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16. Abstract <p>The first two phases of this research study provided a project-level assessment of the accuracy and precision of the automated 3D system developed by the Texas Department of Transportation (TxDOT), and state-of-the-practice commercially available automated systems for the high-speed measurement of pavement surface distresses, rutting, texture and cross slope. The third phase of this study had the objective of extending the automated systems' evaluation with a focus on network-level processes and applications.</p> <p>For this purpose, TxDOT initiated a pilot study with two pavement distress data collection vendors to collect full network-level semi-automated data (as per TxDOT Pavement Management Information System [PMIS] specifications) on the entire network in the Bryan and Houston districts, in conjunction with the PMIS Fiscal Year 2014 data collection season. The two districts selected for the pilot study represent highway characteristics from rural, urban, and metropolitan areas in the state of Texas.</p> <p>The two vendors that collected semi-automated data for the pilot study were Fugro-Roadware and Pathway Services. Fugro's data collection was performed using two Automatic Road Analyzer survey vans equipped with the INO Laser Crack Measurement System and Pathway Services' data collection was performed using two PathRunner Data Collections Vehicles equipped with Pathway 3D Systems. The comparative analyses were conducted on the PMIS aggregated scores (including Ride Score, Distress Score, and Condition Score) as well as on individual distress ratings for instances of alligator cracking, longitudinal cracking, rutting, spalling, punchouts, and failures. Each type of comparison was further analyzed by breaking down the collected highway network into different experimental factors, such as the highway system and pavement surface type. In addition, this report includes an analysis of the automated systems' production rates.</p>					
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**THE UNIVERSITY OF TEXAS AT AUSTIN  
CENTER FOR TRANSPORTATION RESEARCH**

## **Automated Distress Surveys: Analysis of Network Level Data (Phase III)**

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## List of Acronyms

ACP	asphalt concrete pavement
ARAN	Automatic Road Analyzer
CS	Condition Score
CRCP	continuously reinforced concrete pavement
DS	Distress Score
FM	Farm to Market (Road)
GHCN	Global Historical Climatology Network
HMA	hot-mix asphalt
IH	Interstate Highway
INO	National Optics Institute
IRI	International Roughness Index
IWP	inner wheel path
JCP	jointed concrete pavement
LCMS	Laser Crack Measurement System
LRMS	Laser Rut Measurement System
LTPP	Long-Term Pavement Performance
MSE	mean square error
OWP	outer wheel path
PMIS	Pavement Management Information Systems
PSI	Pavement Serviceability Index
RD	rut depth
RFP	Request for Proposal
RS	Ride Score
SH	State Highway
TxDOT	Texas Department of Transportation
US	US Highway



# Chapter 1. Introduction

Collecting accurate and consistent surface distress data is essential for the success of pavement management and preservation strategies. The technologies for collecting pavement distress data have drastically evolved over the last years. Nowadays, it is possible to collect pavement distress data at highway speeds using non-contact high-resolution sensors, thus avoiding the need for traffic control. This has led to a more efficient, safer, and less subjective process for collecting data at the network level as compared to the traditionally used manual methods. In this context, “automated” distress visual data is analyzed by computer algorithms and requires no further human interpretation to provide the final results. “Semi-automated” visual distress data incorporates both computer algorithms and human rates that post-process the results to improve accuracy. Although current automated (or semi-automated) distress measurement systems offer some advantages, several recent studies reported significant measurement errors produced by some of these systems. In addition, discrepancies were identified among measurements produced by different automated systems—even between systems using the same sensor technology. These measurement inaccuracies result in biased data that propagates through the pavement management system, resulting in inaccurate estimation of budget needs and incorrect allocation of resources. Thus, it is important to quantify the ability of automated or semi-automated visual distress systems to provide accurate data for use in the Texas Department of Transportation’s (TxDOT) Pavement Management Information System (PMIS).

The analyses and results presented in this report address the third—and last—phase of TxDOT research project 0-6663, “Evaluation of Pavement Rutting and Distress Measurements.” The primary objective of this research project was an independent evaluation of automated or semi-automated visual distress data collection technologies to improve the accuracy and reliability of pavement distress measurements for use by TxDOT.

This research project was divided into three phases. The first two phases provided a project-level assessment of the accuracy and precision of automated measurements taken by a 3D optical system developed by TxDOT as well as by a number of different vendors’ 3D systems. Phase I evaluated automated measurements of rutting and transverse profile coordinates (Serigos et al. 2012), and Phase II evaluated automated measurements of surface distresses, texture, and cross slope (Serigos et al. 2014). Recommendations for the selection and implementation of automated measurement systems are provided based on the comparison of field measurements collected at highway speeds using different systems as well as statically by visual raters.

The third phase of this study had the objective of extending the automated visual distress data collection system evaluation with a focus on network-level processes and applications. For this phase, two service providers collected semi-automated pavement condition and distress data on the entire highway network of two TxDOT Districts: Bryan and Houston. The automated measurements were compared to the data collected for TxDOT PMIS. Processes were put in place to ensure that all three sets of data were collected on the same routes, roadbeds, and lanes. The results of this research study aimed to help TxDOT make informed decisions about future data collection approaches for populating and maintaining the current PMIS database.

This chapter is divided in three parts. The first two parts summarize the work carried out and lists the conclusions and recommendations obtained from Phase I and II of this study. The

last part of this chapter describes the motivation and objectives of Phase III. Chapter 2 contains a description of the Phase III experimental design and the main characteristics of the highway network in the Bryan and Houston districts. Chapter 3 presents statistics and analyses of the automated data collection production as well as the comparative analyses between the pavement condition and distress data collected by the various automated systems; also addressed are the different data collection methods used to populate the PMIS databases. The last two chapters of this report contain the Phase III conclusions and recommendations, respectively.

## **1.1 Summary and Main Conclusions from Phase I: Evaluation of Automated Rutting and Transverse Profile Measurements**

TxDOT developed a state-of-the-art 3D automated system (Figure 1.1) for the high-speed measurement of pavement surface rutting, cracking, and other types of distress. The goal was to obtain a more accurate and consistent assessment of road performance at both the network and project levels and potentially eliminate the need for manual or “windshield” visual assessments. To ensure the rational adoption of the new systems, TxDOT initiated this project to provide an independent assessment of the accuracy and repeatability of the new automated distress data measurements provided by the TxDOT systems as well as vendors’ systems used by other DOTs. This section presents a summary and lists the main conclusions from Phase I: Evaluation of Automated Rutting and Transverse Profile Measurements. Refer to Serigos et al. (2012) for the complete report.



*Figure 1.1: TxDOT’s 3D Automated Measurement System*

Phase I involved the development of a factorial experiment of over 26 550-ft-long pavement test sections to evaluate the rut and transverse profile measurement capabilities of automated systems at highway speeds. These test sections were located in the Austin District and included dense-graded and permeable friction course hot-mix asphalt concrete pavement, and surface treatments, thus representing the population of flexible pavement textures on the Texas road network. The reference data consisted of transverse profiles measurements collected every 25 ft on each test section using a laser distance measurement meter and a leveled beam (Figure 1.2a) and manual rut depth (RD) measurements collected every 5 ft in both wheel paths using a 6-ft straight edge and rut wedge (Figure 1.2b) based on the ASTM standard E1703.



(a) Leica laser system



(b) 6-ft straightedge and wedge

*Figure 1.2: Measurement of Reference Rutting Values*

In addition to TxDOT's efforts, four service providers collected automated measurements on the same intervals as the reference data: Dynatest, with a National Optics Institute (INO) Laser Rut Measurement System (LRMS) (Figure 1.3a); Fugro-Roadware, with an INO LRMS (Figure 1.3b); Pathway Services, with a 3D system developed in-house (Figure 1.3c); and Applus, with a Laser Crack Measurement System (LCMS) from INO (Figure 1.3d). All of the automated systems used in the experiment were optical 3D systems capable of measuring more than 1,000 points per profile at highway speeds. Each participant used proprietary algorithms to calculate the RD values from their measured transverse profiles. While the sensors used by each participant consisted of a laser and a camera (laser and camera planes represented by the red and yellow triangles respectively in Figure 1.3), the configuration of the system (e.g., the angle at which the laser plane is projected) as well as the number of sensors varied, as Figure 1.3 indicates.



(a) Dynatest's System



(b) Fugro-Roadware's System



(c) Pathways's System



(d) Applus's System

*Figure 1.3: Automated Rut Measurement Systems Evaluated for TxDOT 0-6663 Phase I*

The accuracy and repeatability of each automated system were evaluated by performing two independent assessments. One assessment was of the rut measurement hardware systems, based on the ability of each system to produce accurate transverse profiles in relation to reference measurements. The second assessment accounted for both hardware and software (i.e., filters and data processing algorithms) and was based on the calculated RDs measured on the pavement surface. Table 1.1 shows the summary statistics of the transverse profile measurement errors for TxDOT's and each vendor's system. The observed precision, estimated by the standard deviations of the coordinate measurement errors, are small for all practical purposes, especially considering that the automated measurements were taken at highway speeds. In addition, many of the field sections included in the study presented challenging conditions, including very deep ruts, horizontal curves, and several distresses on the same rated section. Therefore, the overall precision of each automated rut measurement system was considered to be acceptable for pavement management applications in Texas.

**Table 1.1: Statistics of the errors of all the reported transverse profile coordinates**

Vendor	Precision	Error ≤ [16th in]				
	16 <sup>th</sup> inch	50%	75%	90%	95%	98%
TxDOT	2.3	±1.3	±2.2	±3.4	±4.5	±5.9
Pathway	2.8	±1.1	±1.9	±3.3	±5.0	±8.6
Dynatest	1.5	±0.7	±1.3	±2.2	±3.0	±4.2
Fugro	2.3	±0.7	±1.4	±2.5	±3.5	±5.3
Applus	1.5	±0.7	±1.3	±2.2	±2.9	±4.1

Table 1.2 shows the summary statistics of the RD measurement errors for the inner wheel path (IWP), the outer wheel path (OWP) and for both wheel paths. In addition to presenting each system’s accuracy and precision, estimated as the mean and standard deviation of the 5,328 RD measurement errors, the mean square error (MSE) is presented for the purpose of comparison. The negative accuracy values observed in Table 1.2 indicate that all of the systems tended to underestimate the manual measurements and three of them (i.e., the TxDOT, Fugro-Roadware, and Dynatest systems) had an average accuracy less than 1/16th in., which indicates that optical 3D systems can produce RD values similar to the manually measured ones. Also, all of the systems presented a standard deviation of the measurements greater than 2.5 1/16th in., which indicates a significant dispersion of their errors.

**Table 1.2: Statistics of the errors of the reported RD measurement for all stations**

Vendor	Accuracy [16th inch]			Precision [16th inch]			MSE [16th in]		
	IWP	OWP	BOTH	IWP	OWP	BOTH	IWP	OWP	BOTH
TxDOT	-0.87	-0.88	-0.87	2.05	2.92	2.52	2.23	3.05	2.67
Pathway	-1.88	-3.03	-2.45	3.60	6.40	5.22	4.06	7.08	5.77
Dynatest	-1.29	-0.69	-0.99	1.69	3.35	2.67	2.13	3.42	2.85
Fugro	-1.18	-0.47	-0.83	3.46	2.73	3.14	3.66	2.77	3.24
Applus	-2.04	-4.16	-3.10	3.42	4.92	4.37	3.98	6.45	5.35

It is anticipated that the implementation of automated systems will impact the TxDOT PMIS Distress and Condition Scores. PMIS is used to monitor statewide pavement condition and to evaluate the effectiveness of pavement maintenance and rehabilitation treatments. PMIS is also used to report progress in achieving the statewide pavement condition goal (90% of lane miles in “Good” or better condition) and the Condition Score goals established annually for each district. A change in accuracy and precision of pavement condition data will affect the PMIS outputs. For instance, the larger number of distresses captured by transitioning to a more precise measurement system will result in an increase in the deterioration of the pavement network. Consequently, a decision will need to be made whether to accept and publish the new Distress and Condition Scores as recorded, which are expected to show lower Distress and Condition Scores from district to district and statewide. An alternative approach would be to develop new algorithms, utility functions, and methods for reporting Distress and Condition Scores that take into consideration the increased accuracy of these new technologies.

The impact of the measurement errors and associated uncertainties on the PMIS outputs was quantified for the entire Texas highway network by simulating the processes involving measured data (using Monte Carlo Simulation). The findings from the case study showed that transitioning from a five-sensor discrete automated rut measurement system to a continuous one

would result in a drop in Condition Score of approximately 19 points. The quantified drop is significant and it has important implications for TxDOT managerial decisions. A detailed description of the methodology and findings is reported in Serigos et al. (2014).

### **1.1.1 Phase I Main Observations**

The main conclusions and observations from the analyses of both the sensors and processing capabilities in Phase I were the following:

- Although some systems performed marginally better than others during the collection of surface profiles, all five systems are clearly capable of capturing surface profiles with the necessary accuracy.
- In terms of RD measurement (assessment of the combined effect of the hardware and the software systems), no single piece of equipment performed better overall. However, under the conditions evaluated, Dynatest, Fugro, and TxDOT (with the ASTM algorithm) systems outperformed the Applus and Pathway Services.
- The upgrade from the five-point system to a continuous system can generate a drastic change in the number of sections needing rehabilitation. From the quantification of impact on PMIS Scores, it was estimated that:
  - The Rutting Utility Value and the Condition Score dropped with more than 97.5% confidence;
  - The drop in Condition Score was, on average, 19.23 points and ranged from a high of 24.35 points to a low of 8.02 points with a 95% confidence level.

## **1.2 Summary and Main Conclusions from Phase II: Evaluation of Automated Distress, Texture, and Cross Slope Measurements**

Phase II of TxDOT Research Project 0-6663 (Serigos et al. 2014) had the objective of evaluating the accuracy and precision of the automated system (Figure 1.4a) developed by a TxDOT research group (composed of staff from the Construction Division's Materials and Pavement Section) for the high-speed measurement of pavement surface distresses, texture, and cross slope. In addition, equipment vendors participated in the study by providing equipment that represents the state of the practice for the automated distress collection vehicle. The following three vendors participated in Phase II experiment: Dynatest, with an INO LCMS (Figure 1.4b); Fugro-Roadware, with an INO LCMS (Figure 1.4c); and WayLink-OSU, with a proprietary 3D system (Figure 1.4d). The Phase II experiment design comprised 20 550-ft field sections located in the Austin and Waco Districts that included asphalt concrete pavement, surface treatments, portland cement concrete, and continuously reinforced concrete pavements. The experimental design also included variables such as pavement condition (i.e., types and severities of distress) and surface macro-texture (i.e., coarse and smooth). Therefore, the automated measurement systems were evaluated on the most representative types of pavements encountered in Texas.

The current state of the practice in automated collection of pavement surface distresses is that, in general, transportation agencies have to choose between prompt delivery of results and enhanced accuracy. Faster distress data delivery is achieved by reporting the distresses detected and classified by the system's algorithms with minimal or no manual processing or corrections. Enhanced quality of results is achieved by the intervention of trained personnel who visually inspect and correct the automated data. In order to capture the difference in accuracy for different

levels of manual intervention, every participant was asked to report their data within the following three different time frames:

- 1) Fully automated with no manual post-processing, for data delivered at the end of a data collection run with no post-processing by the vendor;
- 2) Semi-automated with minimum manual post-processing, for data delivered within 2 business days from the date that the vendor completes data collection on the last test section; and
- 3) Semi-automated with higher manual post-processing, for data delivered within 4 weeks from the date the vendor completes data collection on the last test section.



(a) TxDOT System



(b) Dynatest System



(c) Fugro-Roadware System



(d) WayLink-OSU System

*Figure 1.4: Automated Distress Measurement Systems Evaluated for TxDOT 0-6663 Phase II*

Each of the 550-ft-long test sections were sub-sectioned at 50-ft intervals and were evaluated manually by an experienced Long-Term Pavement Performance (LTPP) manual distress rating team (Figure 1.5a) and a TxDOT PMIS manual distress rating team. In each case the manual raters followed the LTPP or PMIS Rating Manual protocols (Miller and Bellinger, 2003; TxDOT, 2009) to identify and measure distress on each test section. Phase II analyses also included a qualitative comparison between the crack maps produced by the different automated systems at highway speeds and digital crack maps collected statically through manual measurement of the cracks. A comparative analysis of the digital crack maps allowed the researchers to obtain deeper insight into each system's quality of measurements and identify sources of error that cannot be detected by evaluation of summary statistics alone. Reference crack map images were obtained by manually marking each crack using different colors related

to three crack width (red < 3 mm, blue 3–6 mm, and green > 6 mm) categories and then photographing selected 50-ft subsections using a high-end digital camera.

The three vendors, which already had data collection software and protocols for LTPP data, were evaluated according to the LTPP protocol whereas TxDOT was evaluated using the PMIS protocol. The comparative analyses among the measurements reported by each system were performed for each type of distress separately, although special focus was placed on the analysis of fatigue and longitudinal and transverse cracking.

