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# Management of Chip Seal Through Binder Rate Adjustments Predicted by LiDAR Reflectivity Data

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## Abstract:

This study removes subjectivity from the chip seal binder rate adjustment process which leads to reduced risk for state agencies by using mobile Light Detecting and Ranging (LiDAR) reflectivity data. An automated data analysis method was developed earlier to describe pavement condition changes. In this study, the laser reflected signal intensity of different pavement surface collected using a LiDAR unit was processed and analyzed to generate binder rate adjustments for different chip seal roadways in Texas. The results show that using the average of binder rate adjustment in the left wheel path (LTWP) and right wheel path (RTWP) every 1 mile is feasible and operational for a construction standpoint. However, when the difference of median rate between LTWP and RTWP is greater than 0.03, the use of variable rate nozzle for LTWP and RTWP is highly recommended. The expected surface conditions based on the comparisons between actual and LiDAR predicted binder rates were evaluated and matched well with the observations from the high definition video (HDV) system.

## Keywords:

Mobile LiDAR, Chip Seal, Reflectivity, Pavement Management

## 1. Introduction

One of important preventive maintenance methods applied on pavements throughout the United States is chip seals [1,2,3,4,5]. Through the preventive maintenance program in Texas, seal coats are routinely applied on resurfaced pavements by contracts (~ 16000 lane miles a year) and state forces (~ 3000 lane miles per year) [6,7]. In addition, seal coats can be used in intermediate layers during construction to seal the pavement structure and over $300 million investment is spent annually [1,3]. However, same design methods (i.e., the McLeod and Kearby methods) and construction practices, including equipment used to place the binder or aggregate are used for more than 40 years [8,9].

With little to no changes in design methods and construction practices, the same problems (e.g., rock loss, flushing, and bleeding) reoccurs in Texas continually. In order to potentially reduce these types of problems, new technologies were developed in the previous study by utilizing a mobile Light Detecting and Ranging (LiDAR) system [6]. When determining variations in surface conditions, a significant amount of subjectivity can be removed by the mobile LiDAR system leading to adjust the chip seal binder rates accurately during construction as the conditions change.

The main purpose of this study is to remove subjectivity from the binder rate adjustment process which will lead to reduced risk for state agencies. The LiDAR reflectivity data can be used to describe pavement condition changes through an efficient and effective automated data analysis method. Various chip seal cases were selected in Texas and LiDAR data was collected on the selected cases. The developed automated algorithm [3] was applied to the collected data to estimate binder application rate adjustment. The estimated binder rate was compared to the actual rates from each case along with the evaluation of pavement conditions through high definition video (HDV) system. Visually evaluation and documentation of the performance of the cases as to the accuracy of the automated method in terms of flushing/bleeding or dry/rock loss of the chip seal were summarized as well.

## 2. Materials and Methods

A method developed in earlier study [3,6,7] for adjusting the binder rate based on analysis of reflected laser intensity from the existing pavement surface and then converted to red, green, and blue (RGB) was applied in this study. Binder rate adjustments for chip seal pavements were generated through the k-means clustering algorithm and graph theory by using the RGB values of a pavement surface. A brief description of the developed method is summarized below. The detailed development process can be found in the previous study [3].

### *2.1. Data Collection*

The mobile LiDAR and software package produced by Roadscanners (Rovaniemi, Finland) were used in this study. Laser (SICK, Minneapolis, Minnesota) operated at a 100 Hz frequency used in this study was boomed approximately 10 ft above the ground and emitted a signal at a fixed 0.6667° angular resolution to produce strings of data between 8 and 9.5 inch intervals with the speed of the data collection vehicle between 45 and 55 mile/hr. Approximately 6500 reflective data were record within a 100-ft segment of pavement.

Over thirty cases containing various surface conditions and traffic levels were evaluated but only three cases were selected to present in this study. Laser reflectivity data were collected using a mobile LiDAR unit for all the selected cases. Table 1 provides details of the selected cases and the current annual daily traffic (ADT).

