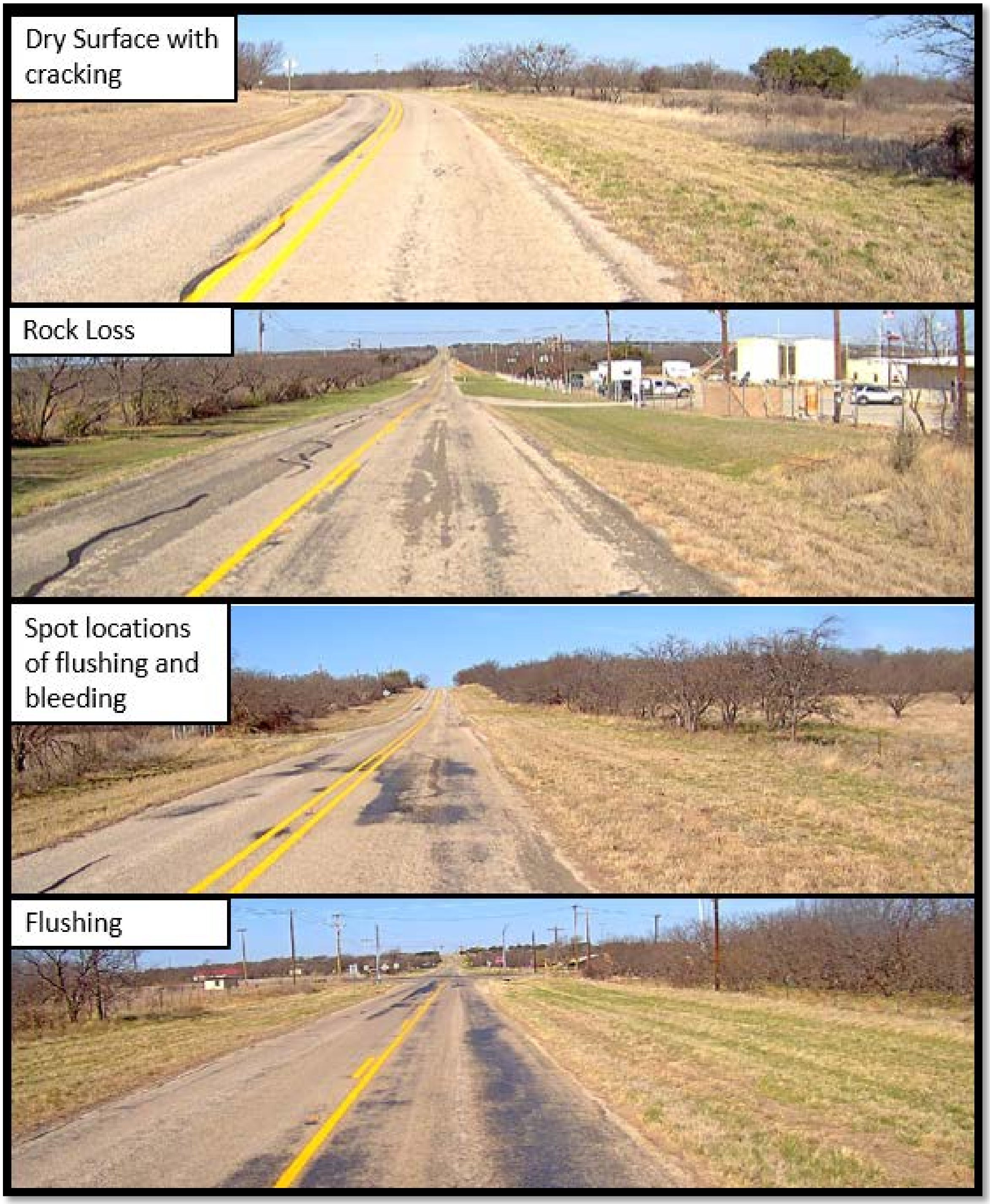


Figure 24. FM 2231 Surface Conditions.

FM 587 Westbound from SH 36 to the Comanche County Line

This is a rural two-lane highway with a low ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 25:

- Short section of flushing or bleeding in intersections and curves.
- Slight flushing mainly in the eastbound lane.
- Narrow lane (appears the wheel paths have shifted close to the centerline).

The pavement changes in the westbound lane were slight flushing (89 percent) and spot locations of flushing and bleeding (11 percent).

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.33 gal/sy before adjustments for traffic or surface conditions. No adjustment would be needed for traffic and surface adjustments would range from −0.04 gal/sy to +0.03 gal/sy. This would result in a rate of 0.29 gal/sy to 0.36 gal/sy. Since the original rate needed for proper embedment of the aggregate was 0.33 gal/sy, additional binder may be needed outside the wheel paths in the flushed areas to prevent rock loss. Based on the equipment currently available and the width of the roadway, the suggestion for this roadway would be to not use variable rate nozzles and adjust the application rate as surface conditions change.

Figure 25. FM 587 Surface Conditions.

SH 36 Westbound from FM 1477 to FM 588

This is a rural two-lane highway with a moderate to high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 26:

- Flushing.
- Bleeding.
- Spot milling.
- Spot level-up.
- Flushing with cracking in wheel paths.
- Full width bleeding with wheel paths treated.

The pavement changes identified by limits in the westbound lane were slight flushing (49 percent), flushing/bleeding (33.2 percent), bleeding (15.8 percent), level up (1 percent), and spot milling (1 percent). Based on the analysis, there is significant variation in the pavement surface.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.33 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.03 gal/sy for traffic, and surface adjustments would range from −0.04 gal/sy to +0.03 gal/sy. This would result in a rate of 0.26 gal/sy over the bleeding section and 0.33 gal/sy over the area with more cracking, milling, and level-up. Since the original rate needed for proper embedment of the aggregate was 0.33 gal/sy, additional binder would be needed outside the wheel paths in the flushed and bleeding areas to prevent rock loss. This section will be very challenging to construct due to the bleeding wheel paths. Based on the equipment currently available, the suggestion for this roadway would be to use variable rate nozzles and increase the application rate slightly over the areas with more cracking, level-up, and milled surface. Fog seal could also be considered over the level-up areas.

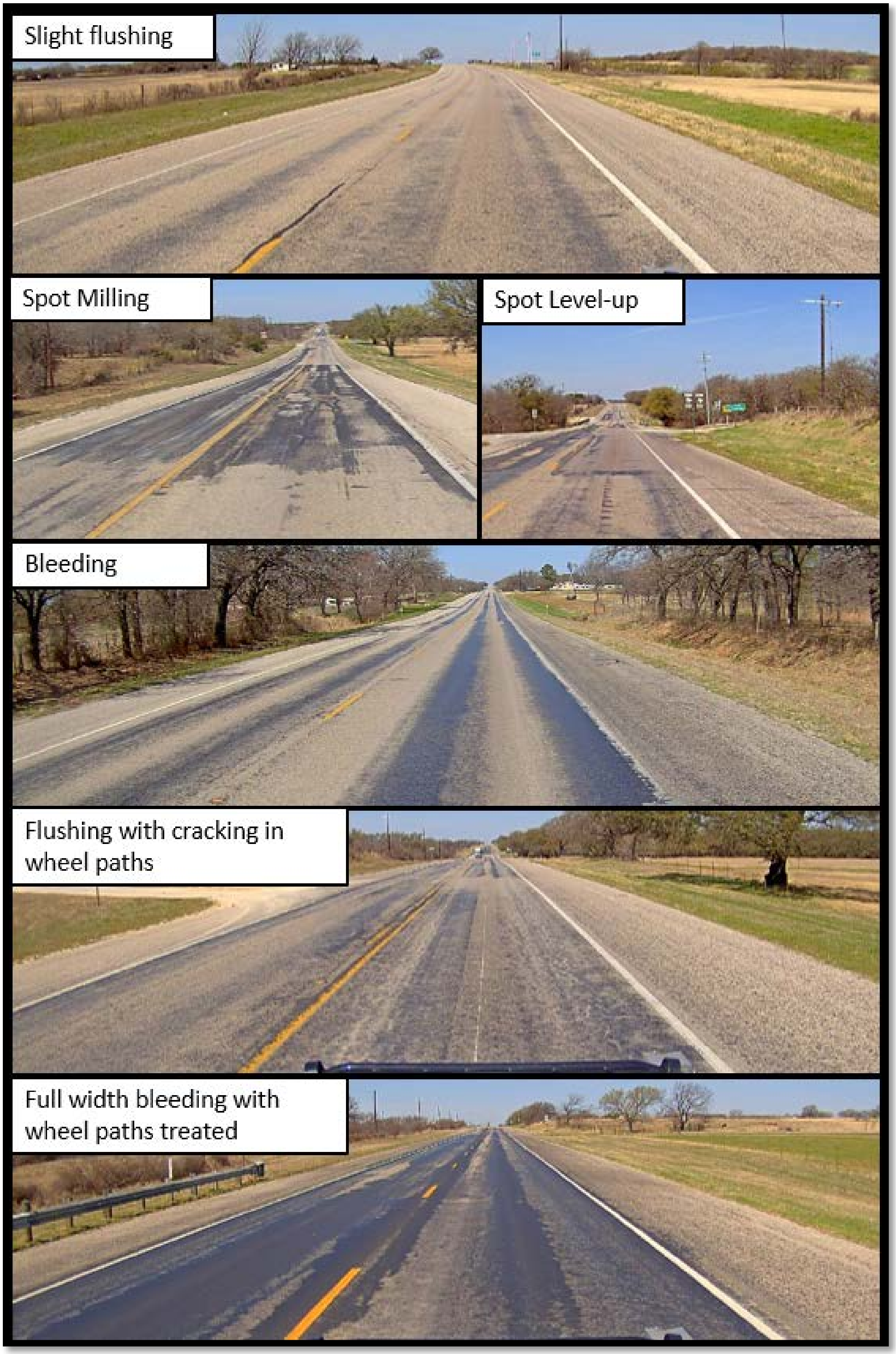


Figure 26. SH 36 Surface Conditions.

US 180 Eastbound from FM 3099 to Rose St.

This is a four-lane highway with a continuous two-way left turn lane (CTWLTL) in a small town with a high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 27:

- Flushing for majority of project.
- Short sections of level-up, dry.
- Spot locations of flushing and cracking.
- Several driveways and intersections.

The pavement changes in the eastbound outside lane were flushing (87 percent), flushing with cracking (8 percent), and level up (5 percent). All lanes have flushing accept the CTWLTL.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.33 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.04 gal/sy for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.27 gal/sy over the majority of the section and 0.32 gal/sy over the area with more cracking and level up. The shoulders and CTWLTL would need a higher rate since the traffic volume is less than in the lanes. However, it is hard to estimate how much lower, so it is suggested to start at 0.33 gal/sy. Since the original rate needed for proper embedment of the aggregate was 0.33 gal/sy, additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. This section will be very challenging to construct since there is a high ADT and several intersections and driveways. Based on the equipment currently available, the suggestion for this roadway would be use variable rate nozzles in the lanes, but not on the shoulders or CTWLTL, and increase the application rate slightly over the areas with more cracking.

Figure 27. US 180 Surface Conditions.

US 183 Southbound from SH 206 to IH 20 N. Fr.

This is a two- to four-lane highway in a small town with a high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 28:

- Oxidized surface.
- Cracking.
- Patches.
- Dry level-up.
- Several driveways and intersections.

The pavement changes identified by limits in the southbound outside lane were oxidized pavement (49 percent) and within the oxidized pavement there was cracking (23 percent), patches (2 percent), level up (4 percent), and raveling (4 percent). The remaining 51 percent of the pavement has an asphaltic concrete surface in good condition.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.33 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.04 gal/sy for traffic, and surface adjustments would range from +0.02 gal/sy to +0.06 gal/sy. This would result in a rate of 0.31 gal/sy over the majority of the section and 0.35 gal/sy over the area with more cracking (unless the cracks are sealed before the seal coat is placed). Since the original rate needed for proper embedment of the aggregate was 0.33 gal/sy, additional binder would may be needed outside the wheel paths in the flushed areas to prevent rock loss. This section will be very challenging to construct since there is a high ADT and several intersections. Based on the equipment currently available and the percent rate change typically available, the suggestion for this roadway would be to not use variable rate nozzles and increase the application rate slightly over the areas with the more oxidized surface and cracking.

Figure 28. US 183 Surface Conditions.

US 67 Eastbound from 0.8 mi. East of FM 503 to Runnels Co. Line

This is a rural two-lane highway with a high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 29:

- Short sections of level-up, dry.
- Flushing.

The pavement changes in the eastbound lane where sections with flushing and level-up (<1 percent). Based on the analysis, the changes from no/slight flushing to more severe flushing were variable and occurred for the length of the project. No locations of severe bleeding were noted.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.33 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.04 gal/sy for traffic and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.27 gal/sy to 0.29 gal/sy over the majority of the section and 0.32 gal/sy over the area with level-up. Since the original rate needed for proper embedment of the aggregate was 0.33 gal/sy, additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. This section will be challenging to construct since there is lot of variability in the surface. Based on the equipment currently available, the suggestion for this roadway would be to use variable rate.

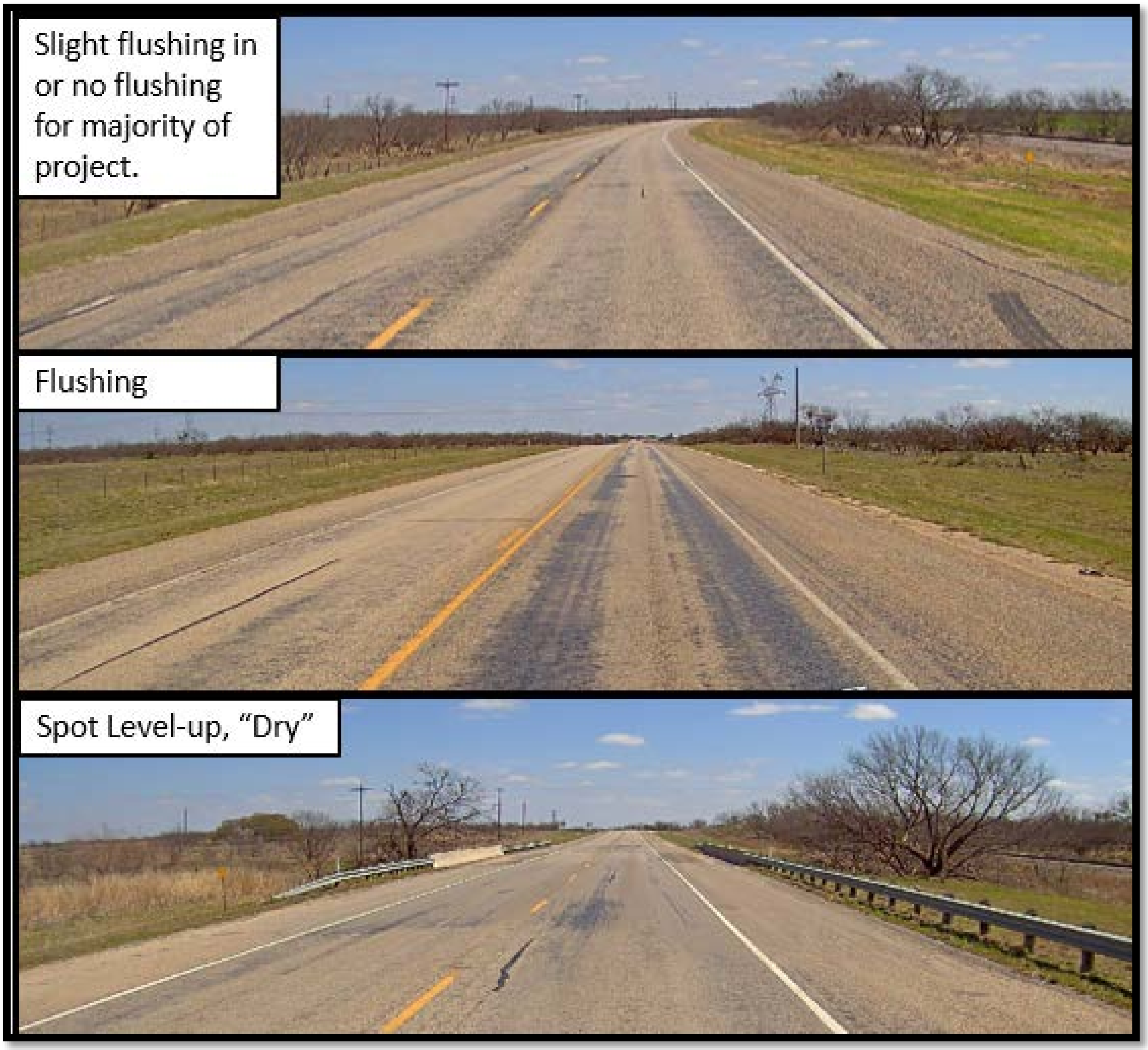


Figure 29. US 67 Surface Conditions.

Waco District

FM 2484 Eastbound from SH 195 to IH 35

This is a rural two-lane highway with a moderate to high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 30:

- Several short sections of level-up, both fresh and dry.
- Long sections of asphaltic concrete surface (overlay).
- Flushing with rock loss.
- Flushing primarily in the right wheel path.

The pavement changes in the southbound outside lane were overlay (14 percent), level-up (24 percent), and raveling (5 percent). The remaining 57 percent of the pavement has seal coat surface with flushing; however, in several areas the flushing is worse in the outside lane.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would range from −0.04 gal/sy to −0.02 gal/sy for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of ranging from 0.30 gal/sy over to 0.37 gal/sy. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. This section will be very challenging to construct since there frequent short level-up locations. Based on the equipment currently available, the suggestion for this roadway would be to not use variable rate nozzles due to the amount of asphaltic concrete present and frequency of the short sections of level-up.