TxDOT was the only participating system capable of reporting data just after collection, although the reported data was not in the format requested for the experiment. In addition, TxDOT did not report data for the second and third time frames (semi-automated with minimum and higher manual post-processing). Only longitudinal cracking and transverse cracking could be reported by TxDOT's current automated equipment setup, whether the section was asphalt pavement or concrete pavement. On many sections in which TxDOT values were significantly higher than the reference, those values moved closer to the reference values after TxDOT's sealed crack counts were removed by the researchers during data analysis and interpretation, thus counting only non-sealed cracks.

The three vendors reported semi-automated data with minimum manual post-processing, and only Fugro and Dynatest reported semi-automated data with higher manual post-processing. WayLink did not submit a dataset with manual corrections since they did not consider it necessary for improving the accuracy of their product.



(a) Visual Rating of Distresses



(b) Crack Map Production

*Figure 1.5: Manual Distress Surveys for Production of Reference Distress Measurements*

### 1.2.1 Phase II Main Observations

The main conclusions and observations from the analyses of both the sensors and processing capabilities in Phase I were the following:

- Among the datasets reported within 2 days, the WayLink-OSU outperforms the remaining participating systems in terms of crack detection. However, WayLink-OSU tended to overestimate the crack widths, and underestimate the extension, suggesting the need for further adapting and calibrating the system's algorithms for Texas conditions.
- Dynatest and Fugro showed a significant improvement in the accuracy of their distress measurements after applying manual post-processing consisting of visual interpretation and correction of the results produced by their systems' algorithms.

Additionally, the results reported within 4 weeks included more types of distresses. These observations show the current need for applying manual interpretation to the automated results produced by state-of-the-art equipment.

- Manual corrections were more effective at removing cracks incorrectly detected than at adding cracks missed by their algorithm. In addition, none of the vendors' measurement precision improved after applying manual post-processing.
- A weak association was observed between the automated measurements accuracy of every vendor and the surface macro-texture either before or after manual post-processing.
- From the analyses of crack maps with minimal or no manual post-processing, it was observed that TxDOT and WayLink-OSU system's algorithms tended to underestimate the crack lengths, TxDOT being the participant with the largest number of missed cracks. On several flexible pavements WayLink-OSU outperformed the other participants at detecting cracks; however, they tended to overestimate the crack width. In addition, WayLink-OSU was the only system that did not misidentify transverse or longitudinal joints on rigid pavements as cracks. The amount of missed cracks was greater for cracks less than 3 mm (.12 in.) wide for all participants and surface types.
- From the analyses of crack maps with higher post-processing, it was observed that the automated results generated by Fugro-Roadware and Dynatest systems' algorithms were greatly improved after applying manual correction. The very fine cracks observed on the rigid pavements were not detected by any automated system and for any level of manual post-processing. In addition, TxDOT and Dynatest presented false positives caused by misinterpreting features such as vegetation, spots with different colors, and rumble stripes.
- The TxDOT crack maps were missing a large number of cracks, suggesting the need for calibrating the algorithms in order to increase system sensitivity for detecting narrower cracks. It is also suggested that TxDOT consider the development of algorithms to quantify crack widths and thus report crack severity levels. In addition, TxDOT could improve crack identification accuracy by differentiating between sealed and unsealed cracks.
- Several types of distresses, such as patching, punchouts, spalling, and joint damage, were reported only after manual post-processing of the crack maps by Fugro and Dynatest, whereas WayLink-OSU reported some of these types of distresses on the 2-day time frame.
- Dynatest and Fugro produced texture results close to the reference in magnitude with minor error. It is suggested that WayLink-OSU and TxDOT consider updating or calibrating their systems since all measurements presented were greater than the reference values.

### **1.3 Phase III: Analysis of Network Level Data**

During Phase II of the project, TxDOT Administration directed the Maintenance Division to issue a request for proposal for possibly one or more service providers to collect pavement condition and distress data automatically in two TxDOT Districts. The selected vendors were to collect full network level data as per TxDOT PMIS specifications on the entire network in the

Bryan District and in the Houston District in conjunction with TxDOT's Fiscal Year 2014 PMIS data collection season (September 1, 2013 to February 28, 2014).

Two service providers (vendors) were selected by TxDOT for participation in the pilot study: Fugro-Roadware and Pathway Services. Fugro's data collection was performed using two Automatic Road Analyzer (ARAN) survey vehicles with one INO LCMS per wheel path and Pathway's data collection was performed using two PathRunner survey vehicles with Pathway 3D systems covering both wheel paths. All automated data collection and any manual processing and distress identification was to be completed within 57 working days from the start date of the service. The two vendors started their data collection in September 2013 and completed their data collection and post-processing in December 2013. None of the vendors were able to comply with the specified timeframe for delivering the data and therefore requested a time extension, which was approved by TxDOT.

The two districts selected for the Phase III pilot study represent highway characteristics from rural, urban, and metropolitan areas in the state of Texas. The pilot study included pavement sections of hot-mix asphalt (HMA) surfaces; jointed concrete pavements (JCP), continuously reinforced concrete pavements (CRCP), and seal coat (chip seal) surfaced pavements, among other surfaces.

The pavement surface distress data was to be collected and reported for every PMIS Data Collection Section according to the PMIS Rater's Manual for Fiscal Year 2012 (TxDOT 2011). This protocol requires that the data shall be collected in the most distressed lane; however, the selection of the actual lane in which data is collected can be subject to the interpretation of the operator. In addition, traffic conditions at the time data collection is performed might result in the data collection van operator selecting a less distressed lane on a multi-lane freeway, especially in high-traffic urban areas. In order to avoid the subjective selection of the lane to rate, all automated systems were asked to collect data at the outermost lane of each roadbed.

Once the automated data collected for the pilot study was processed and converted to PMIS ratings, the research team conducted comparative analyses in order to evaluate the differences between the results produced by the automated systems and the methods currently used to populate PMIS databases. The comparative analyses were conducted on the PMIS aggregated scores—including Ride Score, Distress Score and Condition Score—as well as on individual distresses, including alligator cracking, longitudinal cracking, transverse cracking, surface rutting, spalling, punchouts, and failures. Each type of comparison was further analyzed by breaking down the collected highway network into the following factors: District; County; Highway system; Pavement surface type; and Facility, as a function of the number of lanes.

This report describes the main characteristics of the pilot study experimental design and presents the analysis of data collection production and comparative analysis between the automated data and PMIS data. The comparative analyses are presented by means of descriptive statistics and their distributions as well as in a self-explanatory and user-friendly format as requested by TxDOT. The recommendations provided in this report are based on the network-level comparative analyses carried out for Phase III as well as on the findings and recommendations from the project-level assessment of the automated systems' accuracy and precision conducted for Phase I and II.

## Chapter 2. Description of Pilot Study Data Collection

The automated network-level data analyzed in Phase III of this research project was collected in a pilot study designed and conducted by TxDOT. The two vendors that collected automated data for the pilot study were Fugro Roadware and Pathway Services. This chapter contains the requirements and specifications set for collecting automated pavement data and a description of the study's highway network and collected data.

### 2.1 Pilot Study Specifications

This section describes some of the main requirements and specifications for collecting ride and distress data for the pilot study. The experimental design, as well as the writing of the Request for Proposal (RFP) and specifications for the pilot study, were carried out by TxDOT without input from the research team. The pilot study RFP (No. B442013029310000) refers to Specification No. TxDOT 968-62-65, which sets the requirements to conduct pavement condition data collection services. The scope of the referred specification is to “provide services to gather, assemble, and deliver pavement condition data for two districts in the state of Texas which include the Houston and Bryan District.” The two districts selected present opportunities for data collection in urban, rural, and metropolitan areas. Qualified vendors had to be in the business of pavement data collection services for a minimum of 5 years within the last 10 years.

Each vendor was asked to collect automated data for the entire TxDOT highway network of the two specified districts, resulting in a total of 7,588 roadbed miles of automated data. Due to the sampling process used in PMIS data collection, data is not collected on every lane-mile of the network; rather, one lane of each roadbed is collected to represent the condition of each roadway segment. Out of this total, 4,133 roadbed miles were to be collected at Houston, which comprises six counties: Brazoria, Fort Bend, Galveston, Harris, Montgomery, and Waller (Figure 2.1, in blue); and 3,455 roadbed miles were to be collected at Bryan, which comprises ten counties: Brazos, Burleson, Freestone, Grimes, Leon, Madison, Milam, Robertson, Walker, and Washington (Figure 2.1, in green).

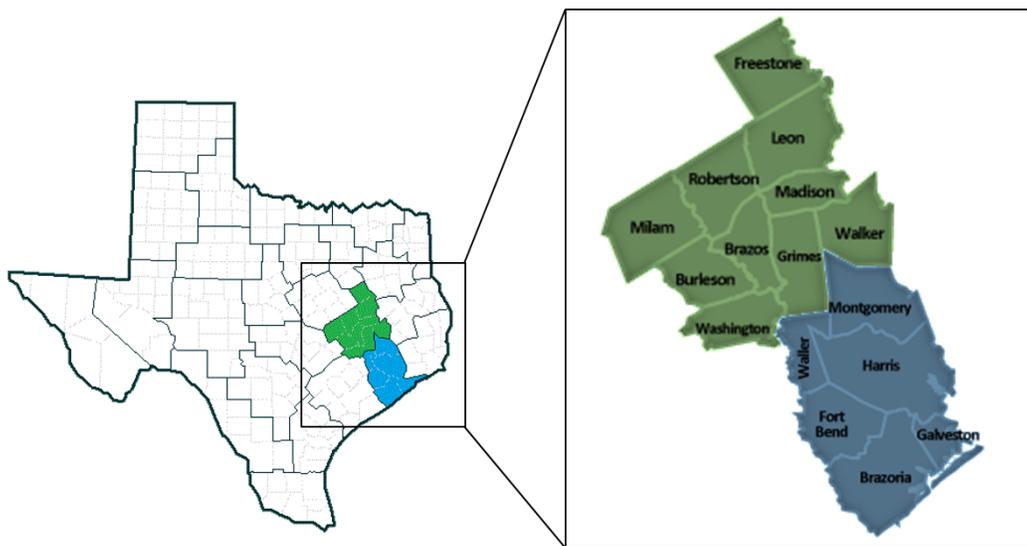


Figure 2.1: Maps of Bryan (green) and Houston (blue) Districts with Their Respective Counties

The total maximum time given to the vendors to complete their data collection was 57 working days, of which 50 working days were allocated for automated data collection and 7 working days for manual processing. Each working day was defined as a 10-hour workday during daylight hours and data collection had to be performed in conjunction with the TxDOT FY 2014 PMIS data collection period—i.e., between September 1, 2013 and February 28, 2014.

Since pavement types may vary significantly along a route, in order to participate in the pilot study the vendor had to ensure that their data collection and reporting system differentiates between different pavement types and provides distress ratings consistent with each pavement section. Although the specification requested that the system differentiates between “HMA surfaces; JCP, CRCP, and seal coat (chip seal) surfaced pavements,” it should be noted that TxDOT PMIS divides pavement surfaces into three “broad” groups for the purpose of defining distresses— asphalt concrete pavement (ACP), JCP, and CRCP—while also defining 10 pavement surface “detailed” groups for inventory purposes (see Table 2.1).

**Table 2.1: TxDOT PMIS broad and detailed pavement types (TxDOT 2011)**

Pavement Type		Description
Broad	Detailed	
CRCP	1	Continuously Reinforced Concrete Pavement
JCP	2	Jointed Concrete Pavement, reinforced
	3	Jointed Concrete Pavement, unreinforced (“plain”)
ACP	4	Thick Asphalt Concrete Pavement (greater than 5½” thick)
	5	Intermediate Asphalt Concrete Pavement (2½ - 5½” thick)
	6	Thin Asphalt Concrete Pavement (less than 2½” thick)
	7	Composite Pavement (heavily stabilized asphalt-surfaced pavement)
	8	Overlaid or Widened Old Concrete Pavement
	9	Overlaid or Widened Old Flexible Pavement
	10	Thin-surfaced Flexible Base Pavement (surface treatment or seal coat)

The accuracy for identifying pavement surface types by the automated systems was out of the scope of this study and each vendor was provided with information of each pavement section to be collected for the pilot study, which included detailed pavement type (1–10 pavement type code). In addition, each participating vendor was required to collect data on dry pavement surfaces during daylight hours, at or near the posted highway speeds and in the outermost lane of each roadbed (i.e., either K1, L1, R1, A1, or X1 from Figure 2.2). Thus, all automated systems were asked to collect data in the same lane.

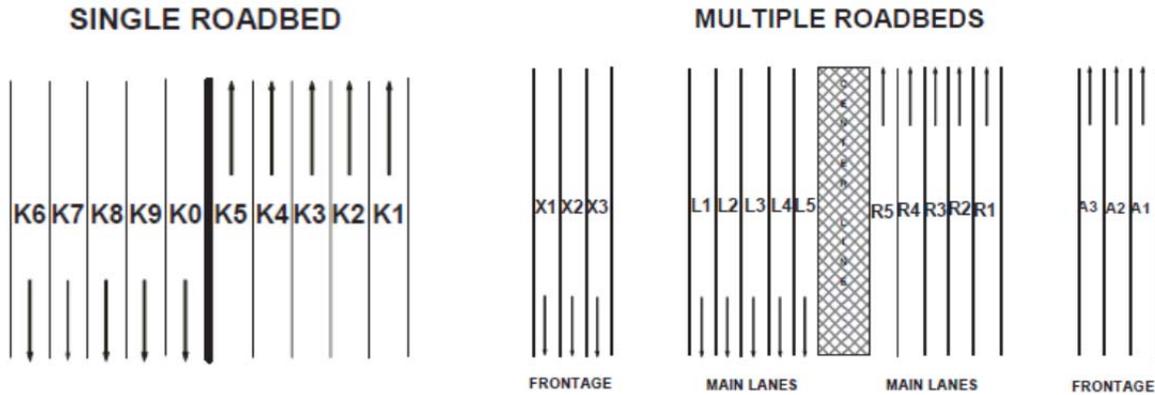


Figure 2.2: Roadbed Types and Lane Codes Defined for PMIS Data Collection (TxDOT 2011)

The following list describes the requirements for the types of data that were to be collected by the automated systems:

- **IRI (International Roughness Index) data**, to be collected following TxDOT Test Method Tex-1001-S using inertial profile equipment certified by the Texas A&M Transportation Institute (TTI). IRI data were to be reported for both wheel paths every 0.1-mile interval;
- **PSI (Pavement Serviceability Index) data**, calculated from the IRI data for each 0.1-mile interval using the algorithm in Equation 2.1;

$$getPSI = 8.8532704 - 4.425873 * \left( \frac{leftIRI + rightIRI}{\frac{63.346}{2}} \right)^{0.35}$$

If  $getPSI < 0$  then  $getPSI = 0.1$   
If  $getPSI > 4.7$  then  
If  $getPSI \geq 5.38$  then  $getPSI = 5$   
Else  $getPSI = 4.7 + (getPSI - 4.7) * \frac{5 - 4.7}{5.38 - 4.7}$  (2.1)

where,

$getPSI$  = calculated Pavement Serviceability Index from measured IRI  
 $leftIRI$  and  $rightIRI$  = IRI measured at the left and right wheel paths in inches/mile

- **Rutting data**, collected on every 0.1-mile segment for both wheel paths to a minimum accuracy of one-tenth of an inch. The rutting data to be reported consisted of average, minimum, and maximum RD for every 0.1-mile segment and wheel path, as well as the extension of rutting for each wheel path in the section as percentages for each PMIS rut category. The PMIS rut categories are “No Rutting” (0–0.24 inches), “Shallow Rutting” (0.25–0.49 inches), “Deep Rutting” (0.5–0.99 inches), “Severe Rutting” (1.00–1.99 inches), and “Failure” ( $\geq 2.00$  inches). Both participating vendors used equipment with optical sensors systems, which calculate rutting from continuous transverse profiles. In contrast, TxDOT collected rutting data using five-point sensor systems. In order to obtain a direct comparison between the automated systems’ measurements and TxDOT

PMIS data, vendors were required to calculate rutting data simulating a five-point collection system from the continuous profile. For this, the sensor spacing was defined as “31.6 inches between the center sensor and the wheel path sensor, and 17.75 inches between the wheel path sensor and the outside sensor.” Figure 2.3 shows an example of a continuous transverse profile in green, and the sensors’ location on the simulated discrete system with yellow circles.