***Table 1.*** *Details of Selected Cases.*

| Case Number | Approximate Length, mile per lane | Number of Lane | Current ADT | |
|---|---|---|---|---|
| | | | Low | High |
| I | 3.5 | 2 | 916 | 1374 |
| II | 13.5 | 2 | 221 | 669 |
| III | 8 | 2 | 918 | 1579 |

### *2.2. Data Processing and Analyzing*

It has been found that how to convert the plethora of data into useful information for the end user is the biggest challenge after performing mobile LiDAR [10,11,12].

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In this study, the reflectivity data generated by the laser scanner are a measure of the signal power returned to the laser after bouncing off of the target surface. Three areas of interest [i.e., left wheel path (LTWP), between the wheel paths (BTWP), and the right wheel path (RTWP)] with 3-ft wide were generated by processing the data from the data collection lane. Grids with 1-ft longitudinal and 4-inch transverse spacing were formed for the collected reflectivity data. The data were then grouped into 100-ft lengths to match with the length of a reference unit (as-expected condition). The returned signal intensity is converted to a 0–255 RGB scale in a postprocessing software (Road Doctor 3). A less reflective surface returns a lower value.

In order to reduce the RGB scale, k-means clustering algorithm [3] was applied and then the data was structuring into a directed acyclic graph (DAG) for the systematic description of the pavement surface condition. Finally, binder rate adjustments were generated by comparing the existing surface and the as-expected condition.

## 3. Results and Discussion

### *3.1. Surface Detection Using Mobile Light Detecting and Ranging (LiDAR) System*

Mobile LiDAR has been found to effectively capture the pavement surface reflectivity [6]. Reflectivity data accurately detected surface changes that when compared to a desired condition can be used to determine flushing, patching, and other surface type changes. Using mobile LiDAR reflectivity data, the location and length of surface changes can be accurately found and noted for design or construction needs. Figure 1 shows the LiDAR reflectivity data and the actual condition of 500 ft of the existing surface of Case I in the eastbound (EB) direction. The different level of blak and white color shown in the LiDAR reflectivity represents how similar or different a chip seal surface was compared with the as-expected condition. Table 2 shows the descriptions combined with rate adjustments for each wheel path for the first 1000 ft of Case I in the EB direction as an example. These descriptions combined with rate adjustments were performed for all cases listed in Table 1.

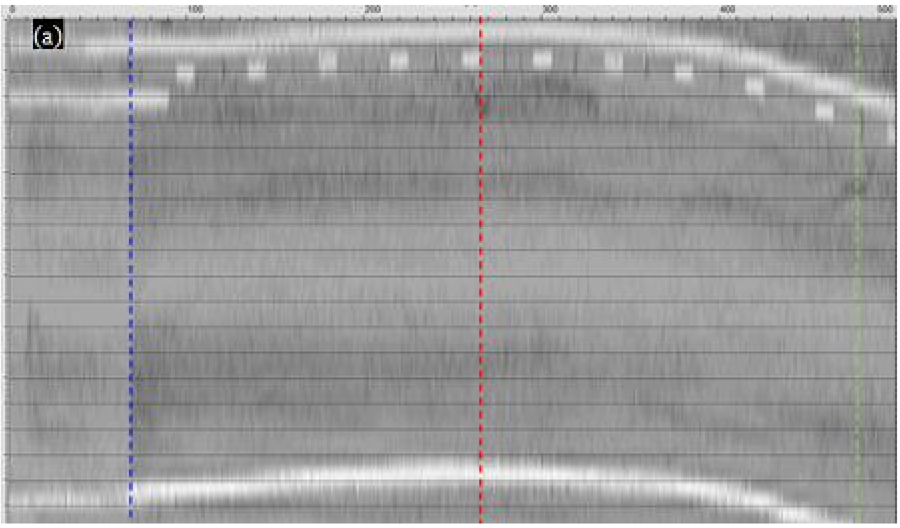

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***Figure 1.*** *(a) LiDAR Reflectivity Laser Signal Intensity and (b) Actual Condition of 500 ft of the Existing Surface of Case I in the EB Direction.*