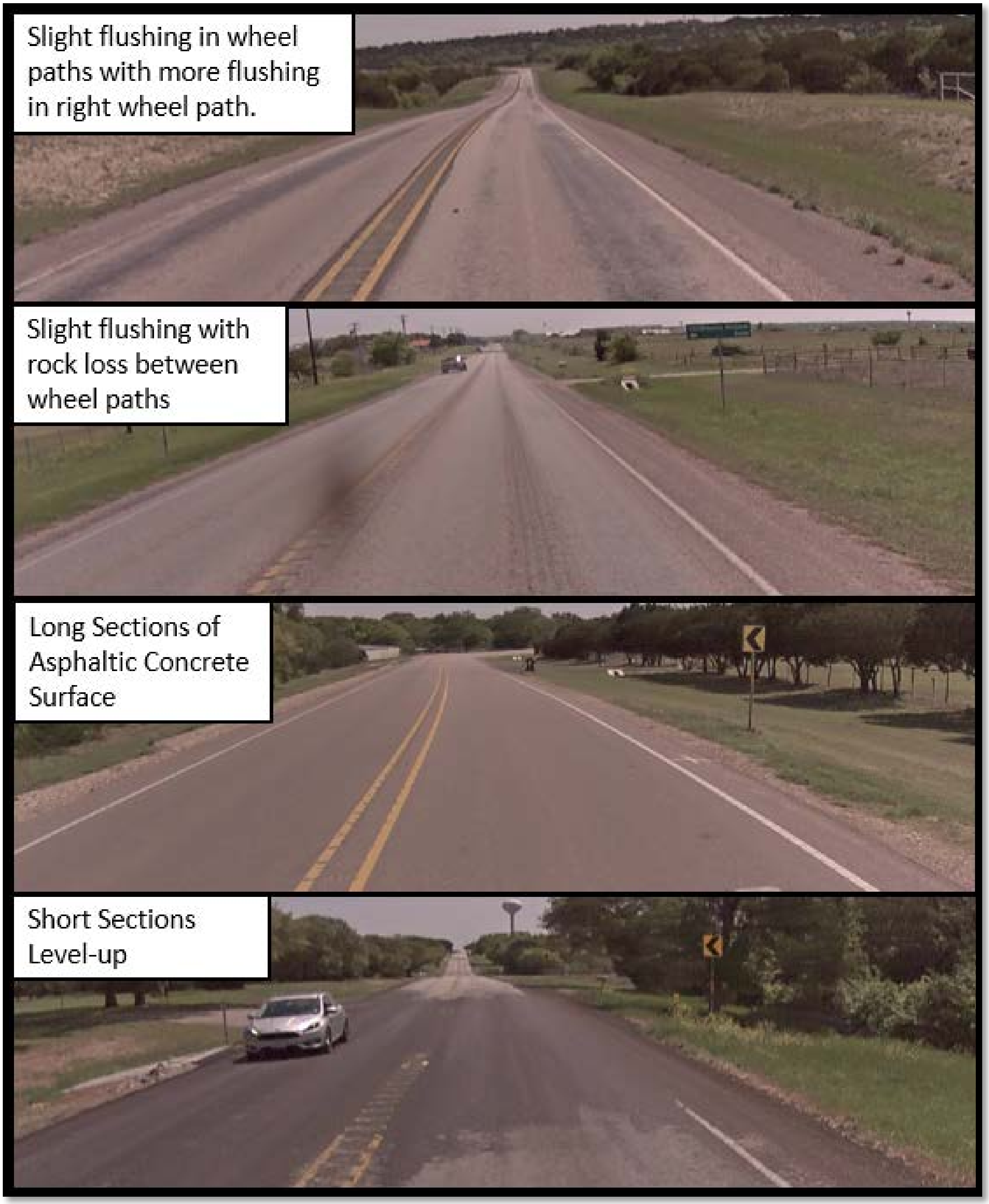


Figure 30. FM 2484 Surface Conditions.

FM 2490 Southbound from FM 56 to McClennan Co. Line

This is a rural two-lane highway with moderate ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 31:

- Short sections of level-up.
- Flushing wheel paths with rock loss outside wheel paths.

The pavement changes in the southbound outside lane were level up (9 percent) and flushing with rock loss (91 percent).

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.02 gal/sy for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.32 gal/sy over the majority of the section and 0.37 gal/sy over the area with level-up. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. Based on the equipment currently available, the suggestion for this roadway would be to use variable rate nozzles and increase the application rate slightly over the areas with level-up or fog seal the level-up areas before the seal coat is placed.

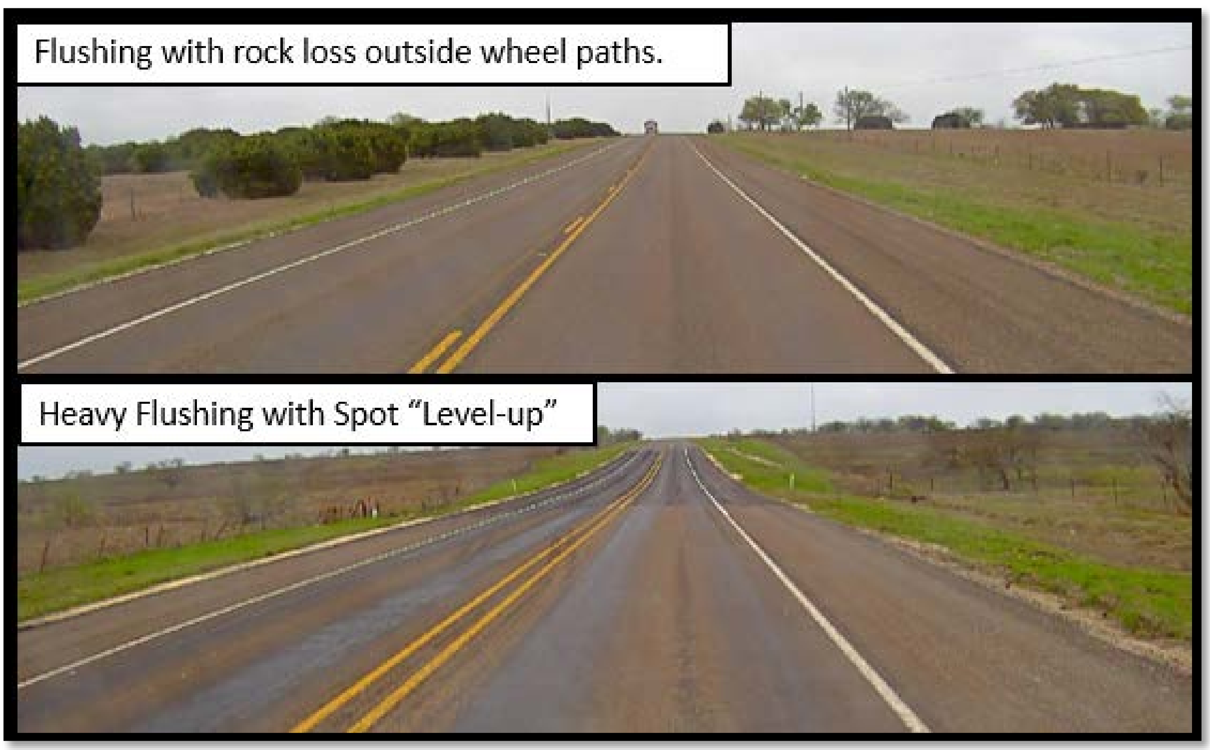


Figure 31. FM 2490 Surface Conditions.

FM 339 Northbound from US 84 to Hill Co. Line

This is rural two-lane highway with a low ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 32:

- Patch, fresh level-up.
- Flushing.
- Milled surface.

The pavement changes in the northbound lane were fresh level-up (38 percent), flushing (18 percent), and milled surface (4 percent). The remaining 40 percent of the pavement has a seal coat in good condition.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.33 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be +0.04 gal/sy for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.35 gal/sy over the flushed areas up to 0.4 gal/sy over the area with fresh level-up. Since the original rate needed for proper embedment of the aggregate was 0.33 gal/sy, no additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. Based on the equipment currently available, the suggestion for this roadway would be to not use variable rate nozzles.

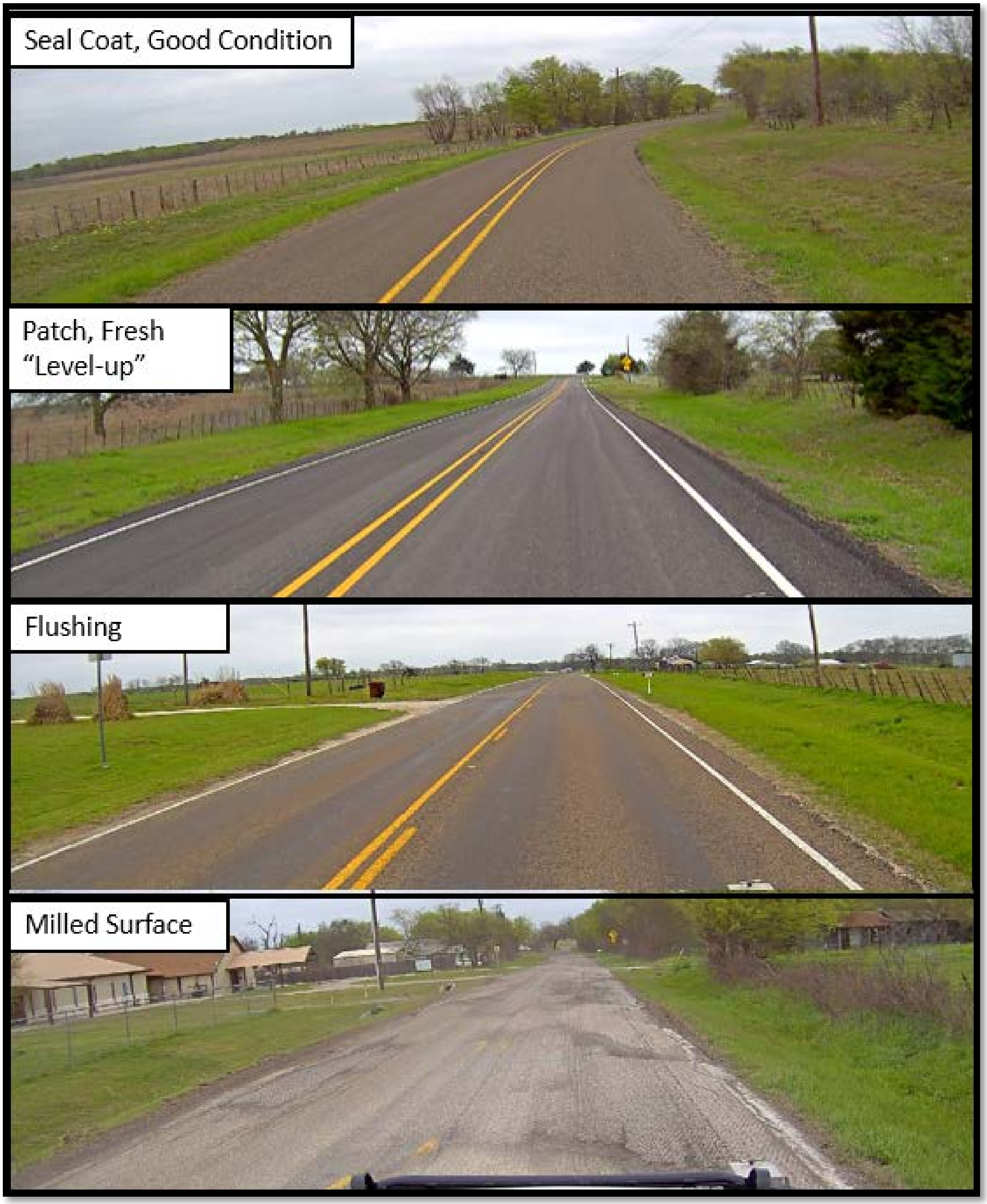


Figure 32. FM 339 Surface Conditions.

SH 174 Southbound from Johnson Co. Line to Bosque Co. Line

This is a rural two-lane highway with a high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 33:

- Flushing.
- Fresh level-up.
- Variable level-up, fresh and dry.

The pavement changes in the northbound lane were fresh level-up (35 percent), variable level-up (47 percent), and flushing (18 percent).

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.04 gal/sy for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.30 gal/sy over the flushed section and 0.35 gal/sy over the area with level-up. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. This section will be very challenging to construct since the surface condition varies transversely but not uniformly in the level-up area, and there are short sections of flushing between the level-up. Based on the equipment currently available, the suggestion for this roadway would be to not use variable rate nozzles over the majority of the area with the level-up. However, there is a long section, approximately 1.8 miles, near the Bosque County line that is flushed where applying variable rates would help the new seal coat.

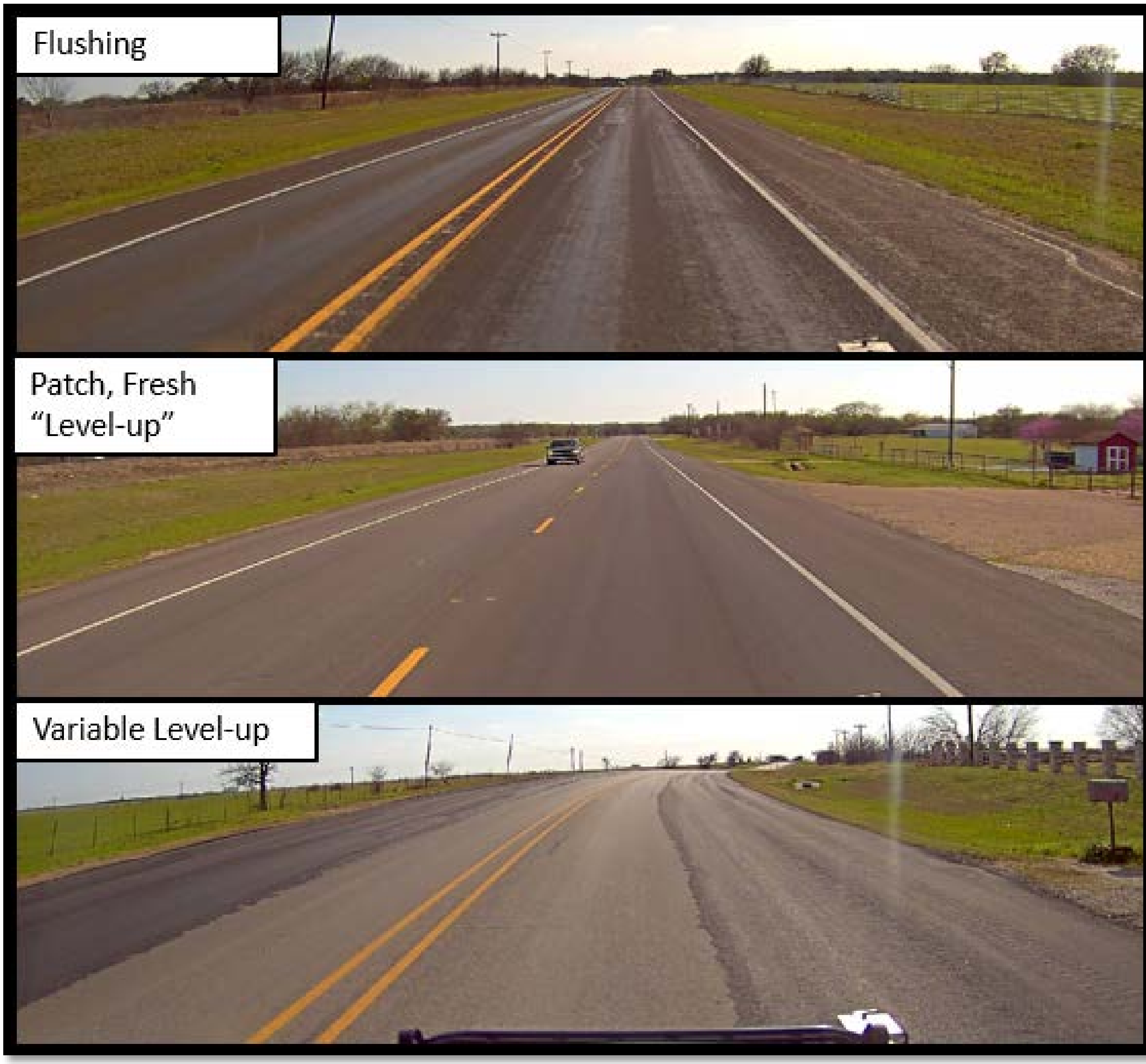


Figure 33. SH 174 Surface Conditions.

SH 31 Eastbound from McClennan Co. Line to 0.4 mi South of CR 3266

This is a rural four-lane divided highway with a high ADT. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 34:

- Dry with some cracks.
- Dry with many cracks.
- Dry level-up.

The pavement changes in the southbound outside lane were level-up (5 percent), some cracking (24 percent), and many cracks (10 percent). The remaining pavement is in good condition with few cracks.

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.04 gal/sy for traffic and surface adjustments would range from +0.03 gal/sy to +0.06 gal/sy. This would result in a rate of 0.35 gal/sy over the majority of the section and 0.38 gal/sy over the area with more cracking. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, no additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. Based on the equipment currently available, the suggestion for this roadway would be to not use variable rate nozzles and increase the application rate slightly over the areas with more cracking.

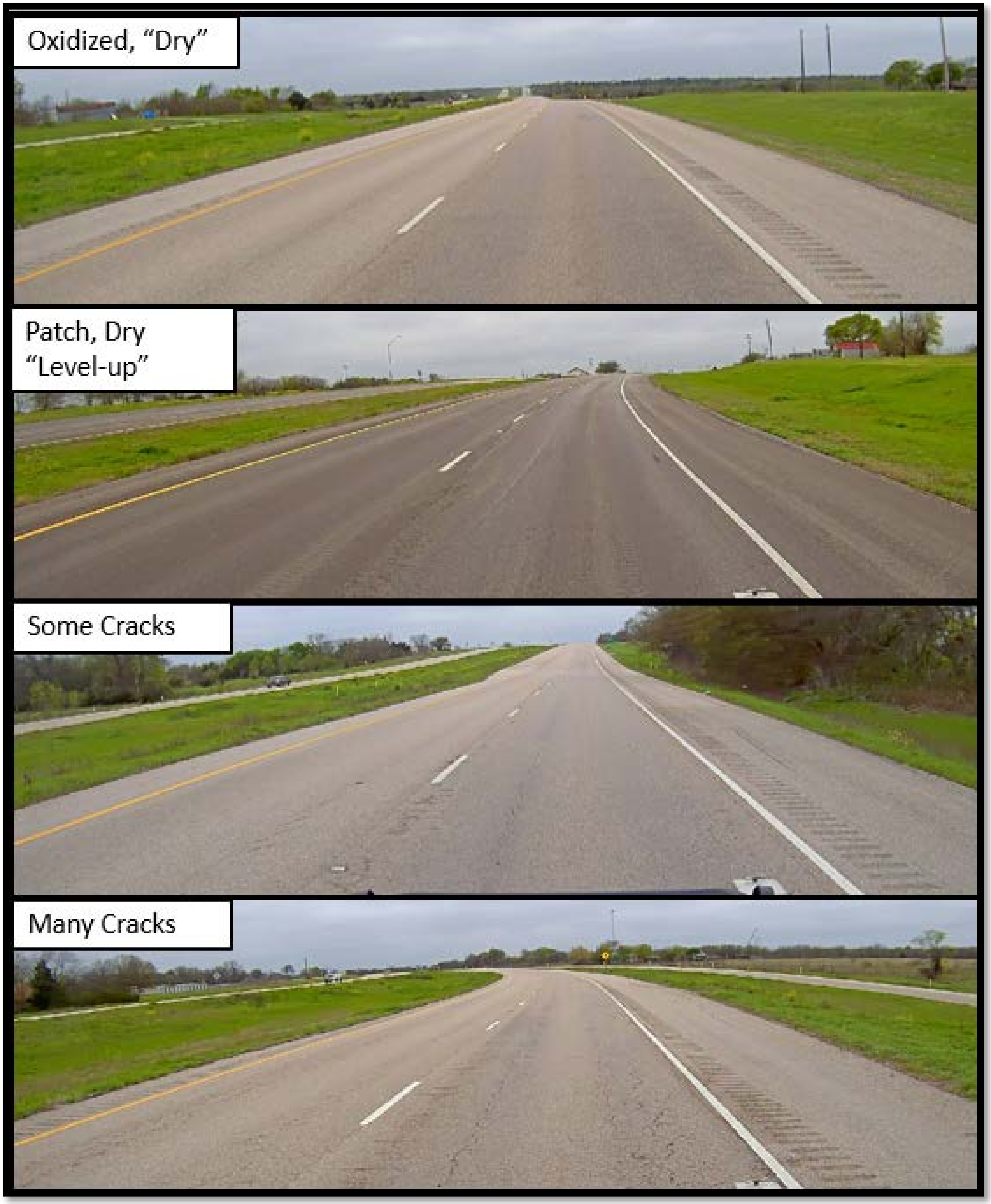


Figure 34. SH 31 Surface Conditions.

SH 36 Eastbound from BU 36 to 0.7 mi. West of FM 931

This is rural highway with a high ADT that varies from two lanes to four lanes with a CTWLTL for approximately half the project. The challenges to designing a successful seal on this roadway are as follows and shown in Figure 35:

- Long and short sections of level-up or asphaltic concrete pavement.
- Flushing and rock loss.

The pavement changes in the eastbound outside lane were new asphaltic concrete pavement and level-up (33 percent) and flushing with rock loss (67 percent).