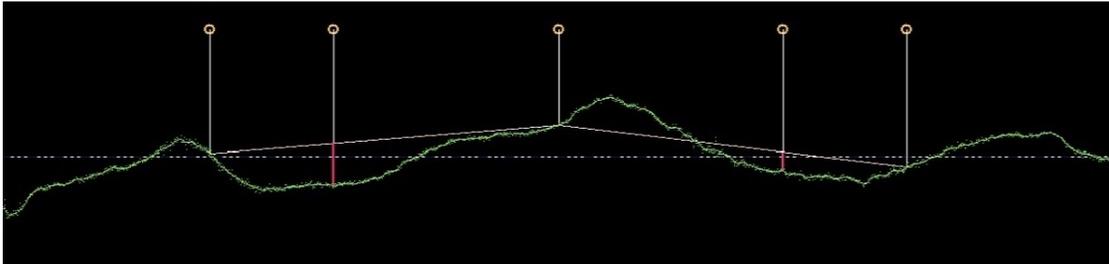


Figure 2.3: Location of Coordinates for Simulation of Five-Sensor System (Huang et al. 2009)

- **Pavement surface distress data**, to be collected following the definitions in the PMIS Rater’s Manual for FY 2012. In order to conduct any semi-automated rating of images, vendors were required to utilize certified visual raters who have attended training and passed the TxDOT visual raters course. According to TxDOT’s personnel, both Fugro and Pathway Services complied with this requirement by providing at least two visual raters that obtained TxDOT certification for this project.

In addition, vendors were also required to report GPS data and right-of-way images. However, this information has not been used by the research team for the analyses presented in this report.

All requested data had to be reported in an ASCII text file (PF99 format). TxDOT has been using PF99 formatting to report ride and rutting data into their PMIS databases for more than 15 years; however, distress data is not regularly reported in this format. Therefore, the processing of distress data in PF99 format was specific to this project; Figure 2.4 provides an example of this format. Information of how to report their data into PF99 format was provided to the vendors as part of the RFP. All data reported by the vendors had to be extracted from PF99 files and exported to PMIS databases. This process required converting the measurements reported for every 0.1-mile interval into PMIS ratings for each ~0.5-mile pavement section. TxDOT PMIS surface distress data, collected visually through windshield surveys, was directly reported for the entire PMIS section length (i.e., ~0.5 miles) and was not formatted to the PF99 format.

```

27 #METAI,VID00,DMI_1,DMI_2,FRW,SoftwareVersion,SoftwareSource,CameraVendor,CameraModel,ImageSize,ImageCompression
28 CMET4,MERCEDES SPRINTER 2500,10BT,855.703,ARAN_48,W03BE7CC2B5553659,06212013,ADON GAITAN:DAVID COLEMAN,Phillip.Hempel@tx
29 PMET1,,0.0000,0.0000,ROADWARE,REL 2013.03.13,ROADWARE
30 PTYP3,,0.0000,0.0000,01,Continuously Reinforced Concrete Pavement
31 HEAD4,,0.0000,0.0000,20130911100501.000,PMIS,PMIS,12,237,FM0359 ,0448 -00.600,R1
32 STAT4,,0.0000,0.1000,44.1,44.5,43.7,44.5
33 RUT05,,0.0000,0.1000,0.07,0.00,0.22,0.05,0.01,0.00,0.14,0.02,100,000,000,000,000,100,000,000,000,0,0,0,0,220,220
34 IRI03,,0.0000,0.1000,69,83
35 RIDE3,,0.0000,0.1000,4.1
36 CRKR5,,0.0000,0.1000,0,0,0,9,,,,,LANCE WILLIAMS,CHALMAND
37 STAT4,,0.1000,0.2000,43.3,43.7,42.9,43.7
38 RUT05,,0.1000,0.2000,0.04,0.00,0.18,0.04,0.01,0.00,0.10,0.02,100,000,000,000,000,100,000,000,000,0,0,0,0,238,238
39 IRI03,,0.1000,0.2000,97,102
40 RIDE3,,0.1000,0.2000,3.7
41 CRKR5,,0.1000,0.2000,0,0,0,9,,,,,LANCE WILLIAMS,CHALMAND
42 STAT4,,0.2000,0.3000,42.4,42.9,41.8,42.9
43 RUT05,,0.2000,0.3000,0.07,0.00,0.20,0.05,0.01,0.00,0.13,0.02,100,000,000,000,000,100,000,000,000,0,0,0,0,237,237
44 IRI03,,0.2000,0.3000,70,77
45 RIDE3,,0.2000,0.3000,4.2
46 CRKR5,,0.2000,0.3000,0,0,0,9,,,,,LANCE WILLIAMS,CHALMAND
47 STAT4,,0.3000,0.4000,41.4,41.8,41.1,41.8
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50 RIDE3,,0.3000,0.4000,4.3
51 CRKR5,,0.3000,0.4000,0,0,0,9,,,,,LANCE WILLIAMS,CHALMAND
52 PTYP3,,0.4000,0.4000,01,Continuously Reinforced Concrete Pavement
53 HEAD4,,0.4000,0.4000,20130911100516.000,PMIS,PMIS,12,237,FM0359 ,0448 -00.200,K1

```

Figure 2.4: Example of Data Reported by Fugro in PF99 Format

The amounts of data reported by the vendors and successfully extracted for the comparative analysis of this study are presented in Table 2.2. The “PMIS” row shows the total number of roadbed miles and total number of PMIS sections contained in TxDOT PMIS databases. TxDOT provided a version of this database—which includes section characteristics such as highway type, pavement type, and section length—to the vendors in order to identify each section in the study. The rows for Fugro and Pathway Services show the amount of data extracted from their PF99 files (in number of roadbed miles) under the columns of “Raw data,” and the amount of data successfully processed, converted to rating and exported to PMIS databases (in number of PMIS sections) under the columns of “Processed data.” Therefore, a large proportion of the two districts’ highway network was successfully processed and available to the researchers for the comparative analyses. The percentage of data reported by the vendors but not successfully processed and exported into the PMIS databases (approximately 7% for Fugro and 10% for Pathway Services) is due to formatting issues, repeated measurements, and data collected on non-TxDOT highways or outside the boundaries of the two districts, among other causes. The “TxDOT” row presents the amount of PMIS data available for the comparative analyses, collected for the FY 2014 PMIS data collection season, and readily formatted and populated into PMIS databases.

**Table 2.2: Percentages of reported and processed data for the pilot study**

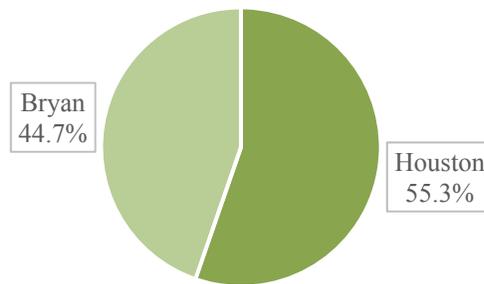
Dataset	Raw data		Processed data	
	Roadbed miles	% of PMIS	PMIS sections	% of PMIS
PMIS	7,549.5	-	16,463	-
TxDOT	-	-	16,454	99.9%
Fugro	7,550.0	100.0%	15,338	93.2%
Pathway	7,326.1	97.0%	14,405	87.5%

## 2.2 Description of Bryan and Houston’s Highway Network

This section describes the highway network on which the pilot study was carried out. The first part of this section provides characteristics of the entire Bryan and Houston highway network, while the second and third parts focus on the distribution of pavement types and highway system classification respectively for each district network. Lastly, the fourth part of this section provides a description of the network formed only by the PMIS sections that were successfully processed from the PF99 files reported by the vendors and included in the comparative analyses.

### 2.2.1 Overall Description of Pilot Study’s Highway Network

The total number of data collection sections in PMIS FY 2014 for Bryan and Houston’s highway networks is 16,463. As shown in Figure 2.5, the number of PMIS sections in each district is similar; Houston has a slightly larger proportion of the pilot study network. The large majority (almost 80%) of the PMIS sections in the two districts are 0.5 miles in length, 16% of the sections are less than 0.5 miles long (mainly 0.2-, 0.3- and 0.4 miles long), while the remaining sections are longer than 0.5 miles. These distributions of section length are similar within each individual district.



*Figure 2.5: Overall Distribution of PMIS Sections by District (16,463 PMIS Sections)*

Within these two districts are thirteen highway types, referred to in PMIS as highway systems. Figure 2.6 presents the distribution of the different highway systems in the pilot study. In general, Farm to Market (FM) roads dominate the distribution of PMIS highway systems in the study, followed by State Highways (SH), Interstate Highway (IH), and US Highways (US). It should be noted that some of the FM roads used in this study are located in rural areas and consist of narrow roads without shoulders while the other three major highway systems typically consist of wider roads, located in urban and metropolitan areas and designed to serve higher traffic volumes.

The IH group was divided into IH main lane and the IH frontage road. Both roadbed types play an important role in the TxDOT highway network and the surface type and condition on frontage roads may differ from those on main lanes. IH main lanes and frontage roads together account for about one-fifth of the PMIS section network in the study. As Figure 2.6 indicates, the number of main lanes is higher than the number of frontage roads.

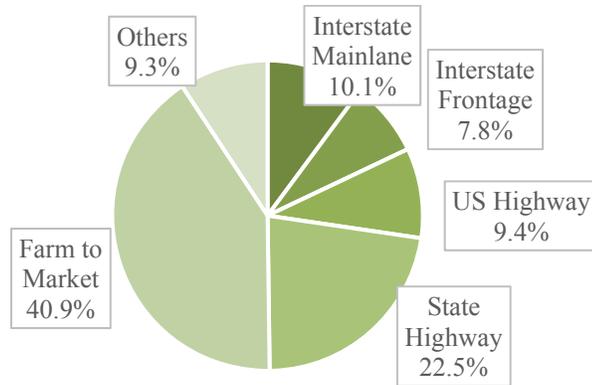


Figure 2.6: Overall Distribution of Highway System (16,463 PMIS Sections)

In addition to the highway system distribution, it is also relevant to analyze the surface type distribution for the network of the study (Figure 2.7). As observed from the distribution, about two-thirds of the network consisted of flexible pavements, composed mainly of medium thickness asphaltic concrete 2.5 in. to 5.5 in. thick (HMA med) and surface treatment pavements. Furthermore, almost half of the sections in the study were medium thickness HMA. Rigid pavements comprised a third of the network, including CRCP, jointed reinforced concrete pavements, and widen composite pavements (composite). A composite pavement consists of an asphalt overlay on top of a concrete pavement or an asphalt overlay on a stabilized (semi-rigid) base. This pavement type behaves essentially the same as rigid pavement under traffic loading; however, it would be rated as a flexible pavement due to having asphaltic material on its surface.

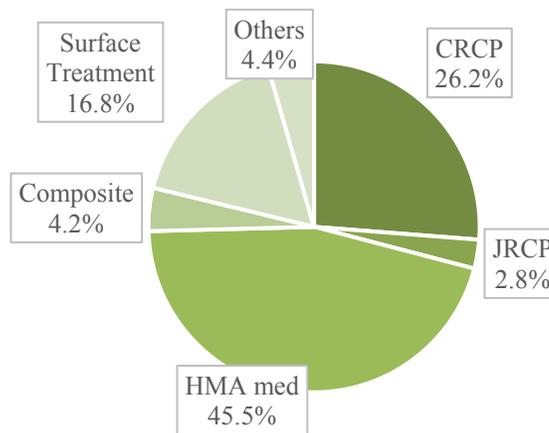


Figure 2.7: Overall Distribution of Pavement Type (16,463 PMIS Sections)

Out of the 4,321 CRCP sections in the network, 4,263 (99%) of them come from the Houston District. Also, 2,636 out of 2,759 surface treated pavement sections (96%) are from the Bryan District. Therefore, analyses and findings performed on CRCP sections will affect Houston while analyses and findings performed on surface treatment sections will mainly affect Bryan. The following sections provide further details on the differences between Houston and Bryan highway networks.

### 2.2.2 Pavement Type Distribution per District

The Bryan District was chosen to represent typical rural highways in Texas while Houston was chosen to represent more urban and metropolitan highways, with a larger proportion of rigid pavements. Figure 2.8 (a) and (b) show the distribution of pavement surface types for the Bryan and Houston districts respectively. As its pavement type distribution profile indicates, Bryan’s highway network is predominantly composed of flexible pavements (more than 95% of the sections) as opposed to the Houston District, which is almost evenly distributed between rigid and flexible pavements. The predominant rigid pavement type in Houston is CRCP with a small percentage of JCPs. Flexible pavement in both districts is mainly composed of medium thickness HMA. Surface treatments have a significant presence only in Bryan.

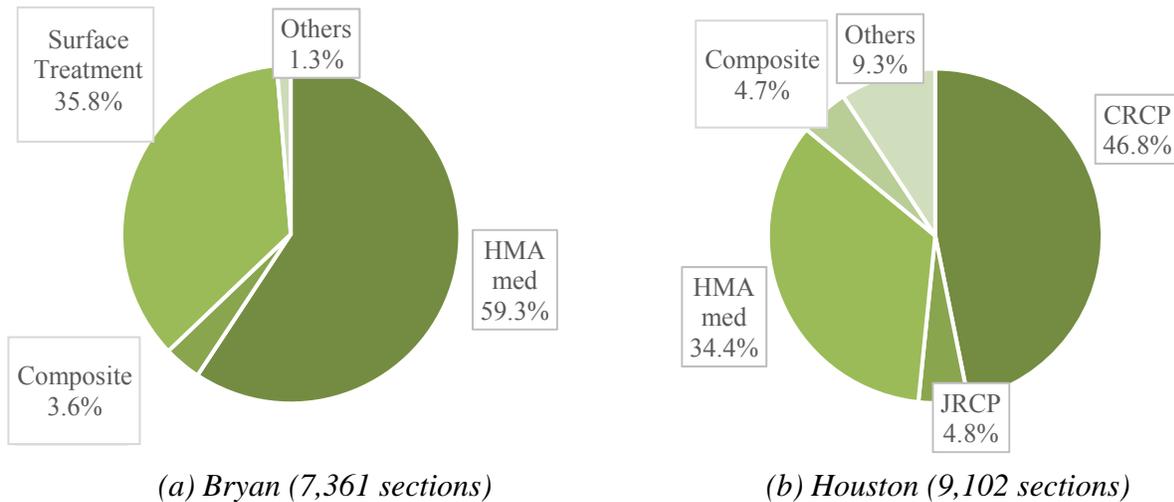


Figure 2.8: Pavement Type Distribution in Bryan and Houston Districts

Figure 2.9 shows the distribution of pavement type in Harris County, which includes a total of 4,047 PMIS sections—about a quarter of the entire two districts’ network. Harris County includes the metropolitan area of the Houston District and, therefore, it contains most of the busiest highway sections in the analyzed network. As Figure 2.9 depicts, about three-fourths of this County’s network is composed of rigid pavements, mainly CRCPs. As opposed to the Bryan District’s network—mainly composed of rural, low-volume medium thickness HMA roads—the high percentage of rigid pavement in the Harris area shows that most of the high-volume corridors of this study heavily rely on the support of concrete pavements.

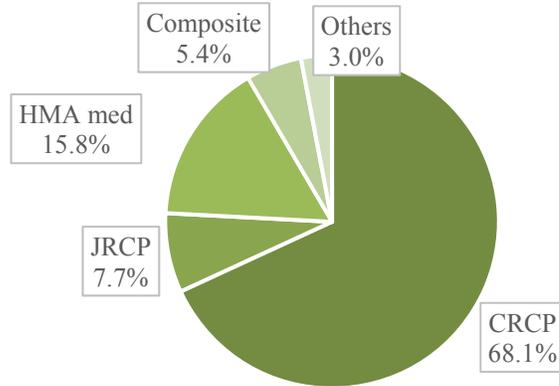


Figure 2.9: Distribution of Pavement Type in Harris County (4,047 Sections)

### 2.2.3 PMIS Highway System Distribution per District and Pavement Type

Figure 2.10 (a) and (b) show the highway system distribution for Bryan and Houston respectively. As Figure 2.10 (a) illustrates, more than half of the sections in Bryan are FM roads, followed by about one-fourth of sections on SHs. IHs and US highways comprise about a tenth of the network each. Figure 2.10 (b) indicates that the Houston District has a larger proportion of IHs than Bryan—from about a tenth in Bryan to about a quarter of the network in Houston, with a smaller proportion of FM and US sections. Still, FM roadways are the predominant route type for both Houston and Bryan. The proportion of SHs is similar for both districts.