***Table 2.*** *Binder Rate (BR) Adjustment Tabular Output for 1000 ft. of Case I in the EB Direction.*

| Beginning Reference Location (ft) | LTWP BR Adjustment (gal/SY) | BTWP BR Adjustment (gal/SY) | RTWP BR Adjustment (gal/SY) |
|---|---|---|---|
| 0 | -0.03 | 0 | -0.01 |
| 100 | -0.03 | 0 | -0.02 |
| 200 | -0.03 | 0 | -0.03 |
| 300 | -0.02 | 0 | -0.02 |
| 400 | -0.03 | 0 | -0.01 |
| 500 | -0.04 | -0.01 | -0.01 |
| 600 | -0.03 | -0.01 | -0.02 |
| 700 | -0.03 | -0.01 | -0.03 |
| 800 | -0.03 | 0 | -0.02 |
| 900 | -0.03 | 0 | -0.03 |
| 1000 | -0.03 | 0 | -0.01 |

The suggested adjustments of binder rates are presented in the 2nd to 4th columns (LTWP, BTWP, and RTWP) in Table 2. In general, the LTWPs and RTWPs suggest a higher change in binder rate than the BTWPs. However, nozzles rate changing every 100-ft station is not operational for a construction standpoint. Therefore, use of the average of binder adjustment in LTWP and RTWP every 1 mile is recommended. In order to revel the applicability of the use of average of binder adjustment for each tested section, the distributions of rate adjustments for every 1-mile section in each case were performed and an example for 1-mile of Case III in the EB direction is represented in Figure 2.

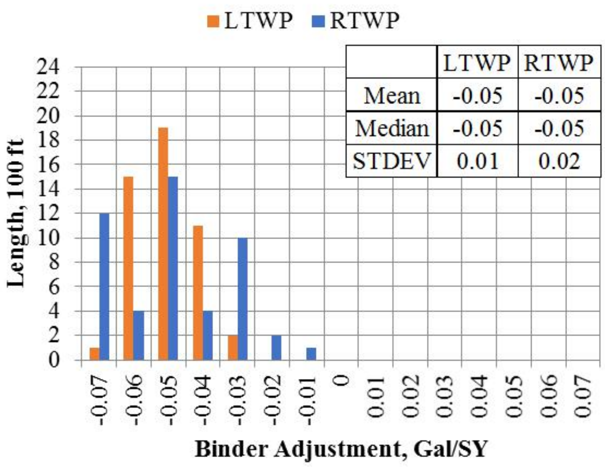


***Figure 2.*** *Distributions of Binder Rate Adjustment Output for 1 mile of Case III in the EB Direction.*

After a detailed analysis and field observations for over thirty cases in Texas, the information implies that when the difference of median rate between LTWP and RTWP is equal or less than 0.03, the use of average of binder adjustment in LTWP and RTWP for 1-mile roadway is feasible for the use of singe rate nozzle. While the difference of median rate between LTWP and RTWP is greater than 0.03, the use of variable rate nozzle is highly recommended. Table 3 summarizes the recommended binder rate adjustments along with the actual binder rates for all the cases listed in Table 1. Based on the comparison between recommended binder rate and actual binder rate (the 3rd and 4th column in Table 3), the expected surface condition is provided in the 5th column in Table 3. These expected surface conditions were evaluated using HDV system and the results are discussed in the followings.