Example Scenario

Assume a grade 4 aggregate, and the binder application rate was determined to be 0.36 gal/sy before adjustments for traffic or surface conditions. The adjustments needed would be −0.04 gal/sy for traffic, and surface adjustments would range from −0.02 gal/sy to +0.03 gal/sy. This would result in a rate of 0.30 gal/sy over the locations with seal coat surface and 0.35 gal/sy over the area with asphaltic concrete. Since the original rate needed for proper embedment of the aggregate was 0.36 gal/sy, additional binder would be needed outside the wheel paths in the flushed areas to prevent rock loss. Additionally, the shoulders and CTWLTL would need additional binder to prevent rock loss due to the lower traffic volumes. Based on the equipment currently available, the suggestion for this roadway would be to use variable rate nozzles on the lanes that currently have seal coat surfaces and not use variable rates over the other areas (including wide shoulders and CTWLTL).

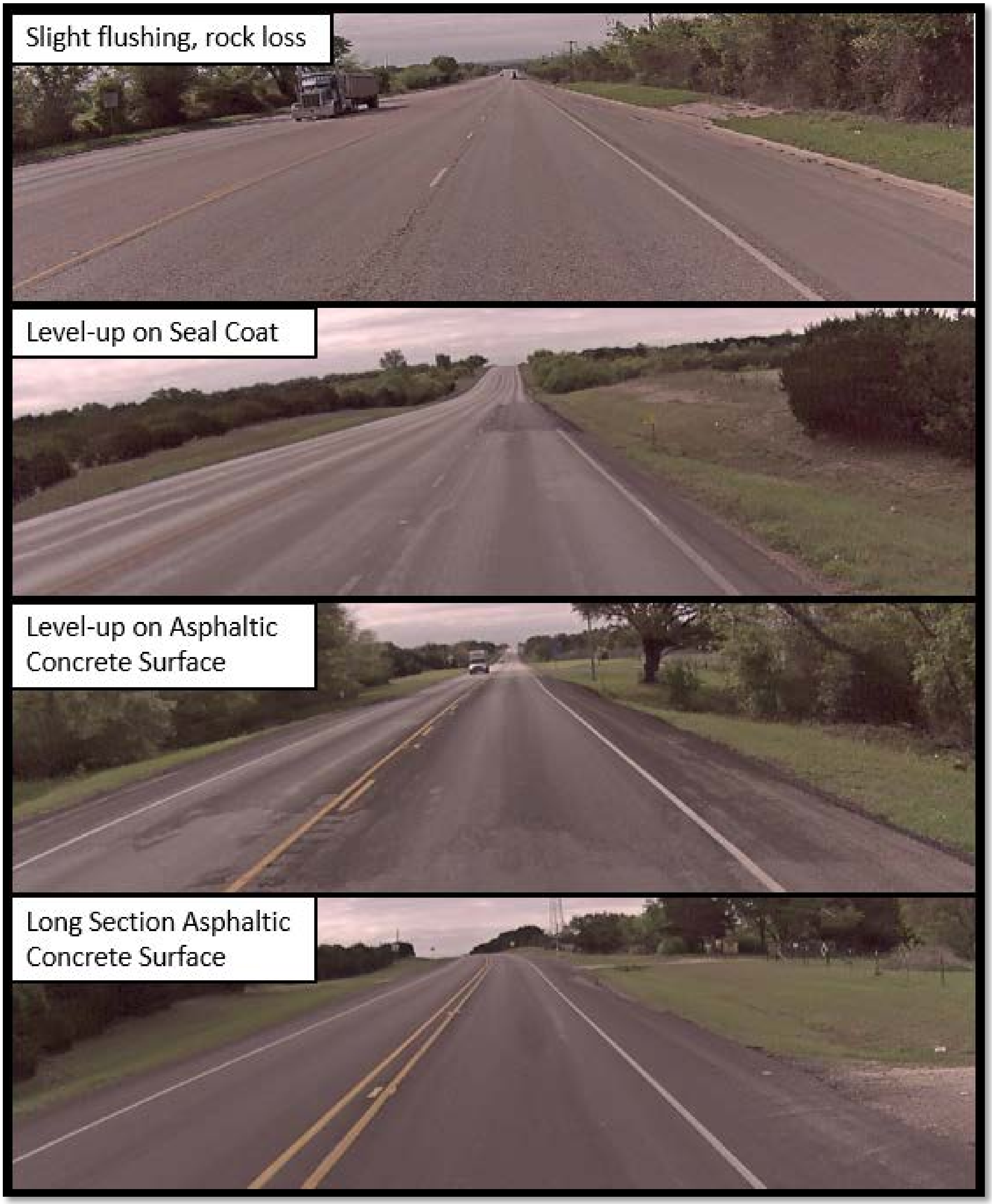


Figure 35. SH 36, Waco District, Surface Conditions.

SUMMARY

A successful seal coat project relies on field adjustments to application rates. Visual inspection of candidate roadways or roadway segments for the seal coat program provides valuable information about the existing roadway surface. However, visual inspection is time consuming, labor intensive and is a safety concern since personnel are on the pavement or in a slow-moving vehicle within traffic.

HDV provides a method to document the existing pavement condition at highway speeds using a camera mounted to a mobile vehicle. Along with the video logging system, software is available to help the designer document pavement condition changes. This method offers an alternative to visual field inspection. The ability to collect data at highway speeds mitigates safety concerns by providing a safe method to collect pavement condition information.

While video logging mitigates safety concerns, processing the data and gathering useful information from the data often requires manually watching the video to identify surface changes and locations for design changes. The labor-intensive nature of this method makes it less attractive and can also lead to potential errors as manually watching video can lead to improper identification or grouping. However, the HDV system is ready to implement and safer than the current visual inspection methods. Additionally, there are several uses of the video including visual tracking of pavement changes and availability to view the video at meetings to discuss potential issues with the project.

CHAPTER 5. MOBILE LIDAR

Visual inspection and video logging roadways offer TxDOT districts the ability to identify pavement surface changes. Knowing the location of these changes strengthens the design process by identifying locations where rate changes are required. In addition to identifying the location where rate changes are required, the length and extent of these changes provide valuable plan information. Within this study, mobile LiDAR is being evaluated as a tool that can identify pavement surface changes through automated means. The ability to identify the location and extent of pavement surface changes in an automated fashion has the potential to alleviate much of the labor burden associated with seal coat design.

MOBILE LIDAR BACKGROUND INFORMATION

The use of mobile LiDAR (or mobile laser scanner [MLS]) to measure and inventory infrastructure attributes is on the rise. The common components of MLSs include the hardware technology mounted to the vehicle, the in-vehicle software interface for data collection, and the software package for post-processing. The MLSs used in this study included the Road Doctor CamLink camera, a single SICK laser scanner, a NovAtel GPS, a NovAtel inertial measurement unit, a 3D accelerometer, Road Doctor CamLink 7.0 in-vehicle software, and Road Doctor 3 post-processing software. The laser scanner package was constructed by Roadscanners Oy of Finland. Two primary pieces of data are generated by the laser: the reflectivity of the target object and the straight-line distance to the object in relation to the angle of the laser. The reflectivity of the target surface is of primary importance in this study.

Figure 36 illustrates the geometry associated with LiDAR measurements. The α value represents the angular resolution. Angular resolution is defined as the angular movement in the laser between measurements. In this study, the angular resolution is 0.6667°. The angular resolution increment spacing does not change so more data points are collected near the laser source. Therefore, the amount of data, or point density, in the data collection lane is high. In fact, at near highway speeds, cross sections are generated at less than 1 ft apart with reflective measurements taken less than 2 in. apart moving across the lane. Within each 100 ft station, across the 9 ft from wheel path to wheel path approximately 6,500 reflective measurements were provided. Figure 37 shows the mobile LiDAR unit used within this study.

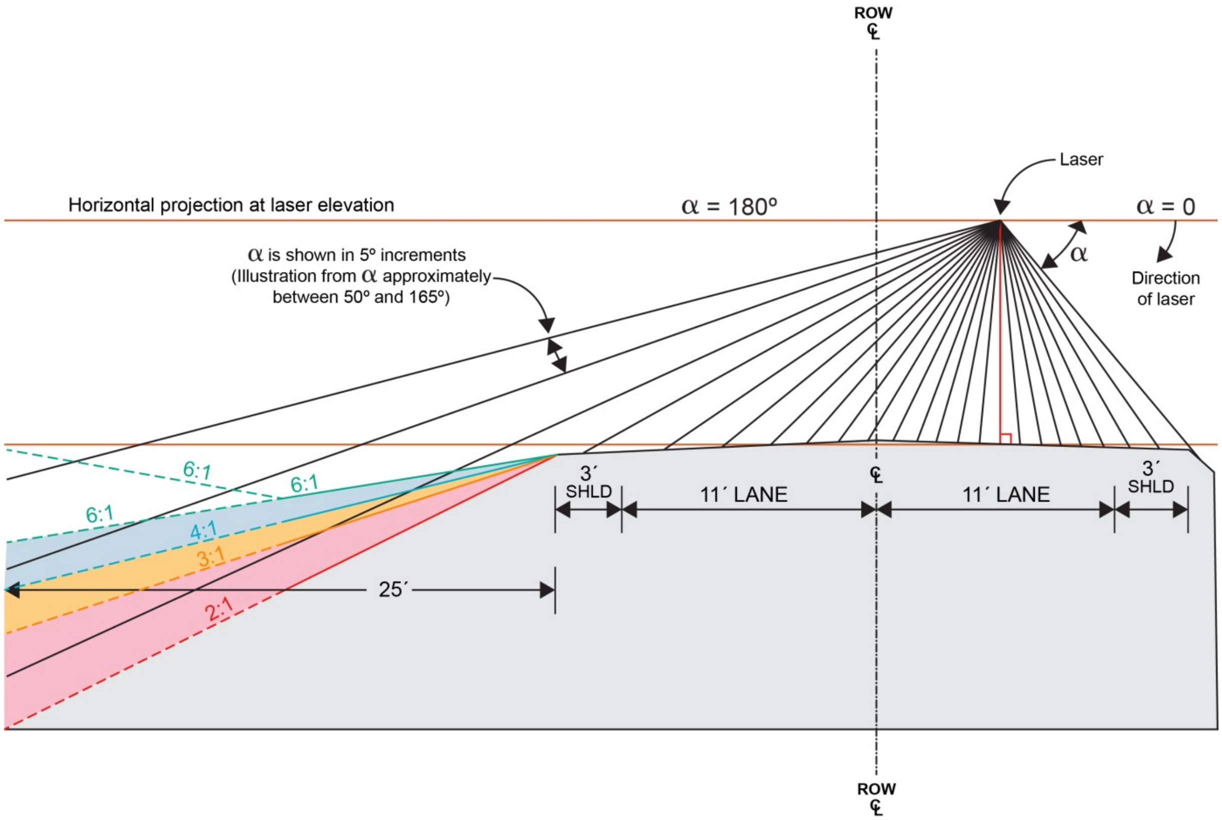


Figure 36. Transverse Laser Geometry.

Figure 37. TTI Mobile LiDAR Unit.

MOBILE LIDAR PROCESS FOR SURFACE DETECTION

As described in the previous section, the point density in the data collection is very high, so only mobile LiDAR data from the data collection lane were used to classify the pavement surface. The data collection lane was divided into three parts: the left wheel path, between the wheel paths, and the right wheel path. The reflectivity data for each of these portions of the data collection lane were gridded for additional analysis. The grid size used to extract reflectivity data was 1 ft long by 4 in. wide across a 3-ft wheel path area and 3-ft area between wheel paths. Therefore, within each 100-ft station, each wheel path and the area between wheel paths had 900 reflectivity values, respectively.

The initial step in automating the surface analysis was to reduce the reflectivity scale from 0 to 255 to something more manageable. A K-means clustering algorithm was used to accomplish this reduction. The K-means clustering algorithm is a form of machine learning within the world of artificial intelligence.

Machine learning can be defined in simple words as improving the performance of a task with experience. Machine learning tasks are classified as supervised learning or unsupervised learning. The difference in these categories is whether data are labeled or not. When labeled, linear and logistic regression, support vector machine, and neural networks provide efficient and reliable solutions. Algorithms try to learn the relationship between the input (training data) and facts (labels) provided, and then map the relationship learned to the new data. However, many real-world problems have unlabeled data.

Unsupervised learning is used to model unclassified and unlabeled data using clustering techniques. This basically becomes a density estimation problem in statistics. Google News is an example of unsupervised learning. There are thousands of articles available on the same topic, which happened at different time instances and different parts of world. Google clusters them and presents it to the user. Other applications of unsupervised learning include astronomical data analysis, social network analysis, organizing computer clusters, etc.

The raw reflective mobile LiDAR data of roadway surfaces function as data distributed between values of 0 and 255. Figure 38 shows the visualization of the LiDAR data of the left wheel path for FM 339. The variations in the intensity can be interpreted as pavement surface differences. Darker surfaces are less reflective and can indicate flushed wheel paths. Uniform surface reflectivity from wheel path to wheel path indicates a uniform surface, whereas different reflective values from wheel path to wheel path indicates different amounts of flushing. This logic is currently used by practitioners to adjust seal coat rates. These logical principles can be combined with automated techniques to improve the sealcoat analysis and better inform design.

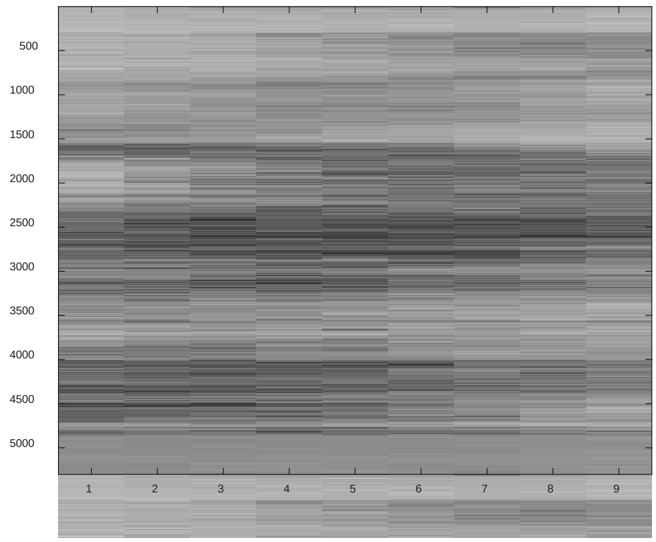


Figure 38. Left Wheel Path Segment of FM 339 Roadway.

One way of analyzing these data is to analyze each value in brute force manner and extract some useful information or pattern. This process may yield good results for short lengths, but the manual effort is large and presents no improvement from current visual evaluations. Also, this process makes the annotation process unrelative.

As mentioned earlier, LiDAR reflective data are initially stored as a single value between 0 and 255. Depending upon the surface, different reflective values inform the decision maker about the characteristics of the roadway. For the case study on FM 339, the existing surface was a seal coat. A control section of 300 ft (3 stations) was chosen that provide reflective values of the desired surface. Using these reflective values, darker reflectivity values indicated a surface that has more binder near the surface and should have a different shot rate. Based on these facts, data can be clustered into different groups, wherein each group represents an index of surface characteristics. K-means algorithm was employed to cluster the raw data.

K-means clustering is an unsupervised learning technique, which results in a distribution consisting of only K values. K-means algorithm determines the underlying structure of unlabeled data. K-means clustering algorithm groups the raw data into K groups based on distance measure. In other words, K-means divides the data into K-clusters, returning the centroids of the data and a new classified distribution. The value of K plays a crucial role in the analysis and differs from problem to problem. The best value of K is automatically determined after initial data visualization using an assumed K value. In this project, after few trial runs and analysis, K=7 was chosen to be the desired initial value.

The K-clusters reduced the scale from 0 to 255 to 0 to 7 or whatever values less than 7 is chosen by the algorithm. The scale reduction ultimately allows for the classification of the surface more efficiently and in an automated fashion.

The algorithm initially considers random centroids and starts tuning them based on the distance measure. The objective is to minimize the within-cluster distances between points and their respective centroid. Hence this is an iterative process. Since it is a numerical solution, the algorithm stops when no data points change (the sum of the distances in minimized) or when the mentioned number of iterations are completed.

A formal way of writing objective of K-means algorithm is: given a set of observations (**x**$_1$, **x**$_2$, . . . **x**$_n$), where each observation is a *d*-dimensional vector, K-means clustering aims to partition the *n* observations into *k(≤n)* sets **S** = {S$_1$, S$_2$, ... S$_k$} to minimize the within-cluster sum of squares, in other words variance. This objective can be represented as:

$$\arg\min_{S} \sum_{i=1}^{k} \sum_{x \in S_i} \left|\left|x - \mu_i\right|\right|^2 = \arg\min_{S} \sum_{i=1}^{k} |S_i| Var S_i$$

Once the data are clustered into seven groups, in this case of reflectivity data returned by LiDAR, unnecessary groups that are very close to each other can be grouped together for additional scale reduction. This is because the data returned by LiDAR will be in the range of 0 to 255, with the most reflective value as 255 and the least reflective value as 0. It can be assumed that portions of the road section with reflective values greater than 220 is the lane or edge striping. Hence this cluster can be merged with the nearest cluster. Similarly, any clusters within difference of 10 can be clustered as they share common features. Suppose the K-means determined centroids at (154, 162, 167, 172, 177, 183, 199), the newly merged clusters would be {(154,162), (167,172), (177,183), 199}. This kind of dynamic grouping can lead to better results and proper ratings to the sections.

Figure 39 and Figure 40 show a section of FM 339. These sections are 5000-ft long by 3-ft wide divided into 100-ft stations with 9 reflectivity value at each 1-ft cross section. K-means algorithm is applied to the entire segment along with the control sections placed on top of each segment. This makes sure the clustering is relative to the control sections, which are assumed to be in perfect or as-expected surface condition. Appending the control section also assures the relative analysis of the rating.

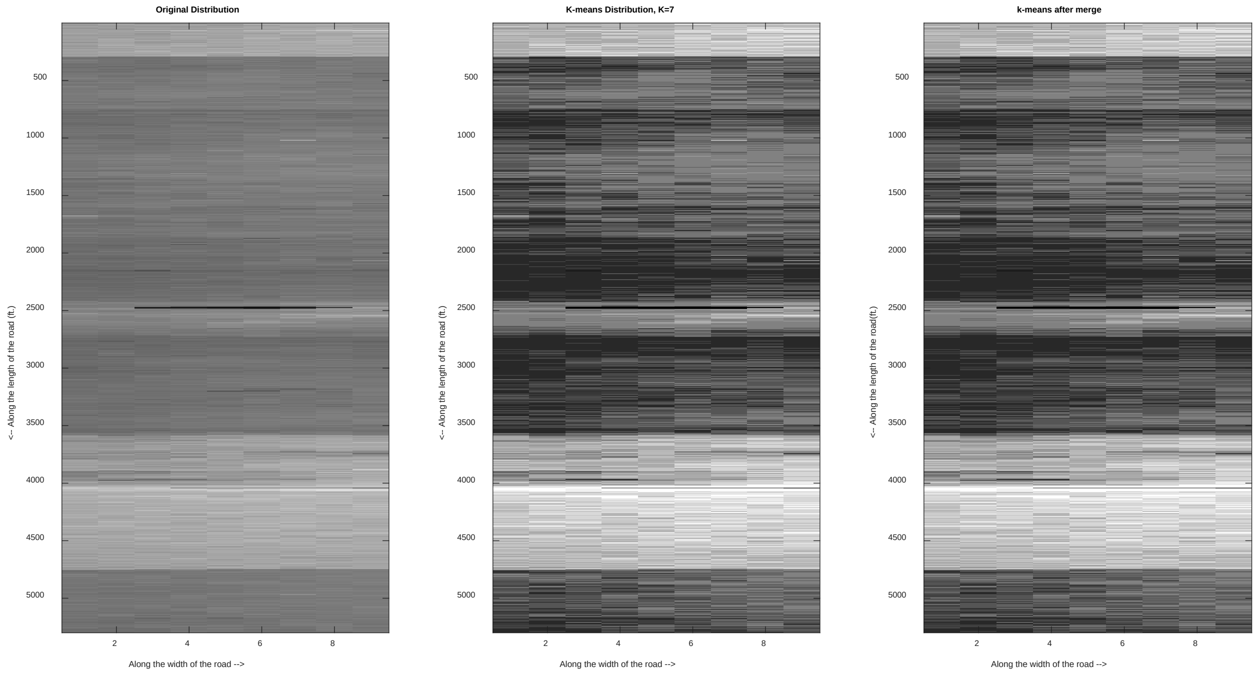


Figure 39. Right Wheel Path of FM 339 Roadway; the Left Most Image Depicts the Actual Roadway, the Middle Image Is the Output of K-means Algorithm, and the Right Most Image Is the K-means Image after Merging Few Groups.