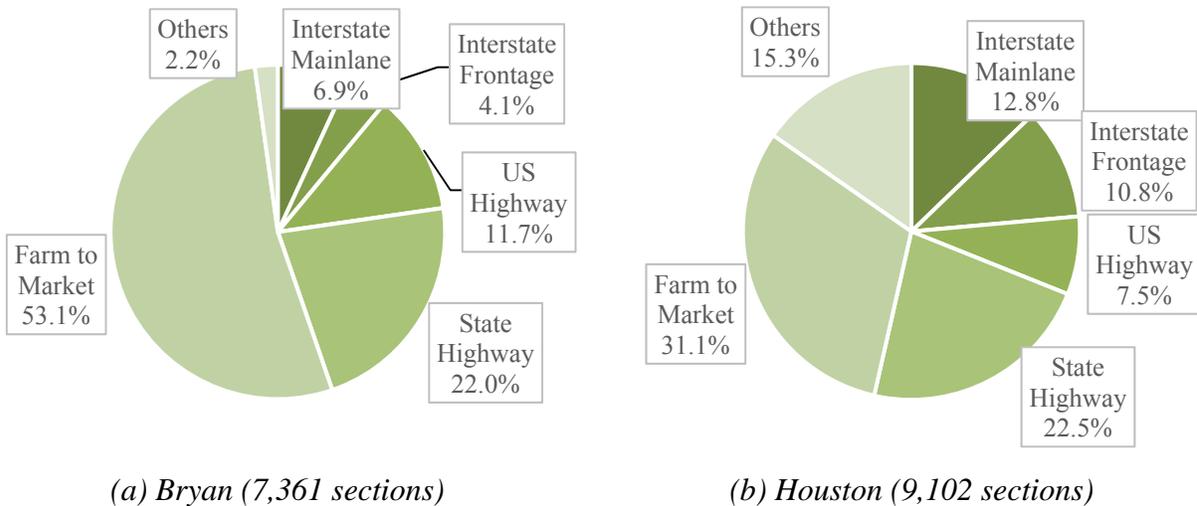


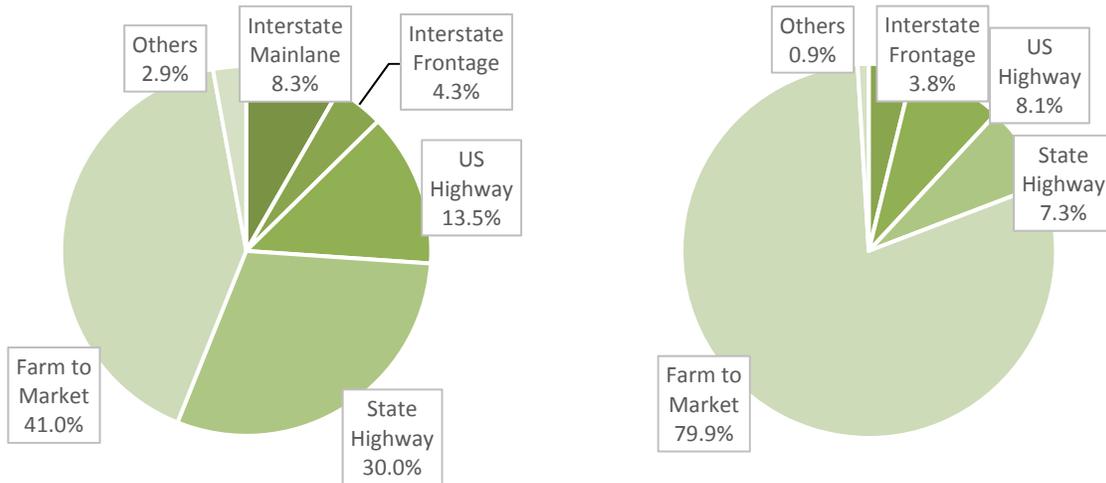
Figure 2.10: Highway System Distribution in Bryan and Houston Districts

### PMIS Highway System Distribution Pavement Type

Figures 2.11 and 2.12 show the highway system distribution grouped by district and pavement type. Figure 2.11 (a) and (b) show the distributions for the two major pavement types in Bryan: medium thickness HMA and surface treatments. According to Figure 2.11, in Bryan medium thickness HMAs are mainly present in FM and SH roads; surface treatments are predominantly present in FM roads. The proportion of IHs with medium thickness HMA sections

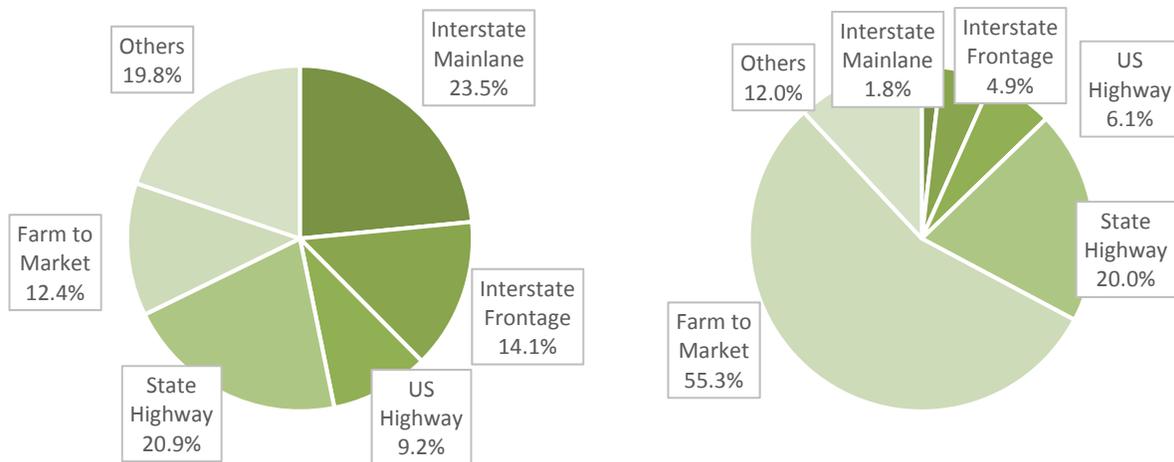
in Bryan is larger than for surface treatment sections. Furthermore, none of surface treatment pavements are reported on IH main lanes, while there is a small percentage reported on IH frontage roads.

Further analysis of the distribution of highway systems for composite pavements in Bryan showed that more than half of composite surfaces are present on IH main lanes while none of them are present on frontage roads. It should be noted that the only IH in Bryan is IH 45.



(a) HMA med - Bryan (4,364 sections)      (b) Surface Treatment - Bryan (2,636 sections)

Figure 2.11: Highway System Distribution per Pavement Type in Bryan District



(a) CRCP - Houston (4,263 sections)      (b) HMA med - Houston (3,129 sections)

Figure 2.12: Highway System Distribution per Pavement Type in Houston District

Figure 2.12 (a) and (b) show the distributions for the two major pavement types in Houston: CRCP, which accounts for almost half of the Houston network, followed by medium thickness HMA. As shown in Figure 2.12, CRCs are mainly located on IH sections and SHs. A relatively smaller percentage of the CRCP sections are on FM. This is expected since CRCs are designed to support higher traffic volumes. As for medium thickness HMAs, more than half of them are on FM roads, followed by SHs.

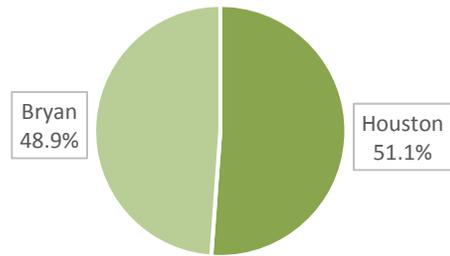
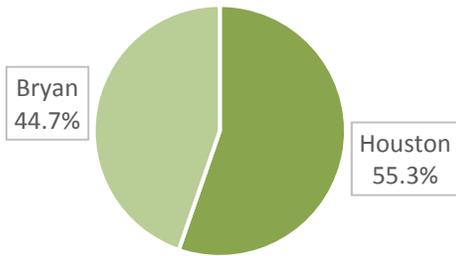
#### **2.2.4 Comparison between Sections in PMIS and Sections in Comparative Analyses**

As indicated in Table 2.2, the amount of data successfully extracted and converted from the raw measurement vendors' files to PMIS rating format did not cover the entire highway network of the two districts. Therefore, the highway network used for the comparative analyses of this study was a subset of the highway network present in PMIS for the Houston and Bryan districts. This subset consists of about 93% of the PMIS sections for Fugro and about 88% of PMIS sections for Pathway Services. Furthermore, when analyzing a particular distress, only sections having values reported from TxDOT and from the two automated systems were considered. Since a section might have values reported by TxDOT and the two vendors for a particular distress but not for other distresses, the amount of analyzed sections varied with the distress being compared. For instance, 12,816 PMIS sections were considered for the comparison of Condition Scores (about 78% of the overall network), whereas 13,511 PMIS sections were considered for the comparison of Ride Scores (about 83% of the overall network). It should be noted that the comparison of Condition Scores represents the worst case scenario since Condition Score is calculated from ride and all the distresses regardless of the pavement type, and therefore, a section was filtered out for the comparison if only one measurement was missing.

Figures 2.13 to 2.15 show the distribution for the overall network in PMIS and for the sections considered in the analysis of Condition Scores (worst case scenario) side-by-side for comparison purposes. Figure 2.13 indicates that the loss of sections in the analyzed subset was larger for Houston, resulting in a slightly more evenly distributed number of PMIS sections per district.

Given the difference in pavement type distribution presented in Figure 2.14, the loss of sections was evidently larger for CRCPs than for surface treatment sections. This difference is related to the smaller proportion of surface-treated sections in Houston. The proportions for the remaining pavement types did not differ significantly between the two datasets. Lastly, Figure 2.15 notes that the larger differences in highway system distribution occur for the proportion of FM roads, which is greater for the analyzed subset, followed by a smaller reduction of SH and US highways. This observation is also explained by the larger proportion of sections in the Bryan District.

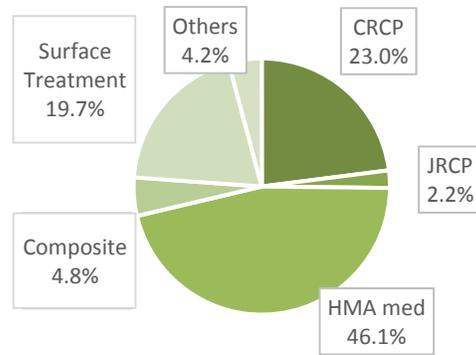
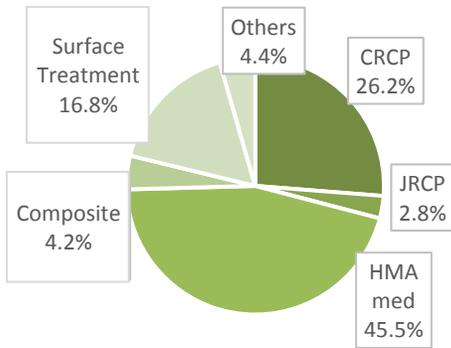
From comparing the characteristics of the overall two districts' highway networks against the subset of successfully processed and analyzed sections, we conclude that although the analyzed network was not complete (consisting of about 78% in the worst case), the networks' characteristics were preserved for all practical purposes.



(a) All Sections in PMIS (16,463 sections)

(b) Analyzed Sections (12,816 sections)

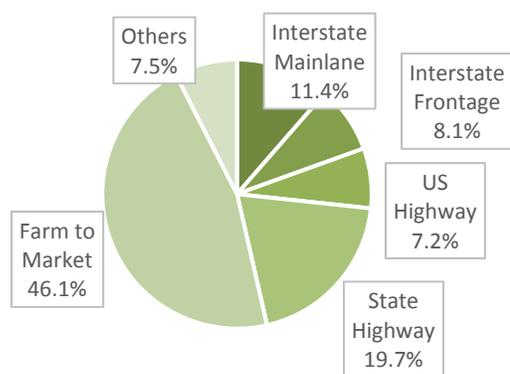
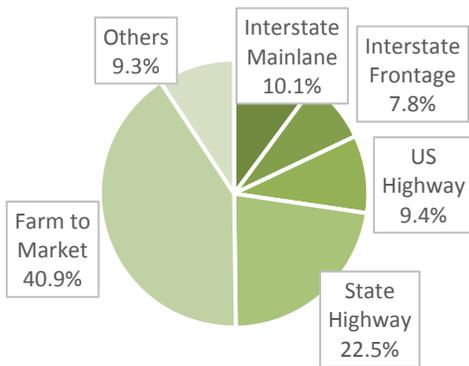
Figure 2.13: District Distribution for All Sections in PMIS and Sections in Comparative Analyses



(a) All Sections in PMIS (16,463 sections)

(b) Analyzed Sections (12,816 sections)

Figure 2.14: Pavement Type Distribution for All Sections in PMIS and Sections in Comparative Analyses



(a) All Sections in PMIS (16,463 sections)

(b) Analyzed Sections (12,816 sections)

Figure 2.15: Highway System Distribution for Sections in PMIS and Sections in Comparative Analyses

## Chapter 3. Analysis of Pilot Study Data

This chapter presents the analyses of the automated ride and distress data collected for the pilot study. The analyses reported in this chapter include statistics of the automated systems' production and a comparative analysis between the scores and ratings reported by the two participating vendors and PMIS data.

### 3.1 Automated Systems' Production

Each of the two vendors employed two survey vans for collecting data in the pilot study. Table 3.1 presents summary statistics for the production of each vendor's data collection while Figures 3.1 and 3.2 present the amount of data produced for each data collection date of the two Pathway Service vans, "PATHRN19" and "PATHRNVa," and the two Fugro vans, "ARAN\_44" and "ARAN\_48." In addition, Figures 3.3 to 3.6 present each vendor's daily production and total precipitation for each district. Both vendors' vans denomination and number of roadbed miles collected per day were extracted from the "CMET" header information reported in their PF99 files (see line 28 in Figure 2.4). The analyzed data in this section consists of the 0.1-mile segments that had been successfully processed into and stored in PMIS format for the comparative analyses. This dataset comprised 6,491 roadbed miles for Pathway Services and 7,076.9 roadbed miles for Fugro.

The first two rows of Table 3.1 show that Pathway Services collected data using one survey van per district whereas each Fugro van collected data at both districts. The third to sixth rows of the table show the dates at which each automated system started and ended their data collection and the total number of miles used for the comparative analyses from each survey van. The first and last data collection dates show that the vendors overlapped their data collection during 38 days, between 09/11/2013 and 10/19/2013. The elapsed data collection times show that Fugro employed their two vans a similar number of days and Pathway employed one van for half as long as the other. It should be recalled that the timeframe required by the pilot study's RFP was 50 days. Pathway Services' survey van used to collect data in the Houston District was employed for more than twice the number of days than the van in Bryan, while the number of miles collected was only about 2% larger in Houston.

In addition, the numbers in parenthesis on the "Elapsed time" row present the percentage of days at which the survey van was active; i.e., the percentage of days the van reported at least a mile of data within the elapsed time between the first and the last data collection date. As observed from the statistics, Pathway Services vans' active times were greater than those of Fugro's vans by about 8% on average. Possible factors that explain the no production days are adverse weather conditions or mechanical difficulties affecting the survey van or the measurement system, among other explanations. Further analyses of the vendor's active times are presented later in this section.

Summary statistics of each automated system data collection are presented in the last four rows of the table. The two Fugro survey vans, which each collected data at both districts, had similar average daily production rates whereas Pathway Services' survey van in Bryan collected more than double miles per day than the Pathway van in Houston. Similarly, Fugro's vans presented similar variability of daily production rate while Pathway Services' van in Bryan was less variable than the one in Houston. It is interesting to note that the minimum production rate of the Pathway Services van in Bryan was similar to the average production rate of the van

collecting data in Houston. One factor that might explain the observed difference in production rate is the higher traffic volumes and more collected miles in urban and metropolitan areas found in the Houston District.

**Table 3.1: Vendors’ production statistics in pilot study**

Production	Fugro		Pathway		
	ARAN_44	ARAN_48	PATHRN19	PATHRNVa	
<b>% data collected at Houston</b>	30%	72%	99.9%	0.0%	
<b>% data collected at Bryan</b>	70%	28%	0.1%	100.0%	
<b>First data collection day</b>	18-Sep	11-Sep	1-Sep	11-Sep	
<b>Last data collection day</b>	2-Nov	1-Nov	19-Oct	3-Oct	
<b>Elapsed time (%Active)</b>	<i>days</i> 45 (80%)	51 (84%)	48 (90%)	22 (91%)	
<b>Total days by vendor</b>	<i>days</i>	96		70	
<b>Total data collected</b>	<i>miles</i>	3,185	3,892	3,365	3,126
<b>Production - Avg</b>	<i>miles/day</i>	<b>88</b>	<b>91</b>	<b>78</b>	<b>156</b>
<b>Production - Min</b>	<i>miles/day</i>	3	1	1	79
<b>Production - Max</b>	<i>miles/day</i>	196	256	224	283
<b>Production - Std</b>	<i>miles/day</i>	61	57	57	45

The charts in Figures 3.1 and 3.2 provide a more detailed view at each vendor’s daily production. The vertical axis in these two charts reports the number of 0.1-mile segments that had been successfully processed and stored into PMIS format per day for the comparative analyses. Thus, for example, PATHRNVa collected almost 1000 0.1-mile segments, or 100 roadbed miles, on 09/26/2013.

From Figures 3.1 it is observed that Pathway Services’ van, PATHRNVa, collecting data in the Bryan District, started around 10 days later and ended around 10 days before PATHRN19, the van collecting data in the Houston District. It is also interesting to note that PATHRN19 tended to reduce production rate over time more evidently than the second van, PATHRNVa. From Figure 3.2 it is observed that the two Fugro survey vans presented similar pattern of changes in daily productions rate over time, especially between mid-September and mid-October. In addition, it is interesting to note how different automated systems tend to report zero, or close to zero, production on similar days. For instance, all survey vans showed a valley in their daily production curves around 09/20/2013. A factor that might partially explain these coincident valleys is the wet surface condition of the road, since it would affect all systems collecting data at nearby locations. As mentioned on Chapter 2, the pilot study’s RFP asked the vendors to collect data on dry pavement surfaces.