***Table 3.*** *Binder Rate Adjustment Recommended for the Selected Case.*

| | **Recommended BR Adjustment (gal/SY)** | **Recommended BR (gal/SY)** | **Actual BR (gal/SY)** | **Expected Surface Condition** |
|---|---|---|---|---|
| Case I – Westbound (WB) | | | | |
| 0-1 mile | -0.03 | 0.41 | 0.42 | G |
| 1-2 mile | 0 | 0.44 | 0.42 | SD |
| 2-3 mile | -0.02 | 0.42 | 0.42/0.44 | G/SF |
| 3-end mile | -0.04 | 0.40 | 0.44 | F |
| Case I – Eastbound (EB) | | | | |
| 0-1 mile | -0.03 | 0.36 | 0.39/0.43 | F |
| 1-2 mile | 0.01 | 0.40 | 0.43/0.38 | F/SD |
| 2-3 mile | -0.03 | 0.36 | 0.38 | SF |
| 3-end mile | -0.04 | 0.35 | 0.38 | F |
| Case II – Southbound (SB) | | | | |
| 0-1 mile | 0.03 | 0.49 | 0.47 | SD |
| 1-2 mile | 0.03 | 0.49 | 0.43 | D |
| 2-3 mile | 0.03 | 0.49 | 0.45 | D |
| 3-4 mile | 0.04 | 0.50 | 0.44 | D |
| 4-5 mile | 0.04 | 0.50 | 0.45 | D |
| 5-6 mile | 0.05 | 0.51 | 0.45 | D |
| 6-7 mile | 0.05 | 0.51 | 0.44 | D |
| 7-8 mile | 0 | 0.46 | 0.44 | SD |
| 8-9 mile | -0.01 | 0.45 | 0.45 | G |
| 9-10 mile | 0 | 0.46 | 0.45 | G |
| 10-11 mile | 0 | 0.46 | 0.44 | SD |
| 11-12 mile | 0 | 0.46 | 0.46 | G |
| 12-13 mile | 0 | 0.46 | 0.45 | G |
| 13-end mile | 0 | 0.46 | 0.45 | G |
| Case III – Westbound (WB) | | | | |
| 0-1 mile | -0.06 | 0.34 | 0.38 | F |
| 1-2 mile | 0 | 0.40 | 0.39 | G |
| 2-3 mile | -0.02 | 0.38 | 0.42 | F |
| 3-4 mile | -0.03 | 0.37 | 0.39 | SF |
| 4-5 mile | -0.04 | 0.36 | 0.4 | F |
| 5-6 mile | -0.02 | 0.38 | 0.41 | F |
| 6-7 mile | -0.04 | 0.36 | 0.41 | F |
| 7-end mile | -0.06 | 0.34 | 0.4 | F |
| Case III – Eastbound (EB) | | | | |
| 0-1 mile | -0.05 | 0.35 | 0.37 | SF |
| 1-2 mile | -0.04 | 0.36 | 0.37/0.38 | G/SF |

| | | | | |
|---|---|---|---|---|
| 2-3 mile | -0.02 | 0.38 | 0.43 | F |
| 3-4 mile | -0.03 | 0.37 | 0.4 | F |
| 4-5 mile | -0.02 | 0.38 | 0.42 | F |
| 5-6 mile | -0.03 | 0.37 | 0.39 | SF |
| 6-7 mile | -0.01 | 0.39 | 0.4 | G |
| 7-end mile | -0.05 | 0.35 | 0.37 | SF |

*G: good; F: flushing; SF: slight flushing; D: dry; SD; slightly dry/rock loss*

### *3.2. Field Test Site Evaluations Using High Definition Video (HDV) System*

A low cost and easy-to-use methodology has been applied for collecting and processing high definition right-of-way images of the pavement. The surface changes performed using the HDV system and PaveView Software for each case (Table 1) before (July 2019) and after (February 2020) chip seal application are summarized below. Chip seals were constructed on all cases in August 2019.

#### *3.2.1. Case I – a Rural Two-Lane Highway with a Low/Moderate ADT*

Case I was a 2-lane rural roadway with a length of approximately 3.5 miles. It is expected that the surface condition might be good or just slightly flushed/bleeding if the actual shot rate (4th column in Table 3) is close to the recommended rate (5th column in Table 3). While the actual shot rate is higher than the recommended rate, there might be flushing or bleeding appearing on the surface. When the actual shot rate is lower than the recommended rate, dry or rock lost might occur on the surface. These expected surface conditions were evaluated using HDV system, and Figure 3 shows example sections of the before and after chip seal application on Case I in the EB direction.