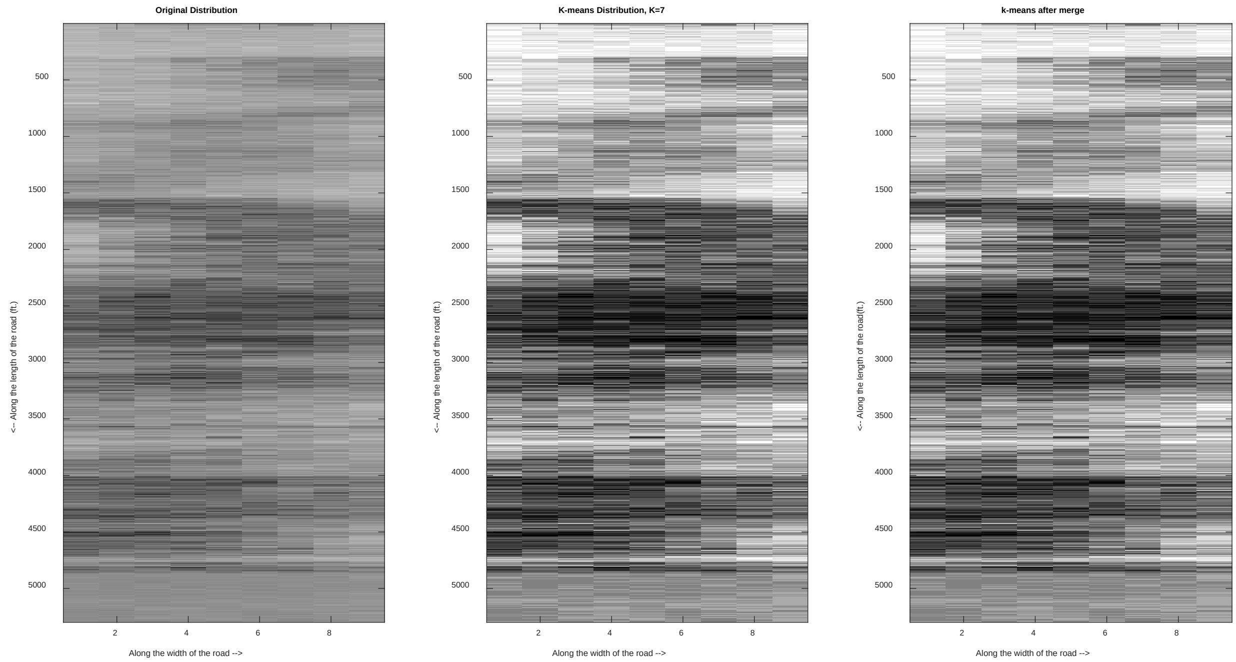


Figure 40. Left Wheel Path of FM 339 Roadway; the Left Most Image Depicts the Actual Roadway, the Middle Image Is the Output of K-means Algorithm, and the Right Most Image Is the K-means Image after Merging Few Groups.

While the K-means algorithm successfully reduces the reflectivity data to a scale of 7 or fewer points, it does not describe the nature to the wheel path surface. Using the simplified scale created by the K-means algorithm, researchers were able to apply an additional technique to extract the actual description of the pavement surface.

Within each 100-ft station, a 9×100 matrix was created for each wheel path and for the area between wheel paths. For the case study on FM 339, three control stations represented the as-expected condition for both wheel paths and between wheel paths. The 9×100 matrices created within these sections hold numerical information about how the roadway surface should look. Therefore, techniques were used that describe the matrices from every other section in relation to these sections. These techniques used a recently developed methodology within TTI to transform the asymmetric matrix associated with each surface area into a symmetric matrix that acts as a generalized form of the Laplacian Graph. The symmetry of the Laplacian Graph means that real eigenvalues exist for the data within the graph. Because the eigenvalue is nothing more than the characteristic descriptive value for the matrix, it offers the key to turning the numerical data into descriptive information.

While the eigenvalues are descriptive, they are abstract in nature and do not directly provide the description required. Therefore, researchers used a comparative technique to create a characteristic curve to describe the surface of a pavement. The characteristic curve was built by comparing various scenarios to the worst-case scenario. The worst-case scenario was described as a surface that is as poor as can be expected. For a seal coated roadway, this would indicate a completely flushed surface that was highly unreflective. The characteristic curve was integrated so that each matrix across each wheel path and the area between wheel paths within each 100-ft station could be described. This description identifies how the existing surface relates to the as-expected or as-desired surface prior to seal construction.

FM 339 was used as case study to apply the methodology to determine if mobile LiDAR reflectivity values could be used to describe the pavement surface. FM 339 was almost 30,000-ft long. The analysis was divided into 5000-ft sections, creating 50 stations per section. The results for the first 5000-ft are shown in Figure 41, Figure 42, and Figure 43. The top of these figures displays the original LiDAR reflectivity, followed by the K-means reflectivity using seven clusters, followed by a final optimized K-means reflectivity with between three and seven clusters.

The bulb chart in the middle of the figure represents the amount of characteristic area curve consumed within each station. The first three lines in the chart represent the control sections and have naturally consumed very little of the area. For example, in Figure 41, the first three lines are near the zero value, but other values are much higher. Between STA 19 and 28, the values are much higher and would be indicative of left wheel path flushing. Figure 42 is structured in the same way but coincides with the area between the wheel paths. For roadways with wheel path flushing, between the wheel paths often maintains the as-expected surface. This is obvious in the bulb chart, which has much more uniformity than the bulb chart associated with the left wheel path. The spikes at STA 27 and STA 28 could indicate that flushing is present between the wheel paths and in the left wheel path. Finally, Figure 43 permits a comparison to the surface of the right wheel path.

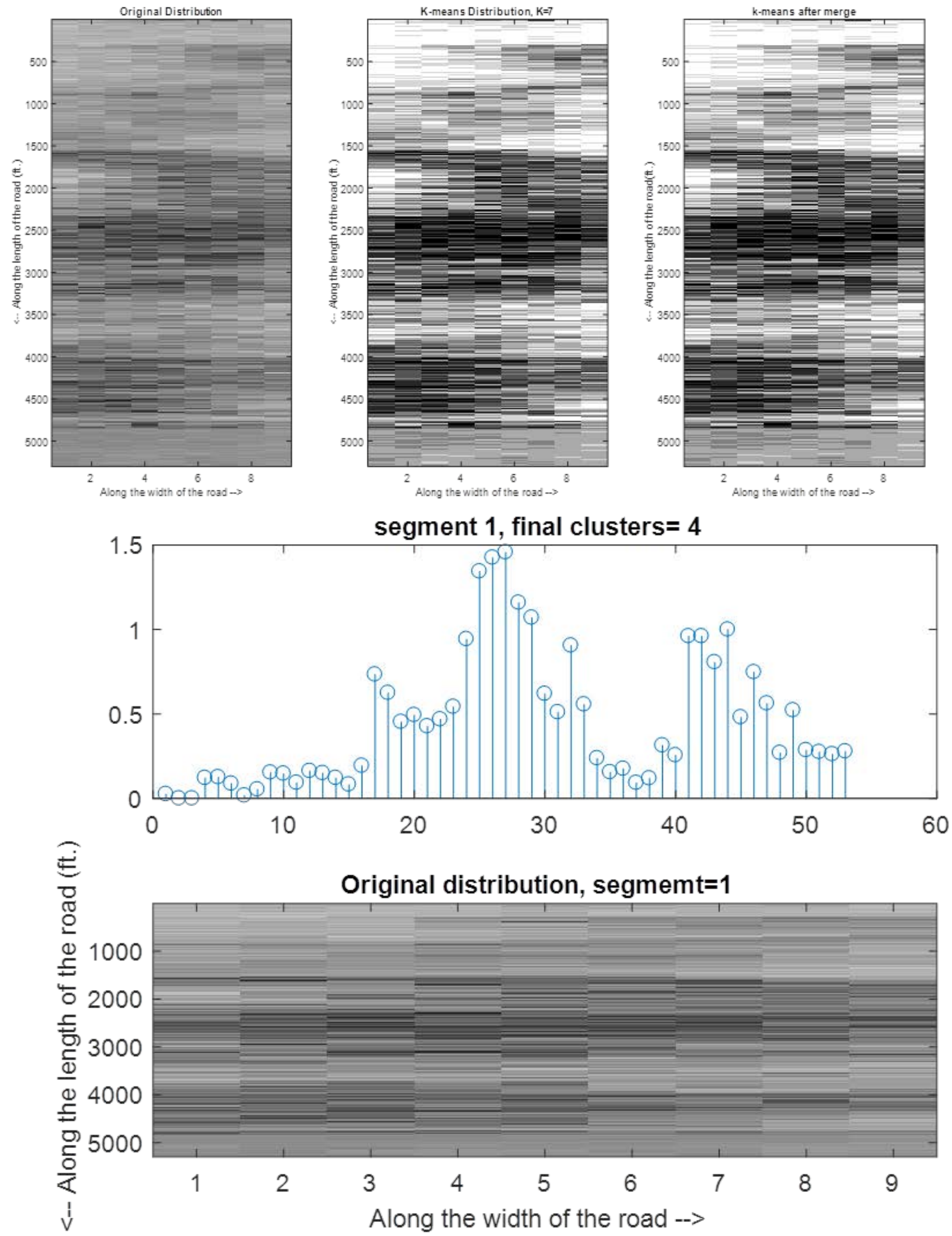


Figure 41. FM 339 Left Wheel Path K-means Progression and Comparative Output for Section 1.

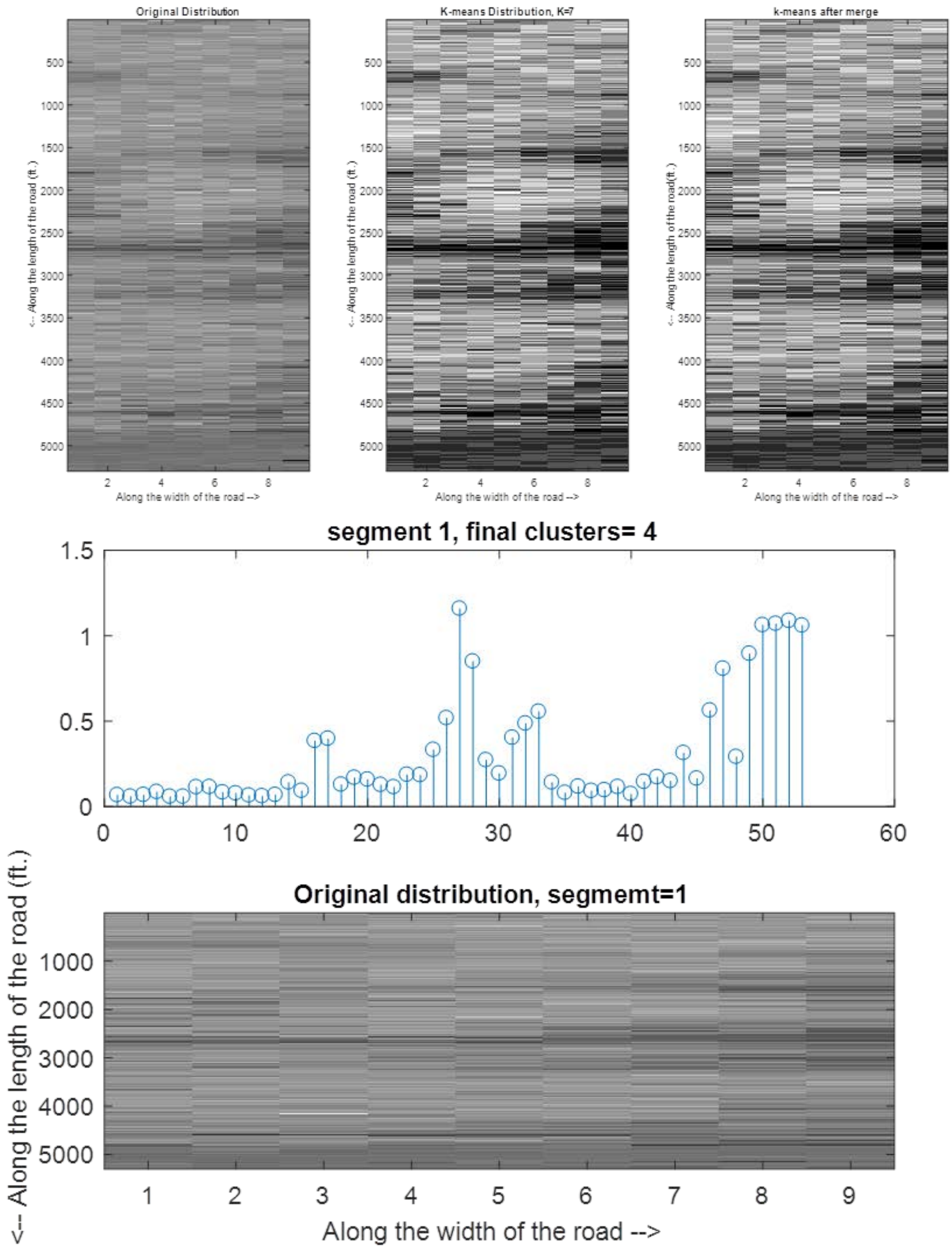


Figure 42. FM 339 between Wheel Paths K-means Progression and Comparative Output for Section 1.

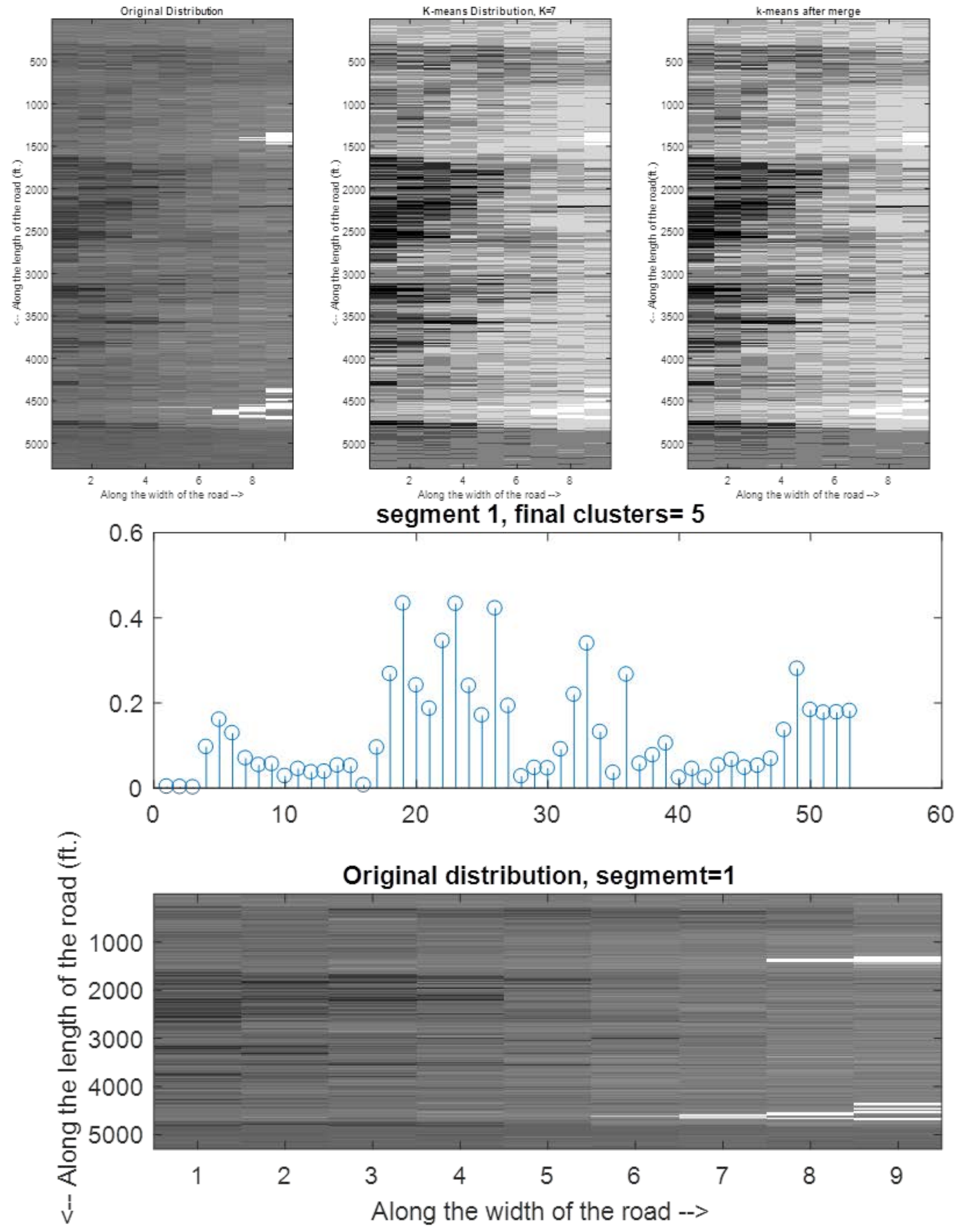


Figure 43. FM 339 Right Wheel Path K-means Progression and Comparative Output for Section 1.

The analysis and charts culminate in a descriptive table for each station of the roadway within the project limits. Table 4 shows the descriptions for each wheel path and between the wheel paths of the first 5,000 ft of the FM 339 project's southbound lane. These descriptions can be combined with rate adjustments for each wheel path for each lane for every station of a project.

Table 4. FM 339 First 5,000-ft Section Summary.