In order to further explore what factors might explain the observed drops in the vendors’ productions rates, the number of miles collected per day (in red) was contrasted against daily precipitation records (in blue), as illustrated in Figures 3.3 to 3.6. The daily precipitation records for the data collection dates was queried from the Global Historical Climatology Network (GHCN) database. This database is maintained by the National Oceanic and Atmospheric Administration’s National Climatic Data Center. The daily precipitation data (expressed in tenths of mm, on the secondary vertical axis of Figure 3.3 to 3.6) for each district was computed as the sum of all precipitation data recorded for that particular day by all GHCN weather stations in the

corresponding district. As the area within a district that is affected by rain increases, the number of stations with positive precipitation record will increase, and thus, higher values of the total computed total daily precipitation will be observed. These results would not only indicate high intensity and volume of precipitation but also a larger affected area.

As Figures 3.3 to 3.6 depict, in general, for every peak on the precipitation curve there is a corresponding drastic drop in the production rate. This observation is more evident for the Bryan District, for which the peaks of total district precipitation curves on 09/20/2013, 09/29/2013, and 10/13/2013 clearly matched the dates for which the vendor’s daily production dropped to zero, or near zero values. This evident association implies that rain, or wet surface condition, was an important factor in explaining the percentage of non-active days reported in Table 3.1.

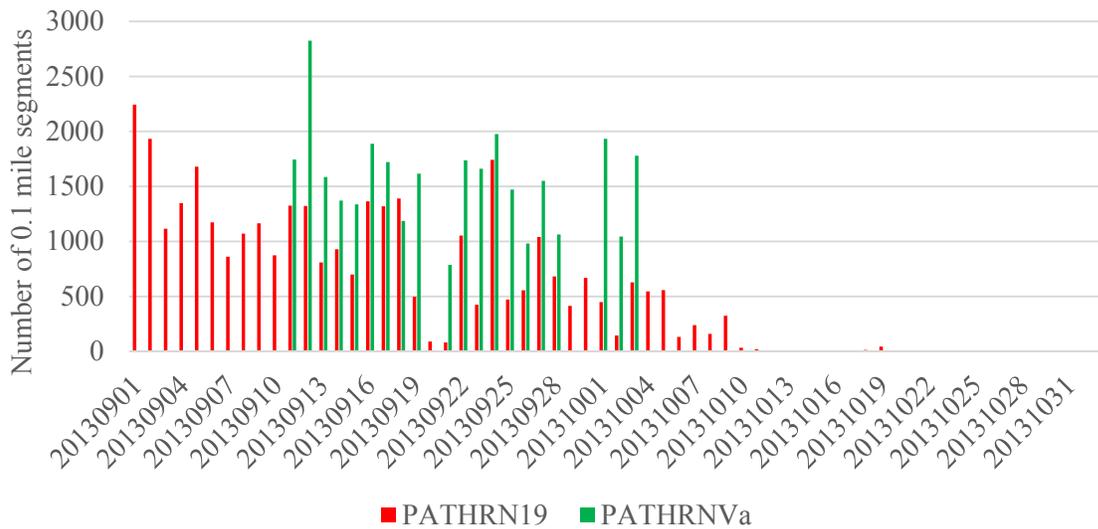


Figure 3.1: Data Collected per Day for the Two Pathway Services Automated Systems

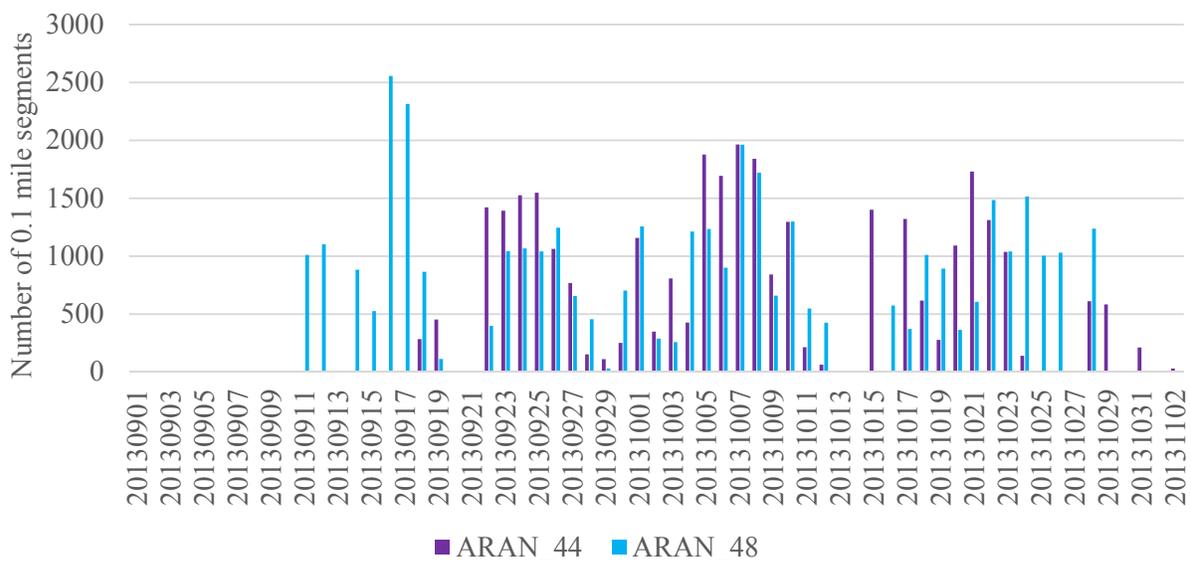
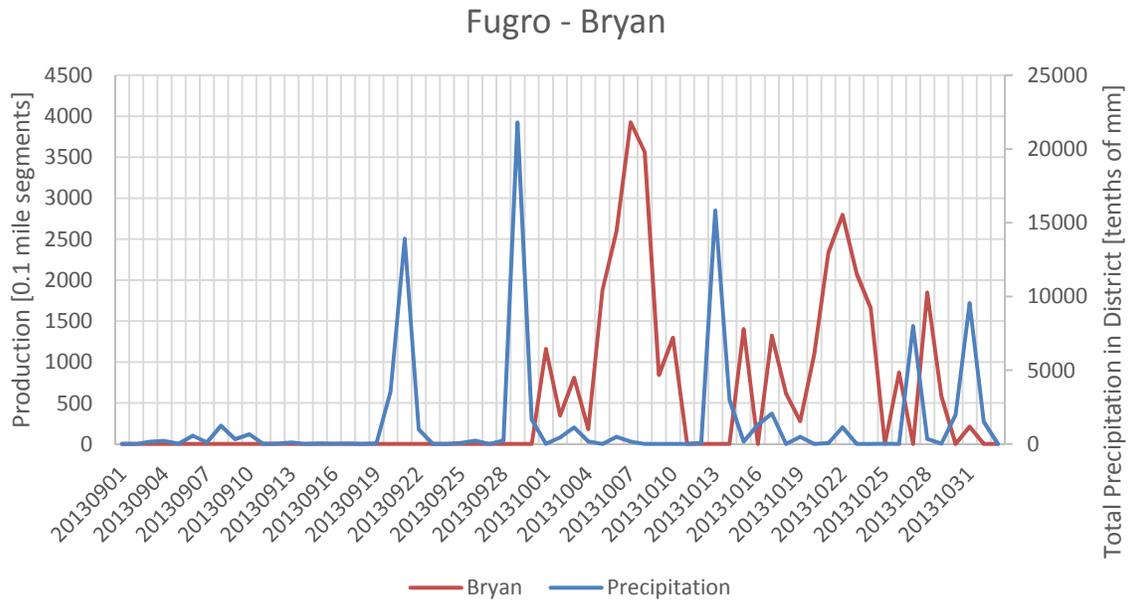
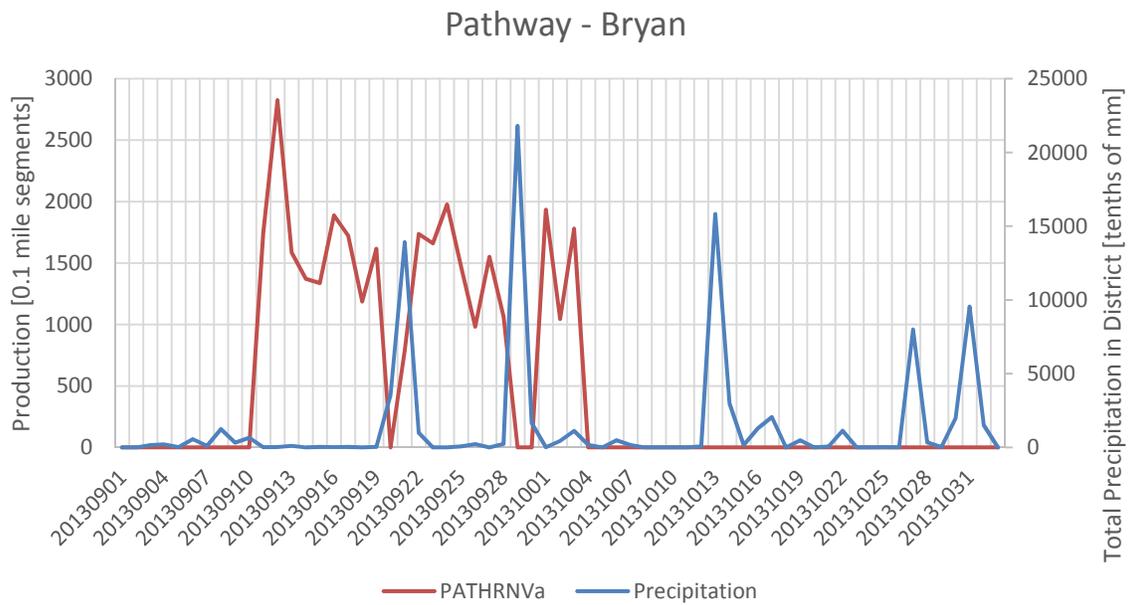


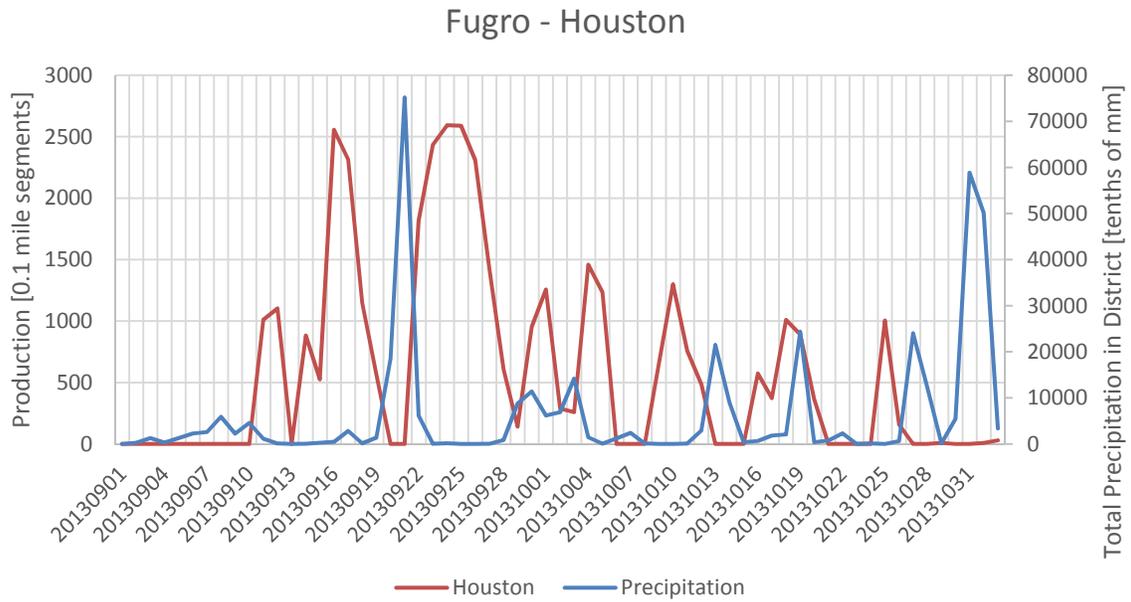
Figure 3.2: Data Collected per Day for the Two Fugro Automated Systems



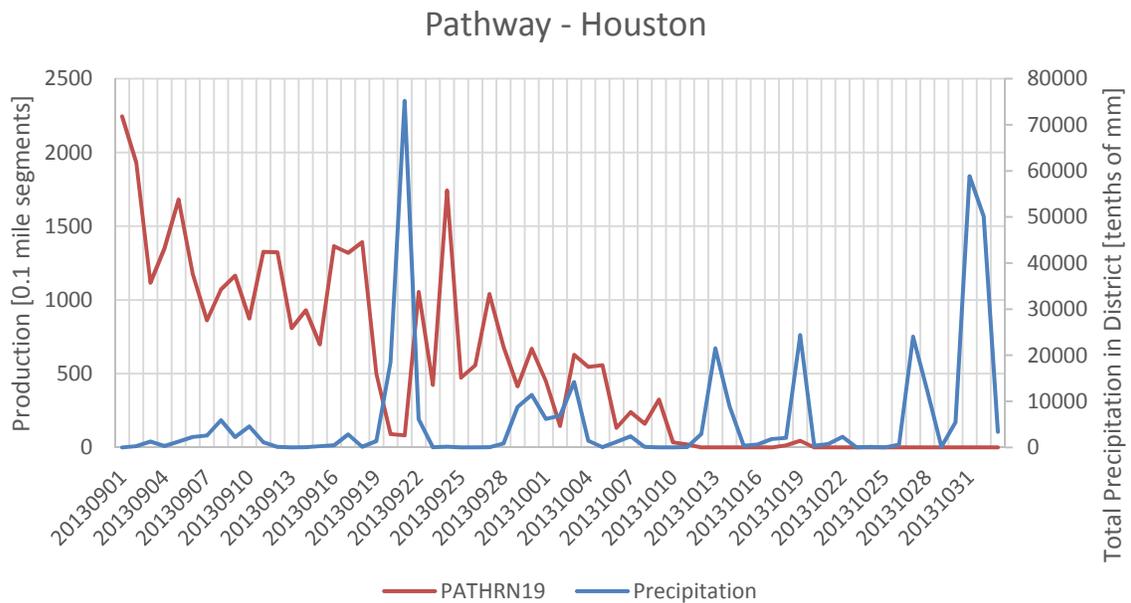
*Figure 3.3: Fugro's Daily Production and Total Precipitation in Bryan*



*Figure 3.4: Pathway Services' Daily Production and Total Precipitation in Bryan*



*Figure 3.5: Fugro's Daily Production and Total Precipitation in Houston*



*Figure 3.6: Pathway Services' Daily Production and Total Precipitation in Houston*

## 3.2 Comparative Analysis of Automated PMIS Scores and Ratings

This section presents the comparative analysis performed on the PMIS Scores and Rating obtained from the automated measurements reported by Fugro and Pathway Services. The vendors' scores and ratings were compared with TxDOT PMIS data collected for the same data collection period (FY 2014).

TxDOT PMIS data was collected using three different methodologies: inertial profilers to collect roughness data; five-point ultrasonic sensor rut bar to collect rutting data; and a manual, visual rating method (known as a *windshield survey*) for collecting surface distress data. On the other hand, both vendors performed semi-automated data collection at highway speeds using survey vans equipped with 3D laser systems. Therefore, the comparative analyses presented in this section consist of evaluating and comparing these two methodologies in describing the condition of the highway network using PMIS data as the baseline. However, the quantified differences do not represent an estimate of measurement error since neither of the two methodologies produce true measurement values. The random and systematic errors of the automated field measurements collected at highway speeds by the automated systems were previously quantified during Phase I and II of this study.

The analyses in this section are organized from a broad-to-specific comparison level, starting with a comparison of high-level indices, such as the percentage of the network in “Good” or better condition, followed by a comparison of PMIS Scores and by an analysis of the individual PMIS distresses. Each comparison was carried out for different factor levels, such as district, pavement surface type, and highway system.

### 3.2.1 Comparison of Percentage of Network in “Good” or Better Condition

TxDOT commonly uses an index based on the percentage of miles in “Good” or better condition to evaluate the overall condition of the highway network. “Good” or better condition means a Condition Score greater than or equal to 70. *Condition Score* (CS) represents the average driver’s perception of the road network and consists of an aggregated index computed for each data collection section from all ride and distress PMIS ratings (Stampley et al., 1995). CS values are between 1 and 100, where 100 represents perfect condition of the pavement and lower scores reflect pavements with surface distresses, rutting, and/or roughness. The percentage of miles in “Good” or better condition is used by TxDOT to allocate funds, to monitor the performance of district 4-Year Plan maintenance and rehabilitation strategies, and making other management decisions.

Table 3.2 presents the percentage of miles in “Good” or better condition in PMIS and as reported by each vendor, for different factor levels. The columns “*diff*” report the difference between the PMIS CS and each vendor’s percentage of roadbed miles with  $CS \geq 70$ . As shown in the first row, both vendors reported lower percentages of “Good” or better condition for the combined networks of both districts. Therefore, a worse overall network condition was measured by the automated systems compared to the PMIS network condition assessment. The observed 6.6% and 3.9% differences between PMIS, Fugro, and Pathway Services respectively are notable, indicating that the impact of changing from the current data collection methods to the vendors’ automated systems is different between vendors. Although both vendors collected data using similar sensor technologies, the difference in results are due to the use of different algorithms for the distress detection and quantification, equipment parts and calibration methods, and manual post-processing.