***Figure 3.*** *Case I EB Surface Conditions: Before (Left) and After (Right) Chip Seal at (a) 1 ml 2230 ft – Slightly Dry/Rock Lost after Chip seal and (b) 2 ml 537 ft – Slightly Flushing after Chip Seal.*

#### *3.2.2. Case II – a Rural Two-Lane Highway with a Low ADT*

Case II was a 2-lane rural roadway with a length of approximately 13.5 miles. The binder application rate based on the LiDAR measurement was determined to be 0.49 gal/SY for the 2nd to 3rd mile in the SB direction (Table 3). Since the actual shot rate is 0.45 gal/SY (< 0.49 gal/SY) for this 1-mile section, the overall surface condition for this 1 mile might be dry or rock lost (Figure 4 (b)). Figure 4 shows example sections of the before and after chip seal application on Case II in the SB direction.

*Figure 4. Case II SB Surface Conditions: Before (Left) and After (Right) Chip Seal at (a) 4439 ft – Slightly Dry/Rock Lost after Chip Seal, (b) 2 ml 2736 ft – Dry/Rock Lost after Chip Seal, (c) 5 ml 1811 ft – Dry/Rock Lost after Chip Seal, (d) 9 ml 3115 ft – Good after Chip Seal, (e) 11 ml 2904 ft – Good after Chip Seal, and (f) 12 ml 3683 ft – Good after Chip Seal.*

### 3.2.3. Case III – a Rural Two-Lane Highway With a Low/Moderate ADT

Case III was a 2-lane rural roadway with a length of approximately 8 miles. The binder application rate based on the LiDAR measurement was determined to be 0.35 gal/SY within the 1st mile in the EB direction (Table 3). Since the actual shot rate is 0.37 gal/SY (> 0.35 gal/SY) within this 1-mile section, the overall surface condition for this 1 mile might be slightly flushing (Figure 5 (a)). Figure 5 shows example sections of the before and after chip seal application on Case III.

***Figure 5.*** *Case III Surface Conditions: Before (Left) and After (Right) Chip Seal at (a) EB 2095 ft – Slightly Flushing after Chip Seal, (b) EB 5 ml 3257 ft – Slightly Flushing after Chip Seal, (c) WB 4488 ft – Flushing after Chip Seal, (d) WB 2 ml 495 ft – Flushing after Chip Seal, (e) WB 4 ml 1531 ft – Flushing after Chip seal, and (f) WB 7 ml 422 ft – Flushing after Chip Seal.*

## 4. Conclusions

Based on the results obtained in this study, the following conclusion are drawn.

Although only three cases (Table 1) were shown in this study as examples, the comparison between the actual binder rates and the rates predicted by analyzing LiDAR reflectivity data (Table 3), and visually evaluation and documentation of the performance of the sections by HDV system (Figures 3 to 5) were performed for over thirty cases in Texas.

The LiDAR information (Table 2) implies that in general, the LTWPs and RTWPs suggest a higher change in binder rate than the BTWPs. However, nozzles rate changing every 100-ft station is not operational from a construction standpoint. Therefore, use the average of binder adjustment in LTWP and RTWP every 1 mile (Table 3) is recommended. However, when the difference of median rate between LTWP and RTWP is greater than 0.03, the use of variable rate nozzle for LTWP and RTWP is highly recommended.

The laser reflected signal intensity of a pavement surface collected using a LiDAR unit can be processed and analyzed to generate binder rate adjustments for chip seal projects without subjectivity. The HDV system can be used to document and evaluated the surface condition without traffic control.

The expected surface conditions based on the comparisons between actual and predicted binder rates (Table 3) are validated and matched well with the observations from HDV system. Thus, the LiDAR can improve chip seal construction by collecting surface information in a safe manner and analyzing it in an automated fashion to describe actual surface characteristics. It can also be deployed shortly before actual construction offers managing agencies the ability to provide detailed binder rates that more accurately address the existing surface conditions, leading to better performance.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

## Acknowledgments

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