STA	Distance	LT Wheel Path	Between Wheel Paths	RT Wheel Path
1	0	as-expected	as-expected	as-expected
2	100	as-expected	as-expected	as-expected
3	200	as-expected	as-expected	as-expected
4	300	as-expected	as-expected	as-expected
5	400	as-expected	as-expected	as-expected
6	500	as-expected	as-expected	as-expected
7	600	as-expected	as-expected	as-expected
8	700	as-expected	as-expected	as-expected
9	800	as-expected	as-expected	as-expected
10	900	as-expected	as-expected	as-expected
11	1000	as-expected	as-expected	as-expected
12	1100	as-expected	as-expected	as-expected
13	1200	as-expected	as-expected	as-expected
14	1300	as-expected	as-expected	as-expected
15	1400	as-expected	as-expected	as-expected
16	1500	as-expected	partially flushed	as-expected
17	1600	partially flushed	partially flushed	as-expected
18	1700	partially flushed	as-expected	marginal
19	1800	partially flushed	as-expected	marginal
20	1900	partially flushed	as-expected	marginal
21	2000	partially flushed	as-expected	as-expected
22	2100	partially flushed	as-expected	marginal
23	2200	partially flushed	as-expected	marginal
24	2300	partially flushed	as-expected	marginal
25	2400	flushed	partially flushed	as-expected
26	2500	flushed	partially flushed	marginal
27	2600	flushed	flushed	marginal
28	2700	flushed	partially flushed	as-expected
29	2800	partially flushed	as-expected	as-expected
30	2900	partially flushed	as-expected	as-expected
31	3000	partially flushed	partially flushed	as-expected
32	3100	partially flushed	partially flushed	marginal
33	3200	partially flushed	partially flushed	marginal
34	3300	as-expected	as-expected	as-expected
35	3400	as-expected	as-expected	as-expected
36	3500	as-expected	as-expected	marginal
37	3600	as-expected	as-expected	as-expected
38	3700	as-expected	as-expected	as-expected
39	3800	partially flushed	as-expected	as-expected
40	3900	as-expected	as-expected	as-expected
41	4000	partially flushed	as-expected	as-expected
42	4100	partially flushed	as-expected	as-expected
43	4200	partially flushed	as-expected	as-expected
44	4300	partially flushed	partially flushed	as-expected
45	4400	partially flushed	as-expected	as-expected
46	4500	partially flushed	partially flushed	as-expected
47	4600	partially flushed	partially flushed	as-expected
48	4700	as-expected	as-expected	as-expected
49	4800	partially flushed	partially flushed	marginal
50	4900	as-expected	partially flushed	as-expected
51	5000	as-expected	partially flushed	as-expected
52	5100	as-expected	flushed	as-expected
53	5200	as-expected	partially flushed	as-expected

To show the application of this methodology and provide confidence that mobile LiDAR offers the potential as a tool to identify the characteristics of a pavement surface in an automated fashion, two specific examples from FM 339 are provided below. Figure 44 displays portions of the bulb charts from the second 5,000-ft section of FM 339. These charts move left to right across the lane and clearly show that something of much less reflectivity occurs all the way across the lane beginning at STA 14. STA 14 corresponds to the 3,000 m location in the analysis software. Figure 45 shows this darker patch extending across the entire roadway and extending for a long distance longitudinally. This was automatically captured using the K-means clustering and combining it with the descriptive matrices technique.

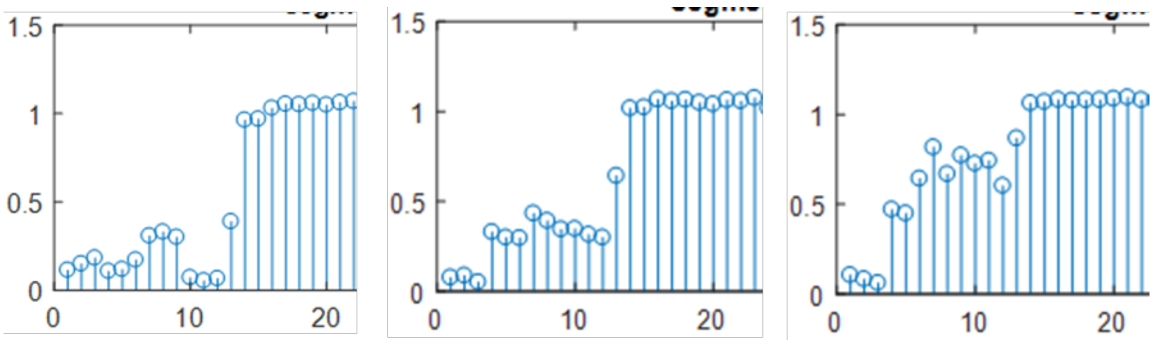


Figure 44. FM 339 Patch Example.

Figure 45. Beginning of Patch Referenced in Figure 44.

In Table 4, STA 25 through STA 28 has a flushed left wheel path with partially flushed area between the wheel paths, but the right wheel path seems to have a much better surface. Figure 46 displays what was described in Table 4. Figure 46 shows the flushing in the left wheel path and shows binder at the surface toward the outside edge line. As the edge line approaches, it appears a joint exists and the seal coat surface over the area to the right of the joint is in better condition than the rest of the lane. This might indicate that the roadway was widened, and the location of the joint coincides with the widening. Regardless, the methodology successfully identified the surfaces differences across this portion of FM 339. This is an example where variable rates would need to be shot across the lane.

Figure 46. FM 339 Example of Flushed Left Wheel Path, Partially Flushed between Wheel Paths, and Better Right Wheel Path.

The preceding discussion showed how mobile LiDAR data could be used to identify pavement surface changes across a lane. Automating this process has the potential to improve the seal coat planning process while at the same time minimizing the labor required. The application of the method will begin to link with suggested rate changes. Successfully linking these will help with implementation of the technique in the design process and improvement of the overall seal coat design.

The example procedure for processing mobile LiDAR data for surface detection is:

1. Establish a control section.
   a. Typical Seal Coat.
   b. Typical Asphaltic Concrete Pavement.
2. Analyze the data by comparing reflectivity data to the control sections reflectivity data.
3. Use the comparison to establish adjustment thresholds.
4. Define locations for adjustments and adjustments.
5. Provide information to construction personnel.

The following are examples of the data analysis based on different scenarios.

Scenario 1

1. Establish a Control Section. The control section is a typical rural seal coat as shown in Figure 47. This section was taken from FM 1774SB beginning at 5150.008 m. Note that the LiDAR equipment collects information in metric units.

Figure 47. Seal Coat Control Section.

2. Analyze the Data. The following section comes from the eastbound direction on SH 36 in the Brownwood District. SH 36 has an existing seal coat surface that was compared to the control section previously shown. This section begins at 2987.17 m in the eastbound direction. Refer to Figure 48. When the mile of data was analyzed that contained the flushed wheel path section, the right wheel path was classified as a highly varied surface, between the wheel paths was a fairly uniform surface, and the left wheel path was classified as an extremely varied surface.

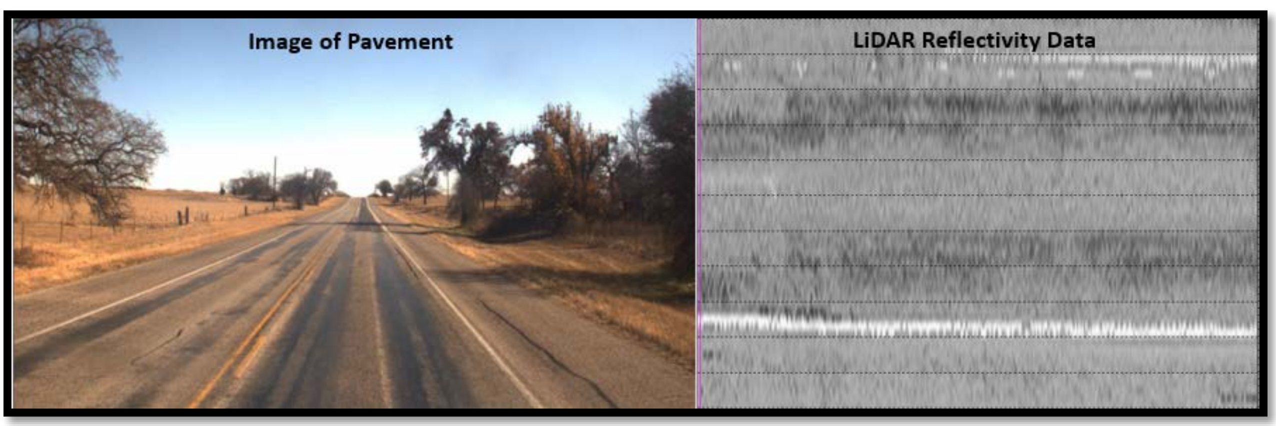


Figure 48. SH 36 LiDAR Data (Example 1).

3. Establish Adjustment Thresholds. The descriptions come from the number of clusters created from applying the K-means algorithm in two steps. The highly varied surface implies 6 clusters were created, while the fairly uniform surface implies 4 clusters were created, and the extremely varied surface implies 7 clusters were created. A larger

number of clusters indicates that when compared with the control section, more clusters are required to adequately capture the surface variability. Ultimately, the number of clusters helps to construct a surface curve that helps capture how different the area of interest is in relation to the control section and whether that difference is a lighter or darker surface difference.

4. Define Adjustments. In order to adjust the binder rates using the current binder rate change methodology, the section of SH 36 shown in Figure 47 resulted in suggested binder reductions of −0.04 gal/sy, −0.01 gal/sy, and −0.05 gal/sy in the left wheel path, between the wheel paths, and the right wheel path, respectively.

Scenario 2

1. Establish a Control Section. Use the same control section as Scenario 1.
2. Analyze the Data. Just beyond the area of SH 36 shown in Figure 48 is another section of SH 36 that has a dark patch across the entire east bound lane with wheel path issues continuing. Figure 49 shows the location and the reflectivity for this section that begins 3048.13 m in the eastbound direction.

Figure 49. SH 36 LiDAR Data (Scenario 2).

3. Establish Adjustment Thresholds. The reflectivity data show the beginning of the patch that occurs at 3050.87 m, slightly offset from the beginning of the section because the roadway is grouped into 100-ft stations.
4. Define Adjustments. Based on the current methodology, adjustments of binder rates are shown in Table 5. The table indicates that the darkest part of the patch with significant right wheel path flushing is approximately 1000-ft long. The reflectivity data show the length of the patch and how the reflectivity data changes. It is easy to see that between the wheel paths begins to lighten-up approximately 60 percent of the way through the patch. This lighting is reflected in the binder rate suggestions as the binder reduction between the wheel paths changes from −0.03 gal/SY to −0.02 gal/SY. The actual length of the patch begins at 3050.87 m and ends at 3363.615 m for a total length of 312.745 m or 1026 ft, accurately captured by the automated methodology to the nearest station.

Table 5. SH 36 Adjustments from LiDAR Data.

Section Group	Left Wheel Path (gal/sy)	Between Wheel Paths (gal/sy)	Right Wheel Path (gal/sy)
1	−0.03	−0.03	−0.07
2	−0.03	−0.03	−0.07
3	−0.03	−0.03	−0.07
4	−0.03	−0.03	−0.07
5	−0.02	−0.03	−0.05
6	−0.03	−0.03	−0.04
7	−0.03	−0.02	−0.05
8	−0.03	−0.02	−0.05
9	−0.02	−0.02	−0.06
10	−0.02	−0.02	−0.06
11	-0.02	−0.01	−0.03

Scenario 3

1. Establish a Control Section. Use the same control section as Scenario 1.
2. Analyze the Data. FM 60 in the Bryan District was analyzed. A section of FM 60 in the eastbound direction contained flushing in the wheel paths along with a lighter colored patch across the entire data collection lane (Figure 50).

Figure 50. FM 60 LiDAR Data (Example 1).

3. Establish Adjustment Thresholds. The reflectivity data are approximately 150 m (500 ft) long and clearly show the lighter colored patch. The patch begins at 3504.941 m and ends at 3544.404 m. The patch is 39.5 m (130 ft) long. Partitioning the analysis into 100-ft stations means the patch will affect multiple stations, but likely only affect one station completely.
4. Define Adjustments. Table 6 shows the suggested binder rates. The flushed wheel paths suggest a reduction in binder rate in both wheel paths, with the outside wheel path have a higher reduction on each side of the patch. The station completely affected by the patch recommends and increase in binder across the entire lane. From a construction standpoint, this information implies that variable rate nozzles would be required for this roadway. For

much of the roadway, a reduced binder rate would be required in both wheel paths, while the plan rate can be shot between the wheel paths. At the patch, a change must be made to apply binder heavier than the plan rate across the entire lane.

Table 6. FM 60 Adjustments from LiDAR Data.

Section Group	Left Wheel Path (gal/sy)	Between Wheel Paths (gal/sy)	Right Wheel Path (gal/sy)
1	−0.03	0	−0.03
2	−0.03	0	−0.04
3	−0.02	0.02	0.02
4	−0.02	0.02	0.03
5	−0.03	0	−0.04
6	−0.03	0	−0.05
7	−0.03	0	−0.05

Scenario 4

1. Establish a Control Section. Use the same control section as Scenario 1.
2. Analyze the Data. FM 1774 in the Bryan District was analyzed. This roadway consisted of a number of patches. Figure 51 shows a section of FM 1774 SB beginning near 19,103.75 m and continuing for 305 m (1000 ft) this section of FM 1774 should be shot at plan rate in all areas of interest with a potential reduction of 0.01 gal/sy in the outside wheel path.

Figure 51. FM 1774 LiDAR Data (Example 1).

3. Establish Adjustment Thresholds. The screenshot in Figure 51 from the video shows driving into the sun and creating an optical perception of potential flushing. For seal coats, the surface of the roadway looks differently depending upon how the sun shines (or does not shine) on the pavement. By using LiDAR, the actual reflectivity of the surface is analyzed regardless of how the surface looks during different lighting conditions.
4. Define Adjustments When comparing the reflectivity picture of this section with the control section at the beginning, the two sections look similar, thus the suggested shot rates are plan or near plan rate. However, caution should be used until additional validation can occur. It is possible that good binder rate decisions have been made based on the look of the surface in

certain lighting conditions. These conditions are washed out by the LiDAR and might require correction of the LiDAR data.

Scenario 5

1. Establish a Control Section. Not all surfaces receiving a new seal coat surface have an existing seal coat surface. Some roadways have a hot-mix surface that has aged. The control section for an aged hot-mix surface comes from the inside eastbound lane of SH 31 from the Waco District. Figure 52 shows this control section and its reflectivity.

Figure 52. SH 31 Hot Mix Control Section.

SUMMARY

Mobile LiDAR provides an attractive technology to collect data at highway speeds, improving the safety of data collectors and the traveling public. Typically, LiDAR provides distance or elevation data along with the reflectivity of the target surface. Within this study, only the reflectivity measurements were of interest. Initially, reflectivity data are processed into a 0 to 255 red, green, and blue scale. In order to deal with the vast amount of reflectivity data generated with mobile LiDAR, researchers divided the roadway into three areas of interest:

- Left wheel path.
- Between the wheel paths.
- Right wheel path.

Each area of interest was 3-ft wide and the roadway was further divided into 100-ft stations. The reflectivity data were placed in 1 ft long × 4-in. wide grids, producing 900 element matrices for each area of interest within each station. By applying the K-means clustering algorithm and a secondary grouping function, reflectivity values were transformed for a 0 to 255 scale into at most a 1 to 7 scale. Using pavement sections in as as-expected condition, researchers were able to determine how an area of interest should look as it relates to the rescaled reflectivity data. The reflectivity data were then reassigned by assigning the largest quantity of rescaled values the new scale value of 1. The reassignment continued until all clustered scale values were reassigned from the largest quantity to the smallest quantity.

With the reduced and reassigned scale, researchers assumed the area of interest functioned like a graph with a central node that fundamentally described the surface characteristics. Using techniques from graph theory, a generalize Laplacian graph was created that could be used to mathematically extract the characteristics of the surface. The characteristics of the surface could be compared with the mathematically extracted characteristics of the control section to determine the relative similarity or difference of an area of interest.

Using a mathematical description of the surface, binder rates could be set based on how mathematically similar or different a section was measured. Computer code was written to perform these calculations in an automated fashion.

CHAPTER 6. BINDER APPLICATION RATE ADJUSTMENT

BACKGROUND

In the TxDOT *Seal Coat and Surface Treatment Manual*, Chapter 4 contains two application rate design methods. The most commonly used design method in Texas is the Modified Kearby Method; however, many times districts base the rates on experience. Once an application rate is determined, adjustments should be made due to field conditions. The most common field conditions that affect the rate are the traffic levels and existing surface condition of the pavement.

During the kickoff meeting, surface and traffic adjustment factors were provided to the project team by the researchers. The traffic levels are based off current ADT and can be considered as vehicles/day/lane (v/d/l) for multilane highways. No changes were recommended by the team for the adjustment charts.

BINDER APPLICATION ADJUSTMENTS

Based on the teams input and evaluation of seal coat projects and pavement surface conditions, researchers recommend using the binder application rate adjustment factors shown in Figure 53; however each district should monitor these adjustment levels and modify them as needed.

Surface Condition Adjustment				
	Aggregate Size	GR 3	Gr 4	Gr 5
Surface Type	Surface Condition	gal/sy	gal/sy	gal/sy
Asphalt Concrete	Very dry with many cracks	0.08	0.06	0.05
	Dry with some cracks	0.05	0.04	0.03
	Good condition with few cracks	0.02	0.02	0.01
Seal Coat	Very dry with many cracks	0.06	0.06	0.04
	Dry with some cracks	0.03	0.03	0.02
	Good condition with few cracks	0	0	0
	Flushed	-0.02	-0.02	-0.01
	Bleeding	-0.04	-0.04	-0.02
Patch	Dry or fresh patch	0.03	0.03	0.02
	Fogged patch	0	0	0
	Flushed patch	-0.03	-0.03	-0.03
Prime	Dry surface, lightly primed	0.02	0.02	0.02
	"inverted" prime w/ GR 5	0.03	0.02	0.02
	Good prime rate, well penetrated	0	0	0
	Waxy and wet, not well penetrated	-0.03	-0.03	-0.02

Traffic Correction	
ADT	gal/sy
SHLD	0.05
50-100	0.05
100-250	0.04
250-400	0.03
400-500	0.02
500-650	0.01
650-900	0
900-1100	-0.01
1100-1500	-0.02
1500-2000	-0.03
>2000	-0.04

Figure 53. Adjustment Factors.

Surface conditions found during the evaluation of the field sites allowed researchers to document the typical surface condition changes found in Texas. These surface conditions vary both transversely and as you travel down the roadway. Figure 54 though Figure 57 are examples of the surface conditions related to the adjustment table including the adjustments in gallons per square yard.

GR 3	Gr 4	Gr 5
0.02	0.02	0.01
0.05	0.04	0.03
0.08	0.06	0.05

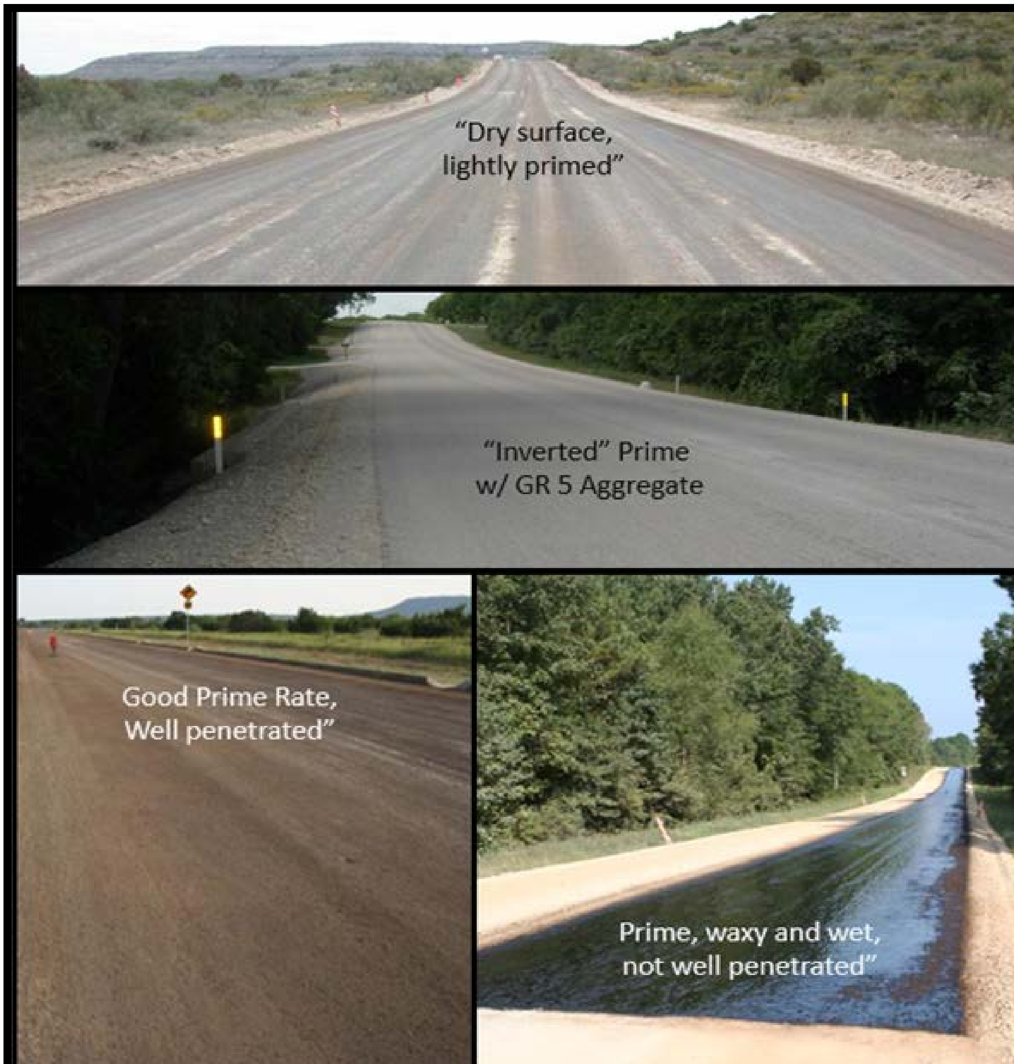
Figure 54. Surface Conditions, Asphaltic Concrete Surfaces.