From the district and county level comparisons, both vendors presented higher differences compared to PMIS for the Bryan District, especially for Milam and Walker counties. In the Houston District, Pathway Services presented higher differences compared to PMIS in Harris County while Fugro's results were more consistent, compared to PMIS, for all counties. Harris County includes more urban and metropolitan areas and has more roadbed miles of rigid pavements than the other counties in the district.

Table 3.2 surface type level comparison shows that Fugro's differences with PMIS were larger for flexible pavements (ACP) than for rigid pavements (CRCP and JCP) whereas the opposite is observed for Pathway Services' data. Therefore, the vendors performed differently for different pavement types. In addition to the three broad surface type categories (i.e., ACP, CRCP and JCP), Table 3.2 includes the percentage of roadbed miles in "Good" or better condition for two major ACP surface types: HMA between 2.5 in. and 5.5 in. thick and surface treatments (detailed pavement types 4 and 10; see Table 2.1). Pathway Services' differences are higher for surface treatments than for ACPs while Fugro's differences were more consistent between these two surface types. Surface treatment pavements are more prevalent in rural areas and lower-traffic highways.

The highway system level comparison in Table 3.2 presents the differences in percentage of roadbed miles with  $CS \geq 70$  for the four main groups: FM, IH, US, and SH. The remaining highway systems are aggregated into the category "others." From these major groups it is observed that Fugro's differences are larger for lower-volume roads (FMs), whereas the opposite is observed for the case of Pathway Services, whose higher differences occurred on IH pavements. The significantly larger difference observed between Fugro and PMIS for US pavements is possibly explained by the relatively small number of miles—the smaller sample size makes it more prone to outliers and random variations. In addition, the IH group was further divided into IH main lanes and IH frontage roads since the pavement characteristics of these two subgroups can differ significantly. From these two subgroups it is observed that Pathway Services' discrepancies with PMIS are slightly larger for frontage roads whereas Fugro's differences were higher at main lanes. Both the windshield method and the automated systems are expected to miss less distresses when the distress level is higher, which is more likely to occur at frontage roads.

Lastly, Table 3.2 shows the percentage of roadbed miles in "Good" or better condition grouped by the number of lanes per roadbed. Higher number of lanes per roadbed indicates higher traffic volumes and importance of the corridor. Pathway Services' differences increase with the number of lanes while a less clear pattern is observed for Fugro's data. However, the unbalanced number of roadbed miles among the different number of lanes complicates the interpretation of the results.

**Table 3.2: Comparison of percentage of roadbed miles in “Good” or better condition**

Condition Score Comparison Level	Roadbed Miles	PMIS	Fugro		Pathway		
		%CS ≥ 70	%CS ≥ 70	diff	%CS ≥ 70	diff	
Overall	6,175.7	83.5	76.9	-6.6	79.6	-3.9	
District	Houston	3,104.3	79.7	74.0	-5.7	77.7	-2.0
	Bryan	3,071.4	87.3	79.7	-7.6	81.6	-5.7
County	Waller	230.1	83.1	78.3	-4.8	85.4	2.3
	Montgomery	456.9	92.4	83.8	-8.6	92.3	-0.1
	Fort Bend	374.0	74.3	68.5	-5.8	75.4	1.1
	Galveston	295.9	78.4	73.3	-5.1	77.6	-0.8
	Brazoria	436.4	82.9	78.4	-4.5	85.4	2.5
	Harris	1,311.0	75.5	70.2	-5.3	69.3	-6.2
	Madison	208.0	80.2	73.5	-6.7	73.0	-7.2
	Washington	284.3	86.4	77.2	-9.2	81.4	-5.0
	Brazos	306.2	84.1	75.2	-8.9	77.3	-6.8
	Robertson	300.2	94.4	87.3	-7.1	88.6	-5.8
	Burleson	236.7	83.7	75.1	-8.6	79.1	-4.6
	Grimes	311.5	85.6	83.7	-1.9	83.8	-1.8
	Milam	292.1	84.7	70.3	-14.4	77.8	-6.9
	Walker	357.7	91.8	81.5	-10.3	84.3	-7.5
	Leon	377.0	88.7	87.1	-1.6	83.7	-5.0
	Freestone	397.7	88.6	80.7	-7.9	82.4	-6.2
Highway System	US	451.5	86.0	74.9	-11.1	82.0	-4.0
	FM	2,906.0	84.0	76.5	-7.5	81.6	-2.4
	SH	1,227.3	84.1	77.9	-6.2	80.0	-4.1
	IH	1,128.0	84.3	80.7	-3.6	77.4	-6.9
	Others	462.9	74.1	69.3	-4.8	69.6	-4.5
	<i>IH-MN</i>	650.3	92.8	87.7	-5.1	86.1	-6.7
	<i>IH-FG</i>	477.7	72.9	71.2	-1.7	65.4	-7.5
Surface Type	ACP <sup>1</sup>	4645.8	85.1	77.0	-8.1	82.5	-2.6
	CRCP <sup>2</sup>	1392.6	81.6	79.3	-2.3	74.6	-7.0
	JCP <sup>3</sup>	137.3	47.6	45.7	-1.9	34.5	-13.1
	<i>Surface Treatment</i> <sup>4</sup>	1258.3	86.8	78.6	-8.2	82.1	-4.7
	<i>HMA (2.5" - 5.5")</i> <sup>5</sup>	2873.7	83.5	74.9	-8.6	81.1	-2.4
Number of Lanes	2	4949.4	84.3	77.1	-7.2	80.7	-3.6
	3	540.7	76.8	76.7	-0.1	72.6	-4.2
	4	508.1	79.3	71.0	-8.3	74.0	-5.3
	5 or more	177.5	92.4	86.5	-5.9	85.7	-6.7

Notes: <sup>1</sup> Includes detailed pavement types 4 to 10  
<sup>2</sup> Includes detailed pavement type 1  
<sup>3</sup> Includes detailed pavement type 2 and 3  
<sup>4</sup> Detailed pavement types 5  
<sup>5</sup> Detailed pavement types 10

### 3.2.2 Comparison of PMIS Scores Categories

TxDOT defines three scores for describing each PMIS pavement Data Collection Section in their network: Ride Score (RS), Distress Score (DS), and Condition Score (CS). RS describes ride quality data and is computed from the IRI measurements, which are converted to the PSI on a scale from 0.1 to 5.0. DS describes the level of deterioration of a pavement and is computed from all PMIS distresses (such as rutting, alligator cracking, and failures). The computation of these two scores takes into account the section’s traffic level, surface type, and other highway characteristics. RS ranges from 0.1 to 5, where higher RS values correspond to smoother surfaces, or higher ride quality, and DS ranges from 1 to 100, where higher values correspond to less distressed surfaces. CS is proportional to both RS and DS, and thus, takes into account all PMIS measurements.

Table 3.3 shows the PMIS score categories used by TxDOT to provide a more detailed description of the state of their highway network at the management level. RS range is divided into five equal intervals whereas DS and CS categories are wider for lower score groups. Most of the network is in “Good” or better condition, as reported in Table 3.2, and therefore, the unequal grouping of the CS range allows for higher definition where its frequency distribution is denser.

**Table 3.3: PMIS score definition (TxDOT, 2014)**

Category	Ride Score	Distress Score	Condition Score
Very Good	4.0 to 5.0	90 to 100	90 to 100
Good	3.0 to 3.9	80 to 89	70 to 89
Fair	2.0 to 2.9	70 to 79	50 to 69
Poor	1.0 to 1.9	60 to 69	35 to 49
Very Poor	0.1 to 0.9	1 to 59	1 to 34

Figures 3.7 to 3.9 show the proportion of roadbed miles in each score category from the data in PMIS and from each vendors’ automated measurements, for the case of CS, RS, and DS respectively. From Figure 3.8 and 3.9 it is observed that both RS and DS are skewed towards “Good” and “Very Good” scores, DS being more strongly skewed. Having about three-fourths of the highway network DS rated as “Very Good” is a consequence of the relative impact and tolerable levels assigned to each individual distress, defined in PMIS through the utility curves’ shape parameters. PMIS utility curves’ parameters were selected by a panel of expert TxDOT engineers (Stampley et al., 1995).

Comparing the PMIS and vendor’s results, the differences between the relative proportion of sections in “Good” or “Very Good” conditions was greater for DS than for RS. Pathway Services has lower proportion of roadbed miles in the “Very Good” group than PMIS, but higher proportions for all other DS categories. Fugro’s DS proportions are lower than PMIS for the “Good” and “Very Good” categories but higher for the groups of pavements in worse conditions. Also, the differences between Pathway Services and PMIS for the “Good” and “Very Good” categories partially compensate and result in a closer “Good” or better score than Fugro (as reported from Table 3.3); however, Fugro was closer to PMIS when analyzing the individual “Good” and “Very Good” categories separately.

It is also interesting to note the significantly higher number of roadbed miles of DS in “Very Poor” condition measured by Fugro. The difference in PMIS scores distributions between data collection methods is analyzed in more detail on the following sections.

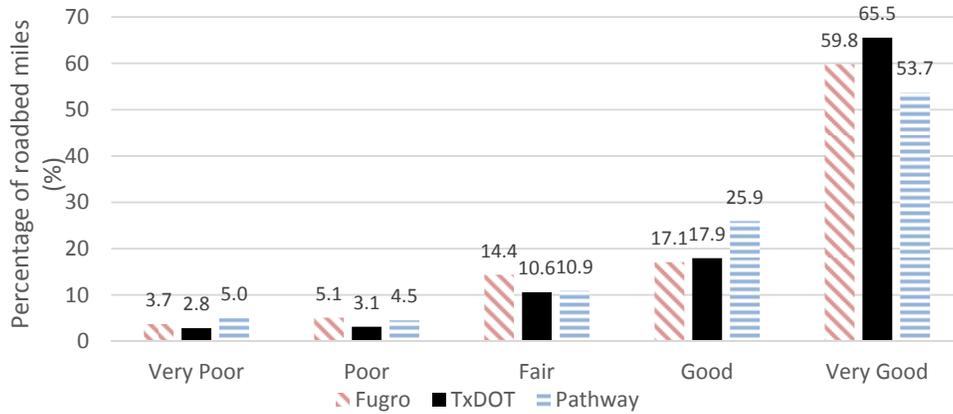


Figure 3.7: Histogram of Condition Score Categories (6,175.7 Roadbed Miles)

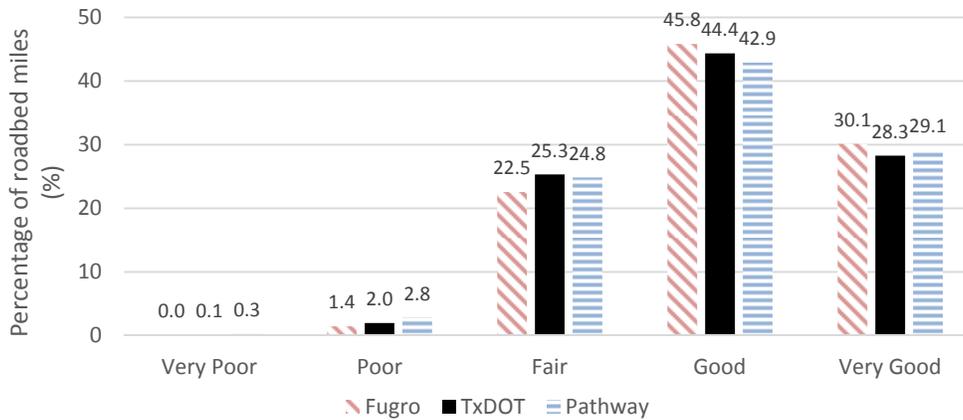


Figure 3.8: Histogram of Ride Score Categories (6,345.7 Roadbed Miles)

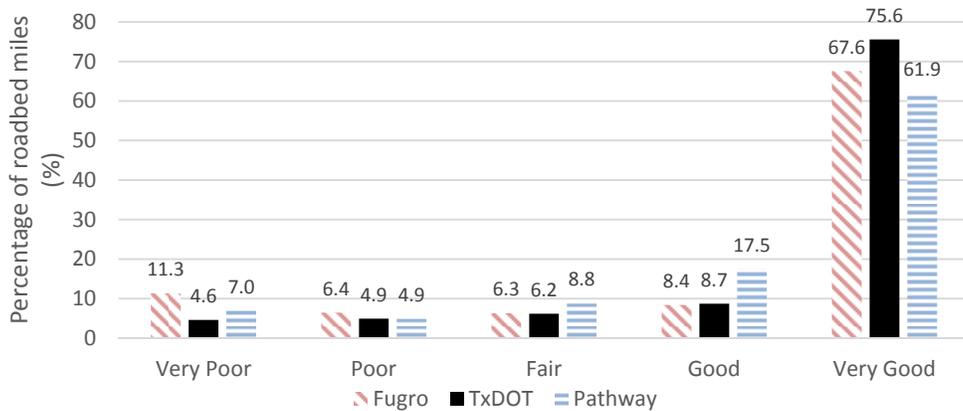


Figure 3.9: Histogram of Distress Score Categories (6,266.7 Roadbed Miles)

### 3.2.3 Comparison of PMIS Score Distributions

This section presents a comparison of the CS, DS, and RS cumulative distributions between the data in PMIS (in black) and the scores obtained from Fugro's (in red) and Pathway Services' (in blue) automated measurements. The cases in which the vendor's cumulative distribution curve lies above the TxDOT curve indicate that the vendor reported a larger proportion of the network in worse condition, while in better condition for the opposite case.

#### Condition Scores

Figures 3.10 and 3.11 show the comparative cumulative CS distributions of each vendor and PMIS for the Bryan and Houston Districts. The distress and ride data collected by both vendors were used to compute CS for each data collection section for the entire two districts. As shown in the figures, the vendors measured a larger proportion of sections with lower CS (worse condition) than PMIS. For both vendors, there is a larger proportion of sections in worse condition for CS greater than or equal to 40. It is also interesting to note that the differences in CS distribution were larger in the Bryan District than in the Houston District for both vendors.

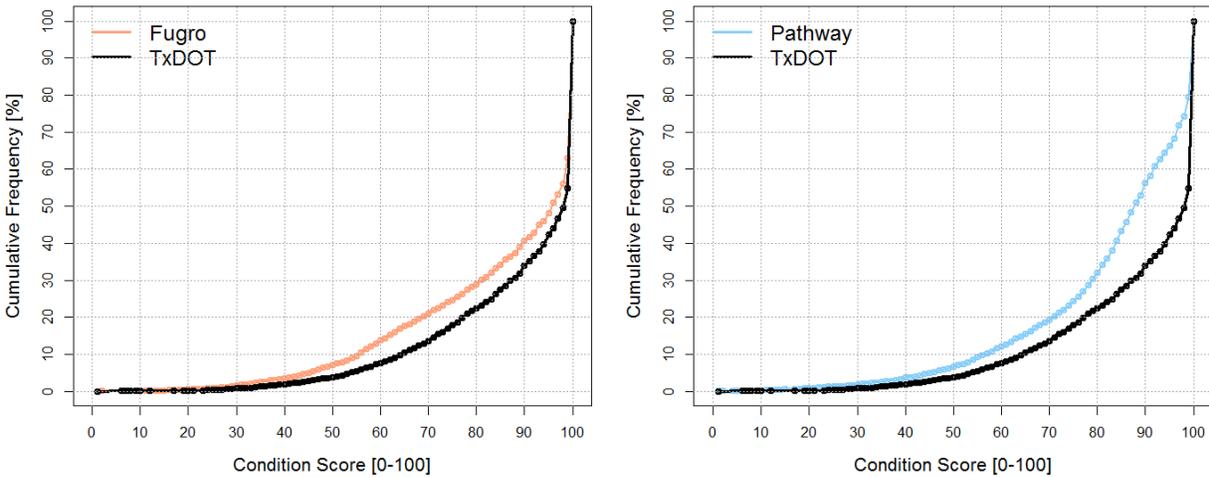


Figure 3.10: Distribution of Condition Score in the Bryan District

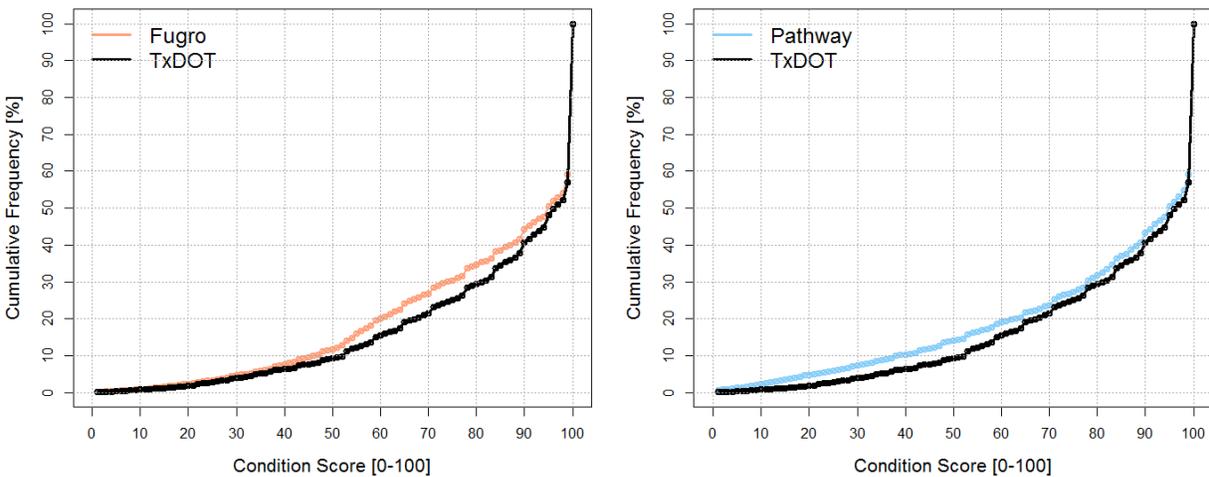
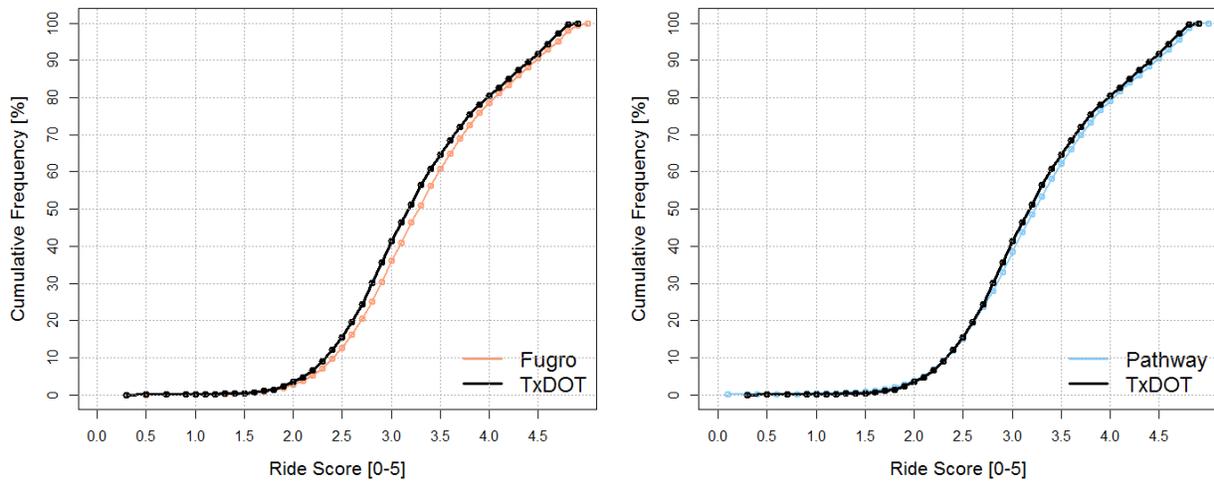


Figure 3.11: Distribution of Condition Score in the Houston District

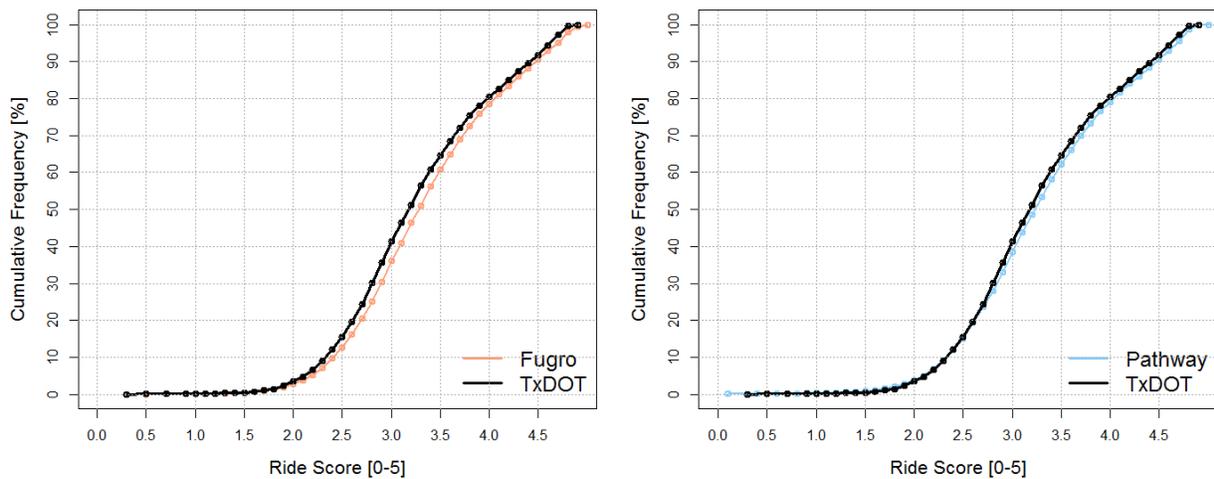
For the data shown in the figures, the percentage of sections in “Good” or better condition in the Bryan District was 86.4 when using PMIS data and 79.0 and 80.6 when using Fugro and Pathway Services data, respectively. In the case of the Houston District, the percentage of “Good” or better was 78.6 when calculating using PMIS data and 73.1 and 76.3 when using Fugro and Pathway Services data, respectively.

### Ride Scores

Figures 3.12 and 3.13 show the cumulative distribution of the RS in the Bryan and Houston districts, respectively. The figures illustrate a close agreement between PMIS and each vendor’s RS in both districts. Therefore, the differences observed in CS are not due to differences in RS but due to the differences in DS. It should be noted that all inertial profiler equipment used to collect IRI data for the pilot study, either TxDOT’s or vendors’ equipment, was certified by TTI under the same certification process.



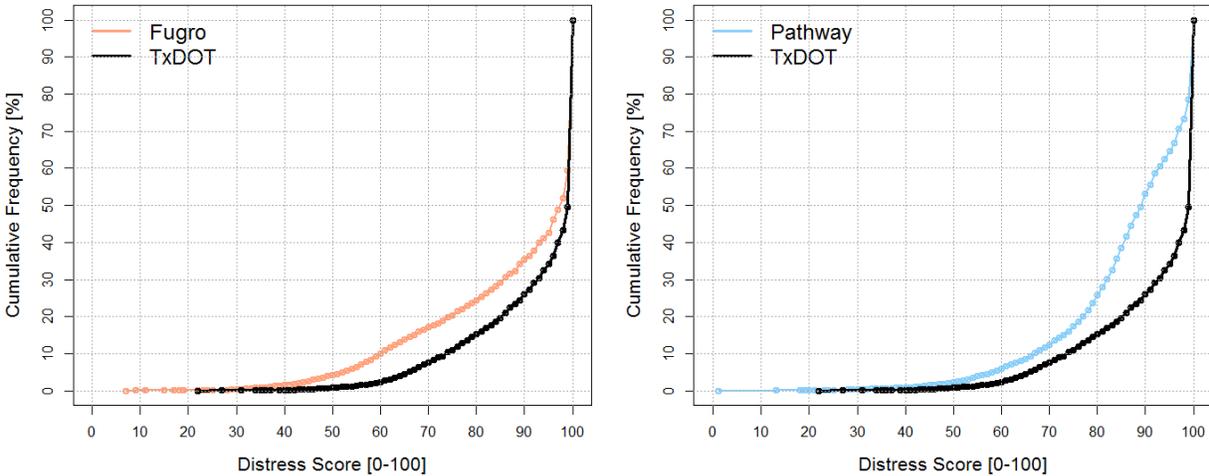
*Figure 3.12: Distribution of Ride Scores in the Bryan District*



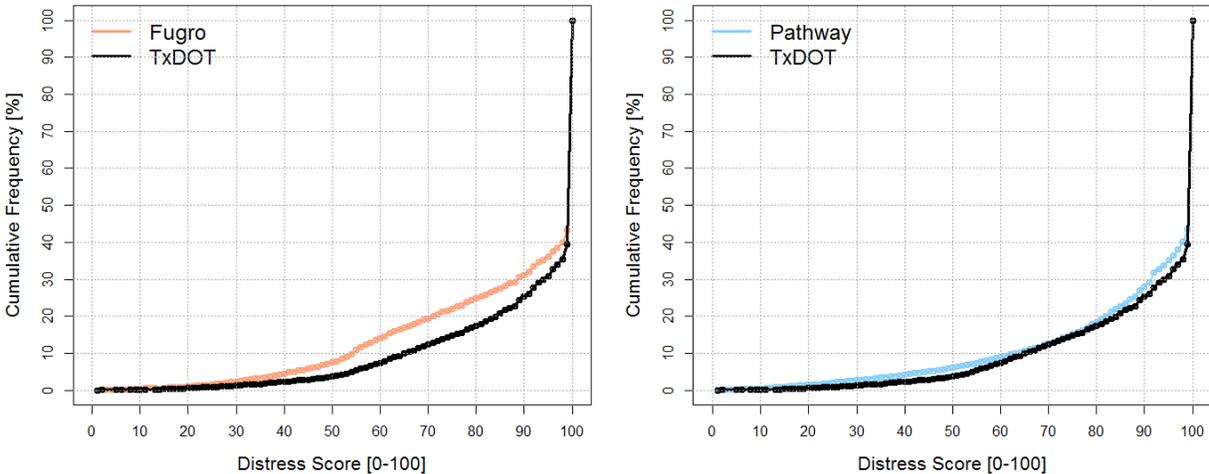
*Figure 3.13: Distribution of Ride Scores in the Houston District*

### Distress Scores

Figures 3.14 and 3.15 show the cumulative distribution of the DS in the Bryan and Houston districts, respectively. It is now evident that the differences in the CS are primarily due to differences in the DS. In general, both vendors captured more distresses than the distresses visually captured and reported in PMIS. However, it is interesting to note that, in the Houston District, a district with a high proportion of CRCP pavements, the agreement between Pathway Services and TxDOT PMIS is noticeable.



*Figure 3.14: Distribution of Distress Scores in Bryan*

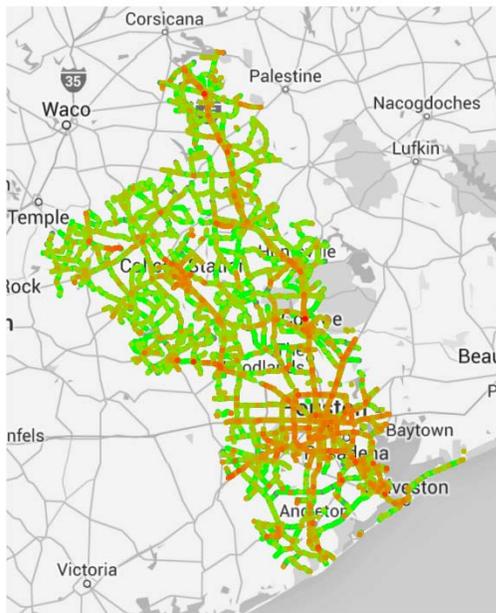


*Figure 3.15: Distribution of Distress Scores in Houston*

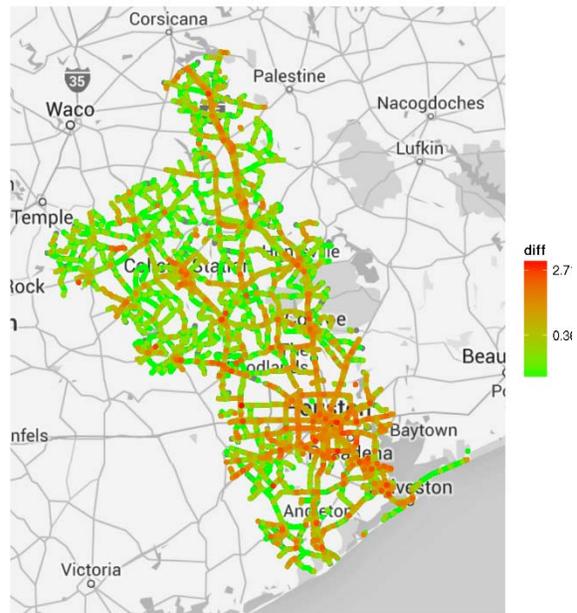
### Spatial Distribution of Distress and Ride Scores

Figures 3.16 and 3.17 show the differences in RS and DS in a network map for both the Bryan and Houston districts in order to determine whether the discrepancies between data collection methods are concentrated on a particular region of highway type. Each map reports the difference in scores between PMIS data and the automated system using a color code in

logarithmic scale for which red dots indicate higher differences and green dots indicate lower differences. Grey dots indicate zero difference.

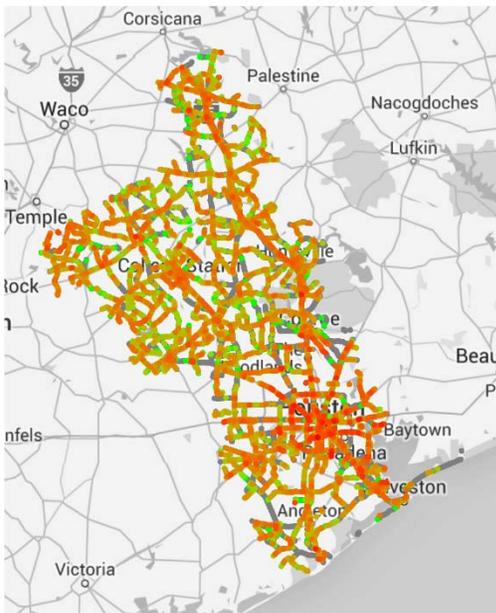


(a) Fugro vs. PMIS

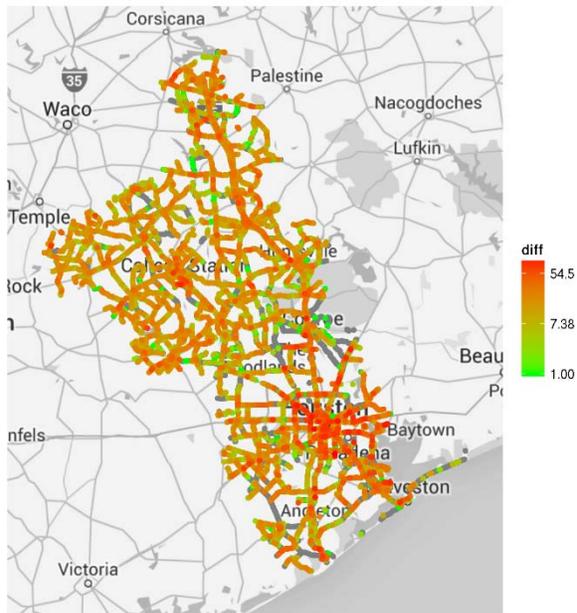


(b) Pathway vs. PMIS

Figure 3.16: Mapping the Differences in Ride Score



(a) Fugro vs. PMIS



(b) Pathway vs. PMIS

Figure 3.17: Mapping the Differences in Distress Score

These figures illustrate that, for both vendors, some of the largest differences in RS are more predominant in major corridors, whereas the differences in DS were more spread out across

the two districts. A more detailed analysis of the data indicated that the main differences in RS were actually reported along the frontage roads of the main corridors, e.g., IH 10 and IH 45.

### Main Observations Based on Scores

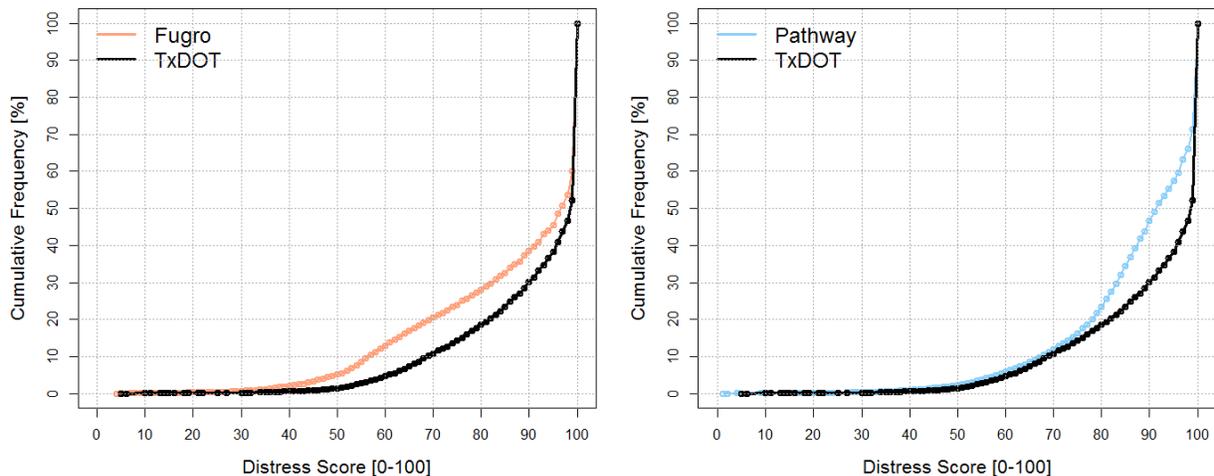
The calculated CSs from the data collected by both vendors are lower than those calculated based on the data contained in TxDOT PMIS. The differences are not the same for each of the districts evaluated. Further analysis of the data indicated that the differences in conditions scores are mostly explained by differences in DS.