GR 3	Gr 4	Gr 5
-0.04	-0.04	-0.02
-0.02	-0.02	-0.01
0	0	0
0.03	0.03	0.02
0.06	0.06	0.04

Figure 55. Surface Conditions, Seal Coat Surfaces.

GR 3	Gr 4	Gr 5
0.03	0.03	0.02
0.00	0.00	0.00
-0.03	-0.03	-0.03

Figure 56. Surface Conditions, Patches.



GR 3	Gr 4	Gr 5
0.02	0.02	0.02
-0.03	-0.02	-0.01
Good Prime		
0.00	0.00	0.00
waxy/wet Prime		
-0.03	-0.03	-0.02

Figure 57. Surface Conditions, Primed Surfaces.

Changes in rates during construction will depend on the surface changes as the asphalt distributor travels down the roadway. Figure 58 is an example of the total change that would be needed when transitioning from one surface type to another. This example is for a grade 4 aggregate. Also note that the change may need to be made transversely and longitudinally down the roadway.

Surface Condition SC = Seal Coat Surface AC = Asphaltic Concrete Surface	Gr 4	SC-Bleeding	Flushed patch	Prime Waxy and wet, not well penetrated	SC-Flushed	Fogged patch	Good prime rate, well penetrated	SC-Good condition with few cracks	AC-Good condition with few cracks	Prime-Dry surface, lightly primed	"inverted" prime w/ GR 5	Dry or fresh patch	SC-Dry with some cracks	AC-Dry with some cracks	SC-Very dry with many cracks	AC-Very dry with many cracks
		-0.04	-0.03	-0.03	-0.02	0	0	0	0.02	0.02	0.02	0.03	0.03	0.04	0.06	0.06
SC-Bleeding	-0.04	0.00	0.01	0.01	0.02	0.04	0.04	0.04	0.06	0.06	0.06	0.07	0.07	0.08	0.10	0.10
Flushed patch	-0.03	-0.01	0.00	0.00	0.01	0.03	0.03	0.03	0.05	0.05	0.05	0.06	0.06	0.07	0.09	0.09
Prime Waxy and wet, not well penetrated	-0.03	-0.01	0.00	0.00	0.01	0.03	0.03	0.03	0.05	0.05	0.05	0.06	0.06	0.07	0.09	0.09
SC-Flushed	-0.02	-0.02	-0.01	-0.01	0.00	0.02	0.02	0.02	0.04	0.04	0.04	0.05	0.05	0.06	0.08	0.08
Fogged patch	0	-0.04	-0.03	-0.03	-0.02	0.00	0.00	0.00	0.02	0.02	0.02	0.03	0.03	0.04	0.06	0.06
Good prime rate, well penetrated	0	-0.04	-0.03	-0.03	-0.02	0.00	0.00	0.00	0.02	0.02	0.02	0.03	0.03	0.04	0.06	0.06
SC-Good condition with few cracks	0	-0.04	-0.03	-0.03	-0.02	0.00	0.00	0.00	0.02	0.02	0.02	0.03	0.03	0.04	0.06	0.06
AC-Good condition with few cracks	0.02	-0.06	-0.05	-0.05	-0.04	-0.02	-0.02	-0.02	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.04
Prime-Dry surface, lightly primed	0.02	-0.06	-0.05	-0.05	-0.04	-0.02	-0.02	-0.02	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.04
"inverted" prime w/ GR 5	0.02	-0.06	-0.05	-0.05	-0.04	-0.02	-0.02	-0.02	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.04
Dry or fresh patch	0.03	-0.07	-0.06	-0.06	-0.05	-0.03	-0.03	-0.03	-0.01	-0.01	-0.01	0.00	0.00	0.01	0.03	0.03
SC-Dry with some cracks	0.03	-0.07	-0.06	-0.06	-0.05	-0.03	-0.03	-0.03	-0.01	-0.01	-0.01	0.00	0.00	0.01	0.03	0.03
AC-Dry with some cracks	0.04	-0.08	-0.07	-0.07	-0.06	-0.04	-0.04	-0.04	-0.02	-0.02	-0.02	-0.01	-0.01	0.00	0.02	0.02
SC-Very dry with many cracks	0.06	-0.10	-0.09	-0.09	-0.08	-0.06	-0.06	-0.06	-0.04	-0.04	-0.04	-0.03	-0.03	-0.02	0.00	0.00
AC-Very dry with many cracks	0.06	-0.10	-0.09	-0.09	-0.08	-0.06	-0.06	-0.06	-0.04	-0.04	-0.04	-0.03	-0.03	-0.02	0.00	0.00

Figure 58. GR 4 Application Rate Changes.

TRANSVERSE VARIATION

Changing surface conditions transversely is the most challenging construction issue since current equipment cannot vary rates transversely without changing nozzle configurations or using a multibar distributor. Due to the time and effort needed to change nozzles, this can significantly impact the production time for placement of the seal coat. Lower production rates will increase costs. Figure 59 shows a good example of a pavement with several different conditions transversely across the width of the roadway; the variable changes are flushing almost full width, slight flushing in the wheel paths, and level-up that extends into the right wheel path from the shoulder.

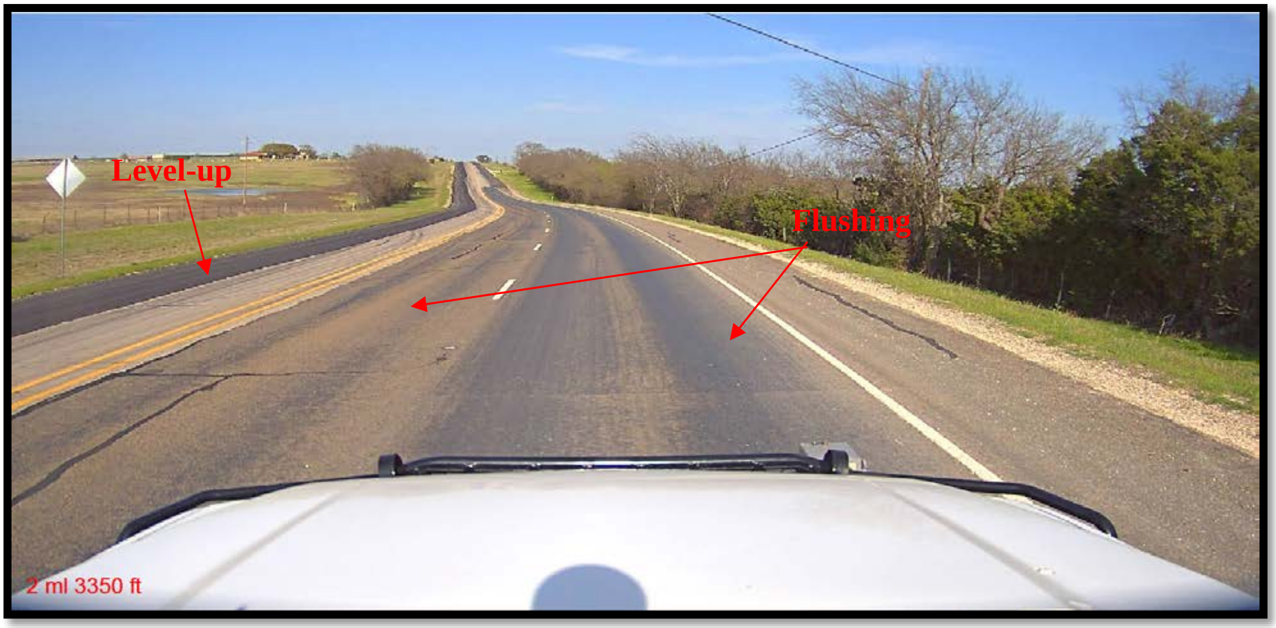


Figure 59. Transversely Varying Surface Conditions.

For most roadways in Texas, the wheel paths are 3-ft wide, and the driving paths are generally centered in the lane. However, for very narrow lanes the left wheel path tends to be located close to the centerline. Figure 60 is a layout showing various lane widths with the left edge of the diagram considered to be the left lane line and shows the typical locations of wheel paths and nozzle locations (standard distributor spray bar). For most conditions, this layout will assist in locating areas for variable transverse rates. The instances that are not standard are locations that maintenance work extends into a lane and may only cover a portion of the right or left part of a lane. Figure 61 shows some examples of these situations.

<table>
<tr><td colspan="28">9-FOOT LANE NOZZLE CONFIGURATION FOR SPRAY BAR</td></tr>
<tr><td>Def</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>Def</td></tr>
<tr><td></td><td colspan="9">Wheel Path</td><td colspan="6">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="3">Not in WP</td></tr>
<tr><td></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">4</td><td colspan="3">5</td><td colspan="3">6</td><td colspan="3">7</td><td colspan="3">8</td><td colspan="3">9</td></tr>
</table>

<table>
<tr><td></td><td colspan="30">10-FOOT LANE NOZZLE CONFIGURATION FOR SPRAY BAR</td></tr>
<tr><td>Def</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>Def</td></tr>
<tr><td colspan="3">Not in WP</td><td colspan="9">Wheel Path</td><td colspan="6">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="4">Not in WP</td></tr>
<tr><td></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">4</td><td colspan="3">5</td><td colspan="3">6</td><td colspan="3">7</td><td colspan="3">8</td><td colspan="3">9</td><td colspan="3">10</td></tr>
</table>

<table>
<tr><td></td><td colspan="33">11-FOOT LANE NOZZLE CONFIGURATION FOR SPRAY BAR</td></tr>
<tr><td>Def</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td>Def</td></tr>
<tr><td colspan="5">Not in WP</td><td colspan="9">Wheel Path</td><td colspan="6">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="5">Not in Wheel Path</td></tr>
<tr><td></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">4</td><td colspan="3">5</td><td colspan="3">6</td><td colspan="3">7</td><td colspan="3">8</td><td colspan="3">9</td><td colspan="3">10</td><td colspan="3">11</td></tr>
</table>

<table>
<tr><td></td><td colspan="36">12-FOOT LANE NOZZLE CONFIGURATION FOR SPRAY BAR</td></tr>
<tr><td>Def</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>Def</td></tr>
<tr><td colspan="6">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="8">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="5">Not in Wheel Path</td></tr>
<tr><td></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">4</td><td colspan="3">5</td><td colspan="3">6</td><td colspan="3">7</td><td colspan="3">8</td><td colspan="3">9</td><td colspan="3">10</td><td colspan="3">11</td><td colspan="3">12</td></tr>
</table>

<table>
<tr><td></td><td colspan="39">13-FOOT LANE NOZZLE CONFIGURATION FOR SPRAY BAR</td></tr>
<tr><td>Def</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>36</td><td>37</td><td>38</td><td>Def</td></tr>
<tr><td colspan="7">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="8">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="7">Not in Wheel Path</td></tr>
<tr><td></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">4</td><td colspan="3">5</td><td colspan="3">6</td><td colspan="3">7</td><td colspan="3">8</td><td colspan="3">9</td><td colspan="3">10</td><td colspan="3">11</td><td colspan="3">12</td><td colspan="3">13</td></tr>
<tr><td colspan="40">Note: Nozzles – 3 nozzles per foot along the Bar, Def is a deflector nozzle and will be the same nozzle as the nozzle used outside the wheel paths.</td></tr>
</table>

Figure 60. Typical Lane Configurations.

<table>
<tr><td></td><td colspan="36">12-FOOT LANE NOZZLE CONFIGURATION FOR SPRAY BAR</td></tr>
<tr><td>Def</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>Def</td></tr>
</table>

Other Scenarios

<table>
<tr><td colspan="6">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="8">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="5">Not in Wheel Path</td></tr>
<tr><td colspan="6">Good Seal Coat</td><td colspan="9">Flushing</td><td colspan="8">Good Seal Coat</td><td colspan="3">Flushing</td><td colspan="11">Variable Level-up</td></tr>
<tr><td></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">4</td><td colspan="3">5</td><td colspan="3">6</td><td colspan="3">7</td><td colspan="3">8</td><td colspan="3">9</td><td colspan="3">10</td><td colspan="3">11</td><td colspan="3">12</td></tr>
</table>

<table>
<tr><td colspan="6">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="8">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="5">Not in Wheel Path</td></tr>
<tr><td colspan="28">Good Seal Coat</td><td colspan="9">Variable Level-up</td></tr>
<tr><td></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">4</td><td colspan="3">5</td><td colspan="3">6</td><td colspan="3">7</td><td colspan="3">8</td><td colspan="3">9</td><td colspan="3">10</td><td colspan="3">11</td><td colspan="3">12</td></tr>
</table>

<table>
<tr><td colspan="6">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="8">Not in Wheel Path</td><td colspan="9">Wheel Path</td><td colspan="5">Not in Wheel Path</td></tr>
<tr><td colspan="23">Good Seal Coat</td><td colspan="14">Patch</td></tr>
<tr><td></td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">4</td><td colspan="3">5</td><td colspan="3">6</td><td colspan="3">7</td><td colspan="3">8</td><td colspan="3">9</td><td colspan="3">10</td><td colspan="3">11</td><td colspan="3">12</td></tr>
</table>

Figure 61. Examples of Variable Transverse Surface Conditions.

SUMMARY

The surface conditions found on Texas highways can be highly variable, not only as you travel down the roadway but across the roadway as well. To have a successful seal coat, it is critical to apply the correct amount of binder. The application rates are influenced by traffic and surface condition due to the required embedment depth needed for the aggregate. Researchers documented the conditions usually found on highways in Texas and provided guidance for binder rate adjustments.

CHAPTER 7. EQUIPMENT DEVELOPMENT

BACKGROUND

Asphalt distributors used in the Texas have a spray bar that applies binder to the roadway. Sometimes dual spray bars are used. In order to vary application rates transversely using the available equipment, the rate in the wheel path is typically lower than the rate outside the wheel paths. The equipment setup to apply variable rates can be time consuming and confusing. The following are examples of issues encountered during construction with this type of equipment:

- It is time consuming to replace nozzles along the spray bar. Contractors are reluctant to do this since the time needed can slow their production schedule.
- Dual spray bar systems typically have a computer for each spray bar. This requires the operator and inspector to understand the application rates needed on each spray bar, but they also have to understand the composite rate used. The composite rate is found by measuring the before and after volume of binder (strapping the tank level). This can be confusing because the combined overall application rate is measured from the strapping check of the tank; however, each individual spray bar has a different rate set on its computer controller.

Additionally, it was documented during the field observations that in some circumstances, variable rates are needed due to maintenance repairs. Many times, these repairs are not full width across the lane and affect a wheel path or a portion of the lane. In these instances, traditional variable adjustments are not appropriate.

LABORATORY EQUIPMENT INVESTIGATION

In order to get some sense of the feasibility of moving toward implementation of more advanced technology to apply transversely varying spray application rates, an existing laboratory spray bar device was modified. Refer to Figure 62. Two elements of more advanced technology were incorporated into the device:

- Solenoid valve functionality was replaced with electro-pneumatic servovalve technology.
- Mechanical/manual controls were not used for spraying operations since the machine is controlled with software through a programmable logic control (PLC) system with a Human Machine Interface (HMI).

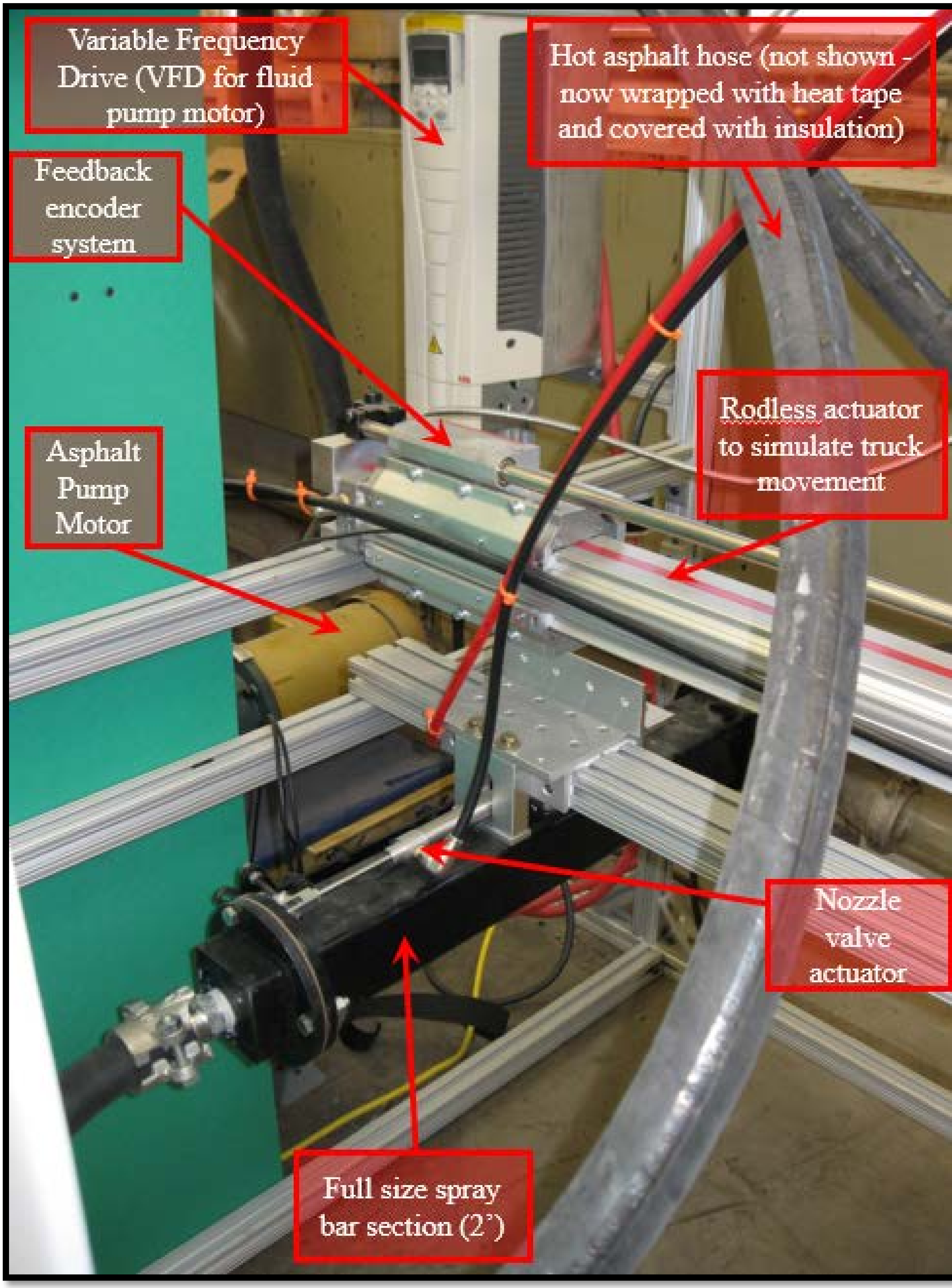


Figure 62. Laboratory Spray Bar Device

The PLC system, coupled with servovalves, enables simple changes to control and offers the possibility of electronic feedback in the control loop. The system was set up to use double-acting cylinders and 0–10 volt control signals (so nominally 5 VDC would correspond to no movement of the cylinder in open loop control, all things being equal). The device uses a full-scale distributor truck spray bar 2-ft section to spray material onto a 2 ft by 2 ft specimen. The bar moves 4 ft, but the largest molded asphalt specimen available in the testing lab is 2 ft by 2 ft, and there is some distance at the start and end of each run that is used for acceleration/deceleration of the bar to and from the desired steady state speed. The speed of the bar is controlled by a rodless pneumatic cylinder with full proportional, integral, derivative (PID) feedback control using a linear encoder for feedback and a magnetic reed switch for identification of the home position. The pneumatic system will not move quite as fast as a distributor truck might move, but speeds in the range of 3 mph are possible without going to non-standard building compressed air pressures.

Discussion of Software Main Screen

The Main Screen, Figure 63, comprises the following buttons and indicators:

- The date is shown in the upper right corner.
- On the center left, a graphical representation of the PID loop controlling the movement of the bar is shown in a time history format.
- An Emergency Stop button is provided. There is also a mechanical mushroom pushbutton stop button on the front of the machine to stop the hot fluid pump drive and a paddle type emergency stop button that stops electrical power to the entire system is located on the left end of the machine.
- The Push to Fire button starts the bar movement if the machine is ready (Not Homed will change to Ready in the bottom center indicator light when the bar is in the home position).
- The inch display button (lower center of screen) will display the distance of the bar from the home position as it is moving.
- The Approx Speed indicator (lower left) will display the average speed achieved in the middle of the bar’s travel for the run just completed.
- The New Test/Jog button initiates the popup window of Figure 64 and returns the bar back to the home position.

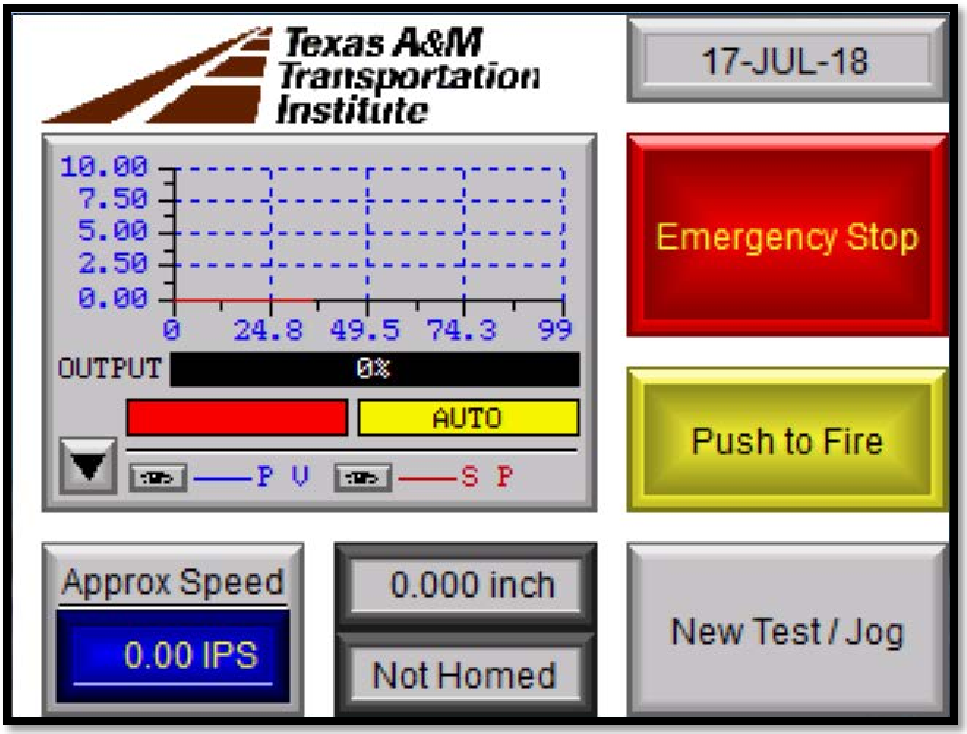


Figure 63. Main Screen on Lab Testing Machine.

Discussion of Parameter Setup Screen

The Parameter Setup Screen comprises the following buttons and indicators:

- A Finished button at the top of the screen that sends the user back to the Main Screen.
- A Target bar travel speed in feet per minute on the upper right.
- A jog slider on the center left of the screen. There is a digital indicator of the slider position in volts just below the slider handle. In addition, the user can directly enter the desired jog voltage using the Direct Set Point button (note that the entry is in mV, 4000 mV = 4.0 V).
- A Current Mode indicator is shown on the lower left. The display flashes red and black and shows one of three values that are set using the Test Mode Setup button:
  - Standard for using the machine in the standard tack coat configuration using only a solenoid valve for the nozzle control (requires a specific hardware configuration).
  - Auto Waveform for using the machine with an automatic variation in the control of the nozzle actuator (requires a specific hardware configuration which employs the nozzle servovalve). The user does not have control of the shape of the control variation (sinusoidal and parabolic waveforms were used in this study).
  - Manual for using the machine with manual control of the nozzle actuator. This uses the same hardware configuration as the Auto Waveform mode.
- A Test Mode Setup button that initiates the popup window of Figure 65.

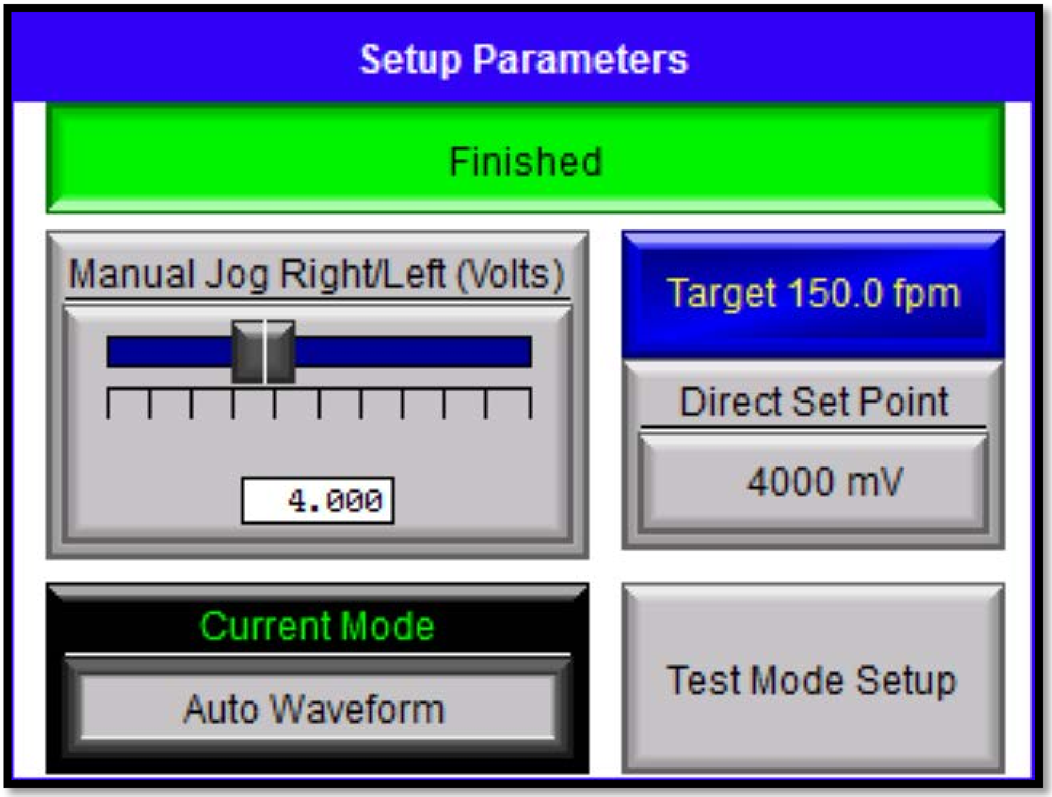


Figure 64. Pop-up Screen Displayed when New Test/Jog Button Is Pressed on Main Screen.

Discussion of Operating Mode Setup Screen

The Operating Mode Setup Screen comprises the following buttons and indicators:

- A Finished button at the top of the screen, which sends the user back to the Parameter Setup Screen.
- A three-button selector to select the mode of operation (as previously defined) along the left side. Note: when the Manual mode of operation is selected, and the Finished button is pressed, the Main Screen will change to the presentation shown in Figure 66, so that the user can directly change the nozzle servovalve signal by using a slider button. The slider button display takes the place of the PID time history plot when operating in Manual mode.
- PID system operation on or off button on the upper right.
- Proportional (P) and Integral (I) values can be changed in the two fields below the PID button.

Normally, the user will not be changing the PID information in the right column of buttons. The Derivative (D) value for the system is not changeable by the user and can only be changed in the software program source code.

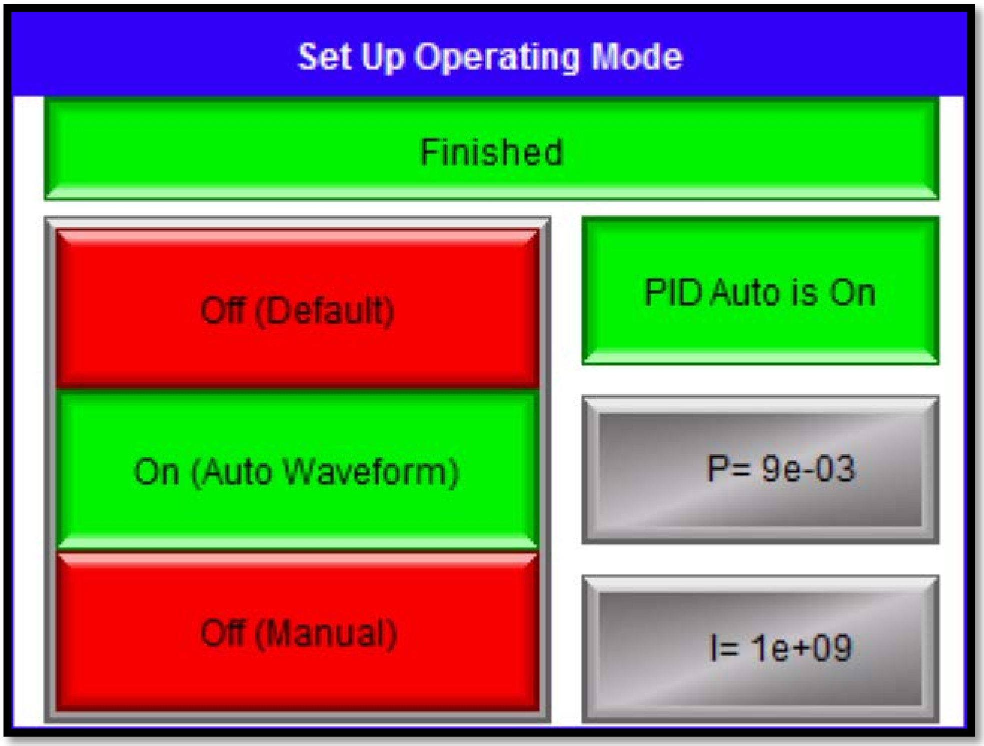


Figure 65. Pop-up Screen Displayed when Test Mode Setup Button Is Pressed on Setup Parameters Screen Is Pressed.

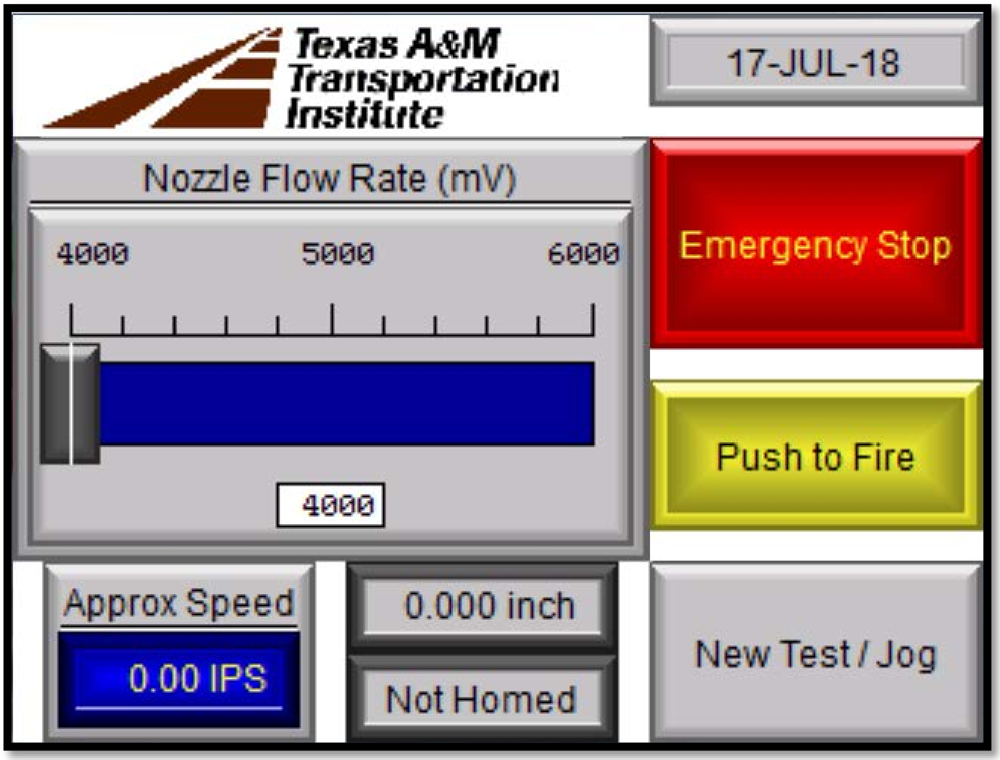


Figure 66. Main Screen Display when in Manual Operating Mode (PID Time History Plot Is Replaced by a Slider Nozzle Control).

Hardware and Software Architecture

Figure 67 overviews the software architecture used in the laboratory equipment. In the Standard mode of operation, the solenoid (on/off only) is used to open and close the nozzles. In the other two modes of operation, the servovalve (electronically adjustable) is used for positioning the nozzle opening cylinder.

Figure 68 overviews the hardware part of the control system used in the laboratory equipment. The PLC/HMI system is used to control all the electro-pneumatic valves in the system. Manual valves are used to change from simple solenoid operation of the nozzles to servo operation.

Observations

The use of the servovalve made it possible to control the movement of the nozzle valve operator (i.e., the pneumatic cylinder on the spray bar). The AutoWaveform mode of operation appeared to work reasonably well, but the Manual mode was very difficult to use effectively for the following reasons:

- This portion of the study did not incorporate a feedback sensor at the nozzle valve operator location, so the full capability of the servovalve was not being used as it was being used more like a proportional valve in an open loop circuit.
- The HMI is a touch screen. Making extremely fine adjustments using a finger on the screen is virtually impossible. In this machine, if one is right-handed, you are also at a disadvantage because looking at the moving bar while trying to adjust the valve opening via the HMI located to your left becomes slightly problematic. An external analog type joystick may work better.
- A pneumatic system was used in this machine for two primary reasons: 1) it enabled the use of a rodless actuator for the simulation of the truck movement, which made the lab space footprint about half the length it would have been if a standard hydraulic cylinder had been used, and 2) the cost to produce the machine is estimated to have been 2 to 3 times lower than a system using hydraulic or electric screw/chain drive components. Using the manual mode makes it even more difficult to anticipate and react to variations due to compressibility of air.

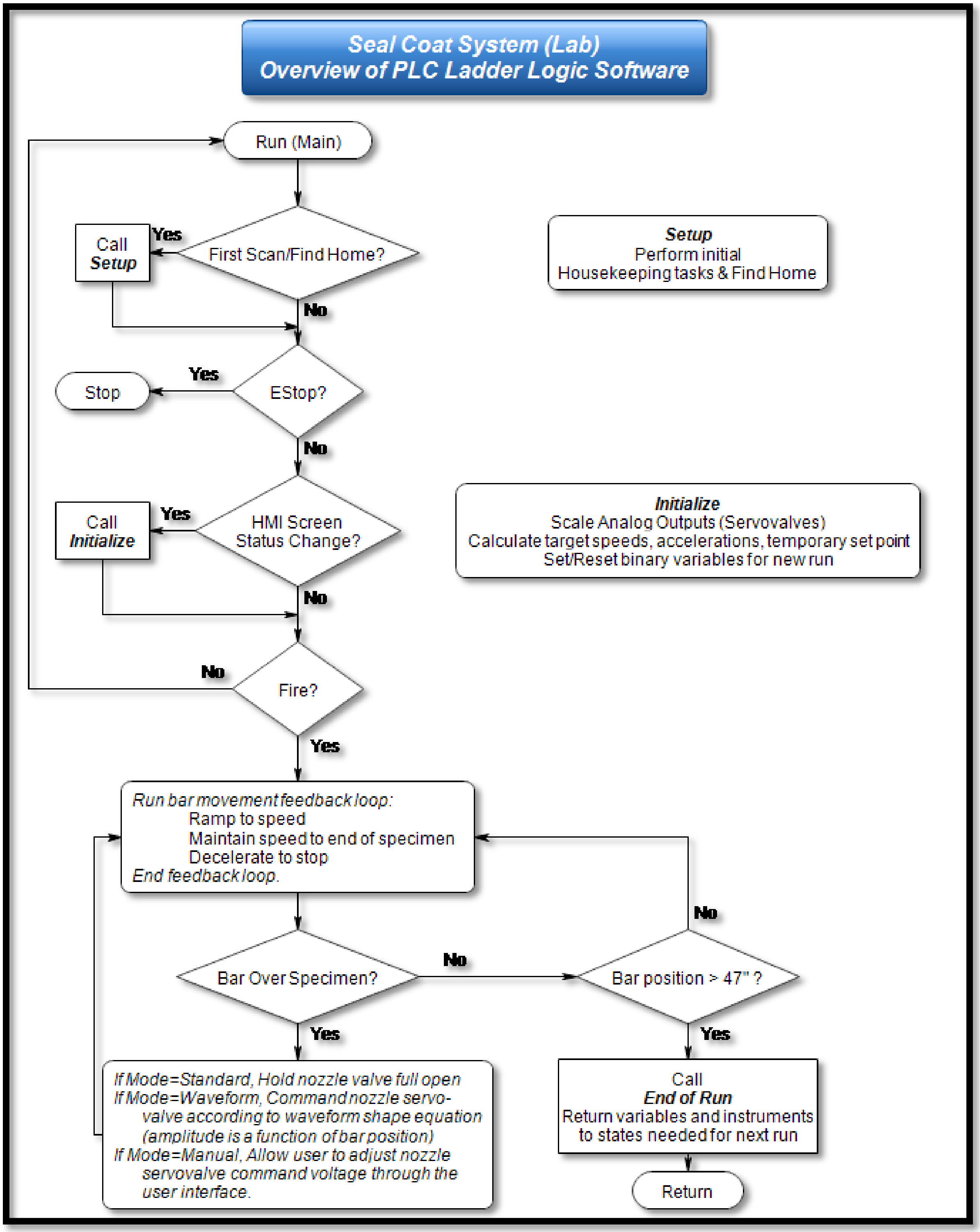


Figure 67. PLC Software Logic Overview.

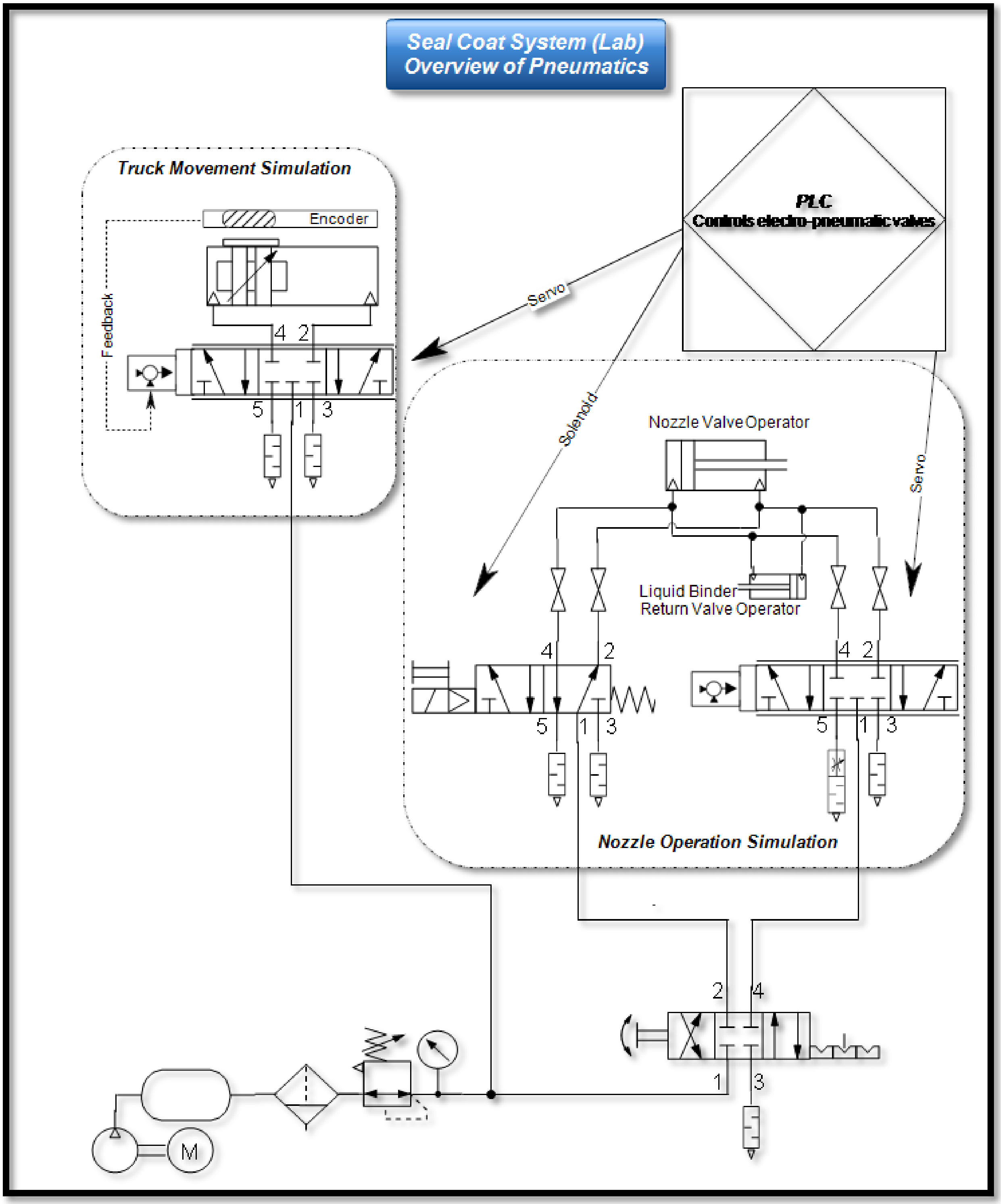


Figure 68. System Controlling Hardware (Pneumatic Circuits).

SUMMARY

Since a successful seal coat project relies on field adjustments to application rates, having equipment that can quickly and easily be adjusted will improve the construction process. The spray bar technology innovations investigated in this study show potential for improvements to asphalt distributors.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

This project focused on improvements to seal coat construction. A successful seal coat project relies on field adjustments to application rates. These field adjustments are affected by the pavement surface condition and the amount and type of traffic. In this project, TTI researchers evaluated innovative ways to document the pavement surface condition, adjust application rates, and improve equipment to apply variable application rates.

HDV and mobile LiDAR were the two systems evaluated in this study to document pavement conditions. Eighteen field sites of FY18 seal coat projects were evaluated to document pavement surface conditions and evaluate adjustments for binder application rates. The field adjustment table was developed based on the traffic, pavement conditions, and experience with rate adjustments. Using traffic data and the pavement condition, recommendations were made to adjust binder application rates.

In the current state of Texas practice, two methods for transverse variation of shot rate were identified:

1. Changing nozzle orifice characteristics at appropriate locations across the distributor bar.
2. The use of a dual bar distributor system.

During the study, some evidence of attempts to use other methods were identified. Some of these methods are PWM for simulating analog behavior to achieve variable shot rates and replacing the nozzle/ball valve/cylinder actuation combination with direct control of an iris type nozzle.

This chapter provides the key findings for documenting pavement condition, adjusting asphalt applications rates, equipment improvements, and recommendations for future work to further improve seal coat construction.

PAVEMENT CONDITION ASSESSMENT

Visual inspection of roadway segments for the seal coat program provides valuable information about the existing roadway surface. However, visual inspection is time consuming, labor intensive and is a safety concern since personnel are on the pavement or in a slow-moving vehicle within traffic.

HDV

Video logging using a camera mounted to a mobile vehicle offers an alternative to visual inspection. Video logging mitigates safety concerns with data collection occurring at or near highway speeds. The pavement condition is documented through a manual process using the video and PaveView software. The video is also available for other project needs.

HDV Conclusions

Processing and gathering useful information from the data is labor-intensive. It requires someone to manually watch the video to identify surface changes and locations for design changes. This process can also lead to potential errors since it is subjective. Even with these concerns, researchers believe that this method is better and safer than the current visual inspection method and provides information that can easily be reviewed without having to revisit the project site.

HDV Recommendations

Researchers recommend using the HDV system. The system is ready to implement. Additionally, there are several uses of the video including visual tracking of pavement changes and availability to view the video at meetings to discuss potential issues with construction. There are only a few HDV systems in the districts, researchers recommend that all districts consider acquiring a HDV system.

Mobile LiDAR

Mobile LiDAR provides an attractive technology to collect data at highway speeds, improving the safety of data collectors and the traveling public. The data analysis is automated which removes subjectivity and is more efficient than manual analysis.

Mobile LiDAR Conclusions

Mobile LiDAR was effective in capturing 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. Researchers developed automated techniques to identify and extract these surface changes.

Mathematical techniques successfully identified the relative difference between a pavement surface area of interest and the as-expected or as-desired surface. Algorithms applied binder rate reductions based on the differences identified through reflectivity data and mathematical analysis of the pavement surface characteristics. These algorithms assigned surface descriptors and binder rate changes to each area of interest on 100-ft station increments. This was done in an automated fashion that has the potential to improve and speed up rate decision making.

The use of mobile LiDAR reflectivity limits exposure to traffic because the data can be collected at highway speeds. The automation of binder rate changes can reduce labor hours and prevent tedious video logging or safety concerns with manual inspection. Mobile LiDAR also helps in identifying exact points where changes need to be made without introducing subjectivity or potential error created by changing light conditions. For example, when a roadway runs east and west, depending on the time of day, light conditions will change the appearance of surface characteristics. Because reflectivity data are based on the actual reflectivity of the surface and is not affected by light conditions, this potential error is eliminated. While the LiDAR system shows much promise, further development is needed to streamline the analysis.

Mobile LiDAR Recommendations

Evaluation and development time was short for this project and researchers recommend that TxDOT consider further development of the automated system to document pavement changes based on the LiDAR data. There are several advantages to this system including removing subjectivity from the evaluation of the pavement condition. This is essential to reducing risk especially as the department moves toward using more third-party inspectors. Reduction of risk will lead to economical projects. Future work would allow for additional validation of the process and improving the efficiency of data analysis. Since the reflectivity portion of the data was used, future work would include investigation of simpler, more cost-effective equipment to collect the data.

Documenting Pavement Condition Recommendations for Future Efforts

While this project provided good evidence to the effectiveness of both the HDV and LiDAR systems for documenting pavement surface conditions, researchers believe ample opportunity and reason exists to further examine the LiDAR process and further refine the capabilities through automated means. Additional work would allow for better validation of the process and improving the efficiency of data analysis. Additionally, there are only a few HDV systems in the districts, researchers recommend that all districts consider acquiring HDV systems.

APPLICATION RATE ADJUSTMENTS

Texas has various roadway surface conditions. These conditions change as maintenance activities are performed. Constructing a successful seal coat relies on achieving the proper aggregate embedment. Low embedment leads to aggregate loss while high embedment leads to flushing and bleeding. Adjustment of the binder application rate is a function of the existing conditions due to the hunger factor of the existing pavement. For example, a cracked, dry, oxidized pavement will have a need for additional binder. This asphalt will go into the old pavement leaving less on the surface to embed the aggregate, so additional binder will be needed. Conversely, a bleeding pavement will have excess binder and less new binder will be needed. Traffic effects this by providing extra force to embed the aggregate, so very high traffic levels will require less new binder while very low traffic will require more binder.

Binder Rate Adjustment Conclusions

The binder rate adjustments that were provided by researchers at the kickoff meeting were found to be realistic and represented the different pavement conditions found in Texas. The traffic adjustments ranged from 0.5 gal/sy added for very low traffic to −0.04 gal/sy for very high traffic.

The pavement condition adjustments ranged from 0.08 gal/sy to −0.04 gal/sy with a grade 3 aggregate, from 0.06 gal/sy to −0.04 gal/sy with grade 4 aggregate and from 0.05 gal/sy to −0.03 gal/sy with grade 5 aggregate. The conditions found in Texas could consist of a need to make large changes transversely and as you travel down the roadway. This can make the seal coat very challenging to construct.

The rate adjustments are based off starting with the original design rate and changing from what is an expected rate to the adjusted rate. It is very important to remember when adjusting rates that there may need to be a large adjustment if the condition changes by extremes. Technical memorandum 3 contained a matrix that laid out the total adjustment needed when moving from one condition to the next.

Binder Rate Adjustment Recommendations

Application adjustment rates are based on traffic and pavement condition at the time of construction, but the initial application rate is determined through experience or design methods. TxDOT is funding a new research project 0-6989, "Update Seal Coat Application Rate Design Method" starting in September 2018 and researchers recommend incorporating the adjustment criteria into the updated rate design method.

Researchers recommend the adjustments shown in Table 8 and
Table 7. These adjustments factors may be slightly modified for each district depending on local materials and conditions.

Table 7. Surface Condition Adjustments.

Surface Condition Adjustment				
	Aggregate Size	**GR 3**	**Gr 4**	**Gr 5**
Surface Type	**Surface Condition**	**gal/sy**	**gal/sy**	**gal/sy**
Asphalt Concrete	Very dry with many cracks	0.08	0.06	0.05
	Dry with some cracks	0.05	0.04	0.03
	Good condition with few cracks	0.02	0.02	0.01
Seal Coat	Very dry with many cracks	0.06	0.06	0.04
	Dry with some cracks	0.03	0.03	0.02
	Good condition with few cracks	0	0	0
	Flushed	−0.02	−0.02	−0.01
	Bleeding	−0.04	−0.04	−0.02
Patch	Dry or fresh patch	0.03	0.03	0.02
	Fogged patch	0	0	0
	Flushed patch	−0.03	−0.03	−0.03
Prime	Dry surface, lightly primed	0.02	0.02	0.02
	Inverted prime w/ GR 5	0.03	0.02	0.02
	Good prime rate, well penetrated	0	0	0
	Waxy and wet, not well penetrated	−0.03	−0.03	−0.02

Table 8. Traffic Adjustments.

Traffic Adjustments	
ADT (v/d/l)	**gal/sy**
SHLD	0.05
50–100	0.05
100–250	0.04
250–400	0.03
400–500	0.02
500–650	0.01
650–900	0
900–1100	−0.01
1100–1500	−0.02
1500–2000	−0.03
>2000	−0.04

EQUIPMENT INNOVATIONS

Currently, TxDOT Item 316 only specifies "that the nozzles outside the wheel paths will output a predetermined percentage more asphalt material by volume than the nozzles over the wheel paths." This could leave some room for subjective interpretation that ends up being handled by plan notes, on-site engineering oversight/field adjustment in real time, and/or contractor/operator experience and procedures. Spay bar technology innovations investigated in this study show a potential for improvements to the construction process.

Equipment Conclusions

The most effective control of the transverse application would be to require closed-loop functionality. In the first stage of equipment innovation, the least resistance to change would likely come about by modifying current technology as opposed to starting from scratch, even if the latter approach might be more effective in the long run.

During the study, some evidence of attempts to use other methods were identified. One of these was PWM for simulating analog behavior to achieve variable shot rates. While PWM is a mature technology in terms of its usage in various process control applications, researchers do not consider it the best approach for asphalt distributor equipment. Other ideas have come up, such as replacing the nozzle/ball valve/cylinder actuation combination with direct control of an iris type nozzle, but this approach is not considered to be feasible in this harsh environment at this point.

Equipment Recommendations

Improvements to the asphalt distributor spray bar system are needed to improve the overall construction process. Researchers recommend further development of the technologies to improve the spray pattern changes during application, referencing the following the points:

- The adjustment factors do not make any reference as to whether they are in the wheel path or outside of it. Innovation should be geared toward addressing surface condition, no matter where it is located on the pavement, and wheel path versus non-wheel path then becomes a secondary factor in R&D efforts.
- Since the adjustment factors are dependent on two factors, surface condition and aggregate, future R&D efforts should consider if and how the complete system process can be better addressed. This potentially includes transversely variable aggregate delivery rates/sizes in addition to binder application rates.
- Nozzle orifice design is not a trivial matter. For that matter, any orifice in what is basically a pressurized hydraulic system, like an asphalt distributor, generally has undergone a detailed design process. Typically, nozzle housings have a valve that is often like a ball valve associated with them on the bar. That valve is typically operated in a binary state open/shut mode. Future R&D is that anything done to alter existing functionality of the distributor, such as this local control assembly (i.e., ball valve/nozzle), must be analyzed for unintended consequences.
- Tex-922-K suggests using water in the calibration process. This is a safety hazard if not properly handled as is noted in the procedure. Future R&D should look for technologies and procedures that enhance safety simultaneously with improving performance.
- While talented, experienced operators may be worth their weight in gold, reducing subjective interpretation, position uncertainty, and reaction time is a goal of the future state. Future R&D efforts should be focused in this area by capitalizing on the evolution of hardware and software technology.

Equipment Innovation Recommendations for Future Efforts

In the first stage of equipment innovation, the least resistance to change would likely come about by modifying current technology as opposed to starting from scratch, even if the latter approach might be more effective in the long run. In this example, researchers use the Etnyre product line as a base technology, specifically, the Centennial fixed and variable width spray bar, and the RoadArmor Macrosurfacer.

In many distributors, there are three fluid flow circuits:

- Asphalt (material being distributed).
- Hydraulic (e.g., to move the entire bar left and right on a variable width distributor).
- Pneumatic (e.g., to open and shut nozzle valves).

In the Centennial device, the schematic of the hydraulic system (*27*) shows an electronically variable solenoid (similar to a proportional control valve) coupled with a smart cylinder. This configuration is substantially similar to the Truck Movement Simulation part of the laboratory device shown in Figure 68. Therefore, the basic elements of closed loop operation are already available in the hydraulic portion of the Centennial machine. The cab control panel has 24 binary on/off switches for control of the nozzle valves. These operate what are effectively on/off solenoid valves like the one shown in Figure 68 in the Nozzle Operation Simulation block of the laboratory device. The laboratory work pointed out that while options such as operator joystick controls could prove useful in a transversely variable shot rate capable distributor, the most effective control of the process would require closed-loop functionality.

Our recommendations for future equipment development efforts are as follows:

- Apply the proportional valve/smart cylinder concept already present in the Centennial hydraulic system to the individual nozzle valve operation currently done with switches. If space and/or cost become limitations to full implementation, explore the option of combining this approach with flow dividers to reduce the number of proportional or servovalves.
- Implementing the proportional valve/smart cylinder approach to individual nozzles, or short sections of nozzles, enables precision control of the mechanical ball valve opening. Evaluate this capability for unintended consequences (e.g., pressure/flow changes across orifices and viscosity/additive movement restrictions through the orifice) and/or a need to tweak the nozzle orifice design or the design of the ball valve. Once proper operation has been verified, interface with software and electronic controls to move toward a servo control system with position feedback at the nozzle.
- The above approach, if successful, could provide nozzle-level feedback control. However, this does not fully ensure that what is delivered to the pavement surface is what is needed at any given point. Currently, this is done through a combination of plan notes and operator judgement. An approach to solving this part of the puzzle is through a second feedback system. This is where HDV, LiDAR, and other similar systems come into play. Using current technology and process control algorithms, the equipment development would optimally incorporate real time sensing and feedback of the surface conditions over the full areal extent of the pavement. For example, if two LiDAR sensors were used, one in front of the distributor and one behind it, the first sensor could be used to set an estimated valve opening position and the second sensor could be used to evaluate whether the nozzles were set correctly. This evaluation would then be used as feedback to fine-tune the nozzle opening going forward. In this scenario, the largest error would be in the first section of pavement for a distance equal to the distance between the first and second sensor. After that first distance is covered, the system would become almost self-calibrating. With the addition of this second level of feedback, variable rate application could address both transverse and longitudinal variation in surface condition.
- Evaluate LiDAR in more detail as a rut depth measurement tool for usage in the overall seal coating process, as it might be useful in both distributor and spreader applications.
- Evaluate the overall distributor system control enhancements for applicability to spreader systems and combined systems like the RoadArmor Macrosurfacer.
- Improve the nozzle calibration test method, Tex 922-k.

SUMMARY

This study found promising innovations in technology to improve the seal coat construction process. Researchers concluded:

- The HDV system is an excellent tool for documenting the surface condition and is ready for implementation.
- The LiDAR system shows much promise to remove a significant amount of subjectivity when determining variations in surface conditions. Additional work is needed so that this technology can be automated to identify surface conditions and suggest rate changes, thus reducing labor hours and improving efficiency. With automation, the methods developed using Mobile LiDAR can be deployed shortly before actual construction, making decisions more real-time. More real-time decisions will ultimately lead to better performance.
- Binder application rate adjustments should be made during construction. The binder adjustments should be used, but these adjustments can be fine-tuned for local conditions and aggregate sizes.
- The spray bar technology innovations investigated in this study show a potential for improvements to asphalt distributors and should be investigated further.

Researchers believe that implementing these methods will improve the seal coat construction process and reduce risk to TxDOT.

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