It was also noticed that differences in DS between Pathway Services and PMIS were more significant in Bryan while closer agreement existed in Houston. This observation suggests that changing the data collection method for PMIS will have a different impact to different Districts, which might affect the allocation of funding strategies.

RSs calculated from the data collected by both vendors were in very good agreement with those in TxDOT PMIS. Somewhat larger differences in RS were observed along major corridors, particularly on frontage roads.

### **3.2.4 Comparison of Distress Scores per Pavement Type**

Figures 3.18, 3.19, and 3.20 show the differences in DS observed in both districts for the three broad surface types: ACP, CRCP, and JCP. For all types of pavements, the distributions of DSs calculated from the data collected by the vendors lie above the distributions using PMIS data. This means that, in general, the automated surveys capture more distress than the visual surveys. However, it is important to note that the differences vary depending on the pavement type. For example, in the case of ACP, the differences between Fugro and PMIS are most noticeable for DSs above 50; while the differences between Pathway Services and PMIS are only noticeable for DSs above 75 (Figure 3.18).



*Figure 3.18: Overall Distribution of Distress Scores for ACPs*

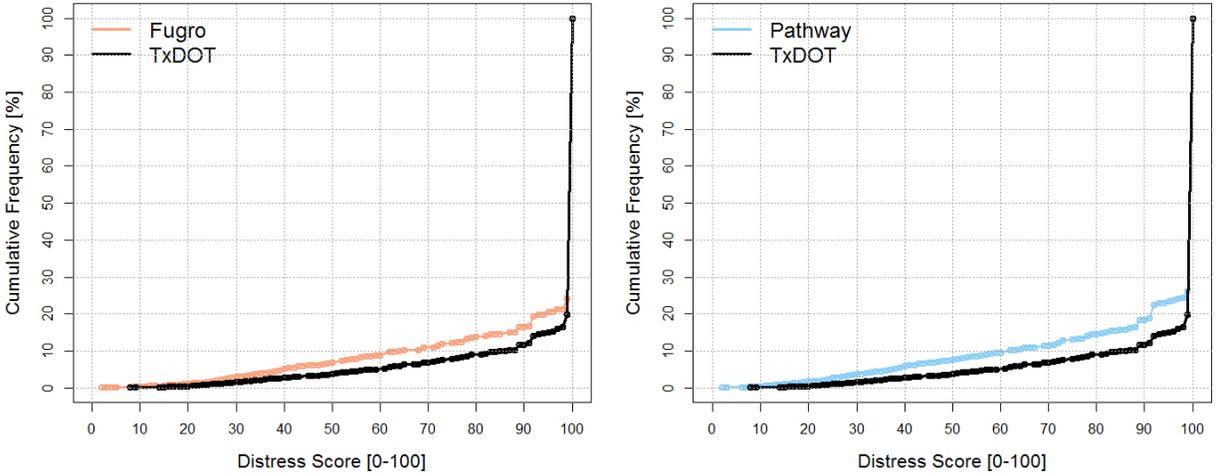


Figure 3.19: Overall Distribution of Distress Scores for CRCP Sections

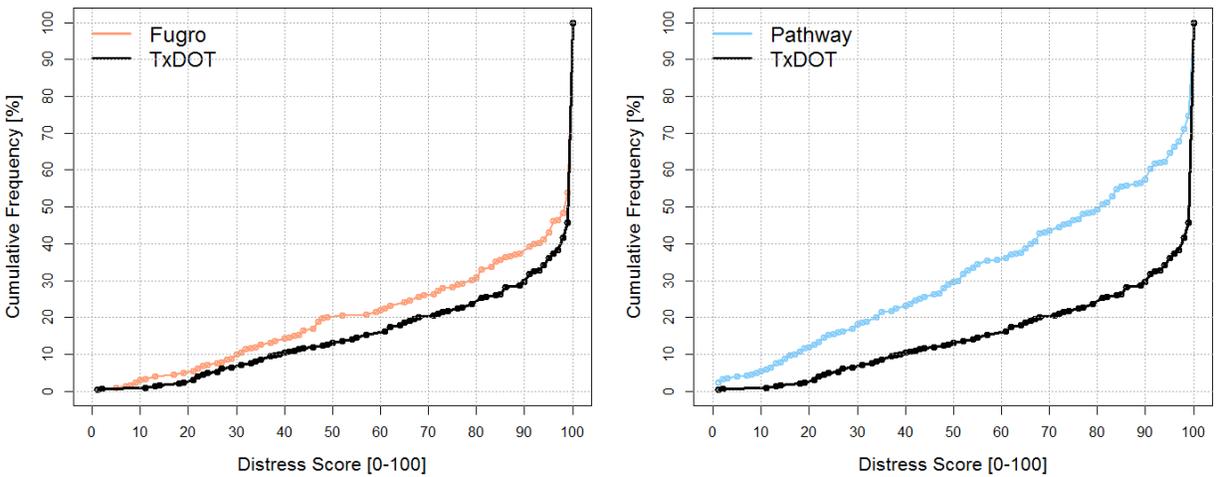
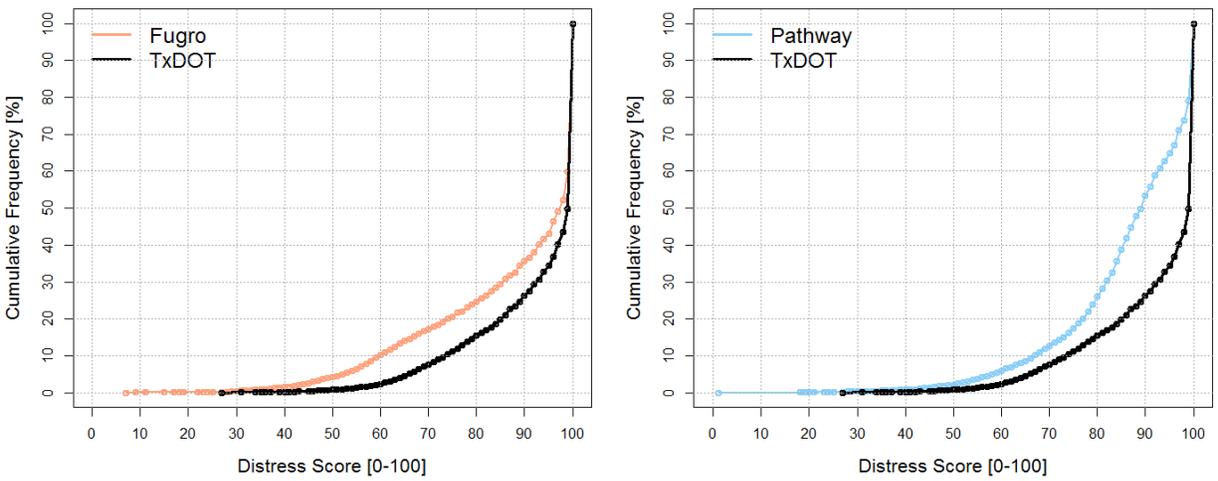


Figure 3.20: Overall Distribution of Distress Scores for JCP Sections

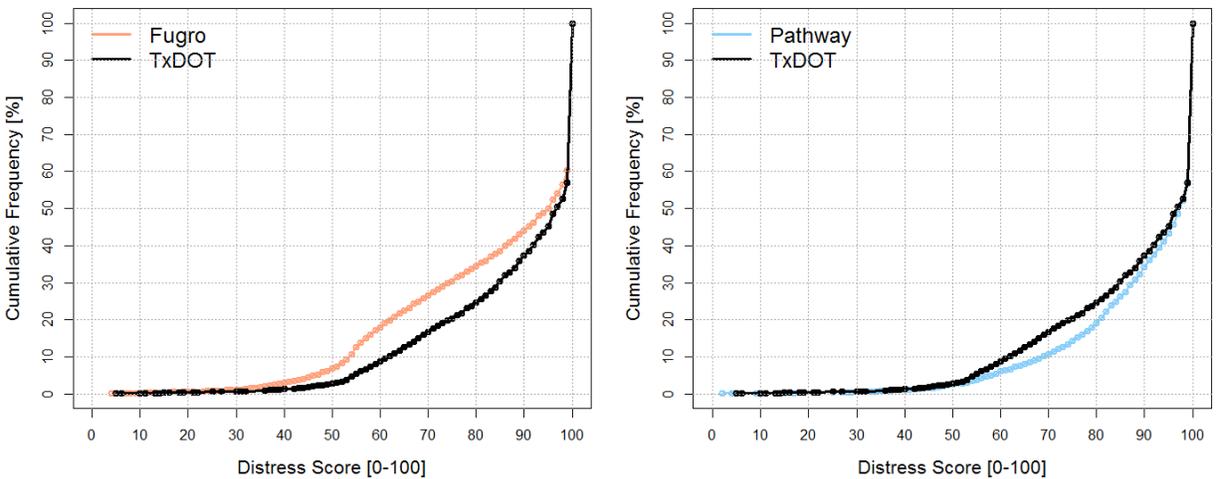
For the case of CRCP (Figure 3.19), the differences are less significant and seem to be quite systematic. In this case, calibration may be required and more familiarity with distresses as they are defined in Texas. It is apparent that the vendors will need to adjust and improve their algorithms to estimate distresses based on the raw data collected. In addition, as observed in Figure 3.20 for JCP sections, Pathway Services' data differs significantly from that in PMIS while Fugro's data shows a much better agreement. As before, it is believed that further calibration of the algorithms to estimate distress will be required.

Figures 3.21 and 3.22 show the distribution of DSs for ACP sections in Bryan and Houston respectively. The differences in DS distribution between Fugro and PMIS are consistent between the two districts while the DS for Pathway Services was not. Pathway Services' distribution curve lies above the PMIS distribution (detected more distresses) for the ACP sections in Bryan, but fell below the PMIS distribution (detected less distresses) in Houston. Possible factors that might explain this discrepancy include 1) inaccuracies for certain types of distresses are more prevalent in one of the two districts or 2) differences in performance between

the two Pathway Services' survey vans, among other factors. It should be noted that each Pathway Services van collected data in one distinct district (see Table 3.1).



*Figure 3.21: Distribution of Distress Scores for ACP Sections in Bryan*



*Figure 3.22: Distribution of Distress Scores for ACP Sections in Houston*

Main Observations Based on Distress Scores as a Function of Pavement Types

DSs calculated from Pathway Services data showed larger differences compared to PMIS for ACP and JCP sections. Differences between DSs calculated from Fugro data and PMIS were more consistent across pavement types, although slightly larger differences were observed for the case of ACP sections.

Further analyses of the data indicated that for ACP sections, Pathway Services detected more distresses than PMIS in Bryan but less distresses than PMIS in Houston. Aside from this case, the differences in distribution of DS by pavement type were similar for the two Districts.

### 3.2.5 Comparison of Individual Distresses

This section presents the comparative analysis between each of the two vendors' data and the data in PMIS for each individual distress. In order to determine what distresses best explain the observed discrepancies for DSs between the data collection methods, the analyses included in this section focus on the types of distresses with higher discrepancies. Additional types of distresses were also included to provide a more complete analysis.

#### ACP – Shallow Rutting (Percentage of Rutting between ¼ in. and ½ in.)

Figures 3.23 and 3.24 show the differences in shallow rutting for ACP in Bryan and Houston, respectively. It can be observed that Fugro's data match PMIS data relatively closely, while the differences in shallow rutting between Pathway Services and PMIS are significant. It is important to highlight that, as requested by TxDOT, rutting was to be calculated by simulating the use of a five-sensor measurement system -which consistently underestimates actual surface rutting- in order to match the technologies used for PMIS data collection. However, Pathway Services chose to report the rutting measurements obtained using the entire transverse profile, which explains, in part, the differences observed in Figures 3.23 and 3.24.

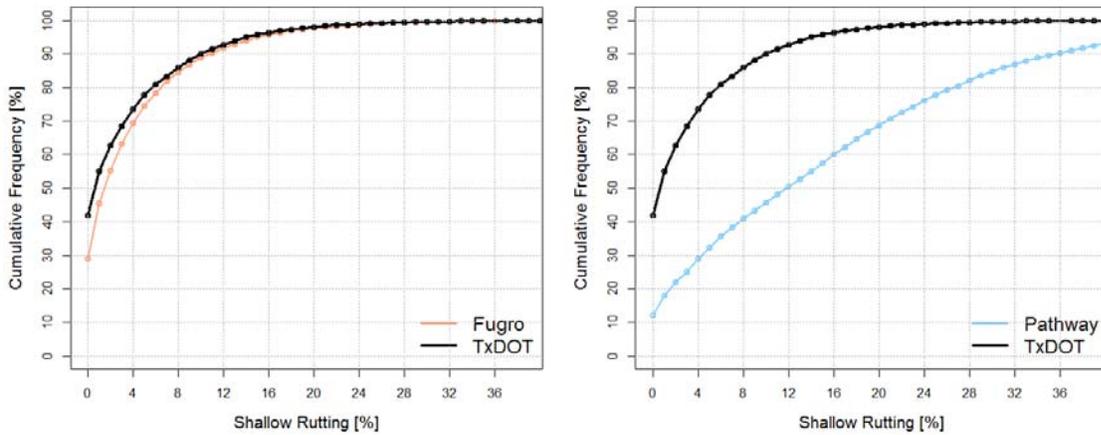


Figure 3.23: Distribution of Shallow Rutting for ACP in Bryan

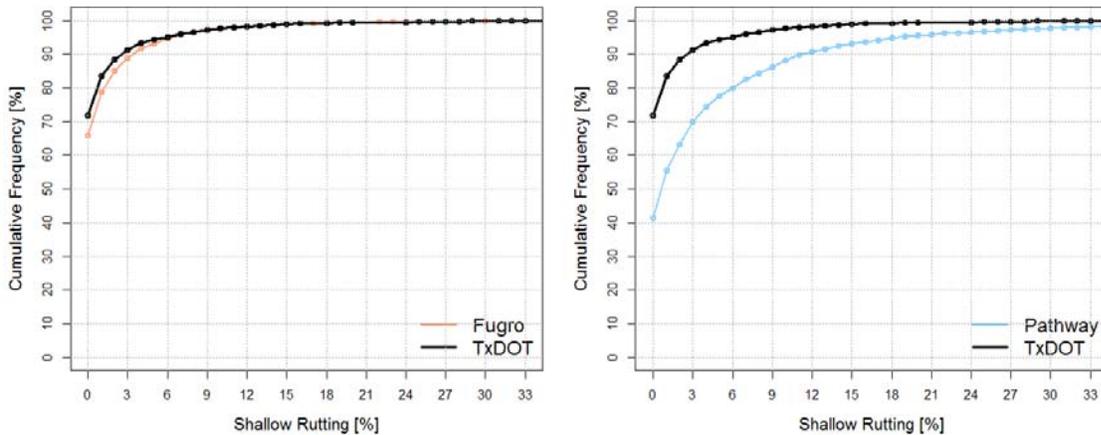
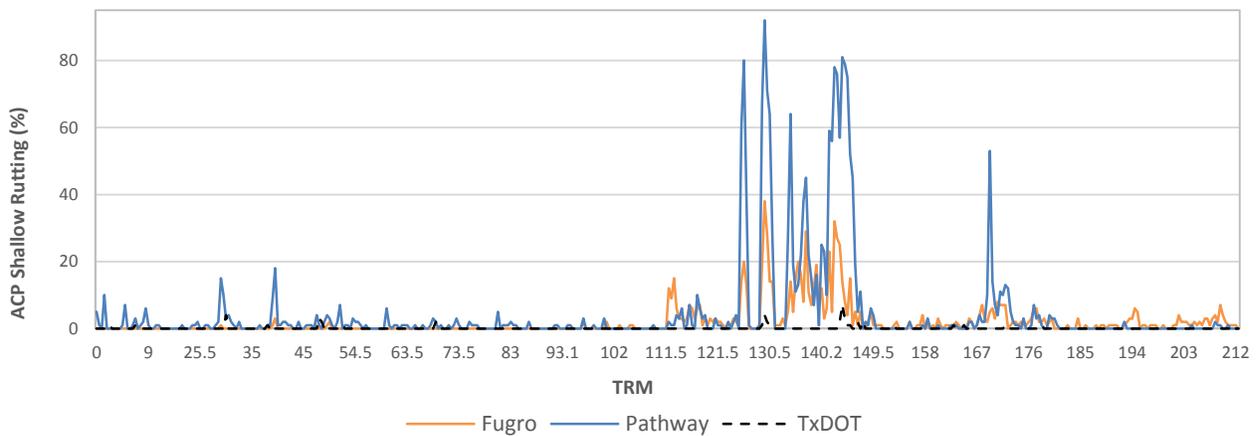


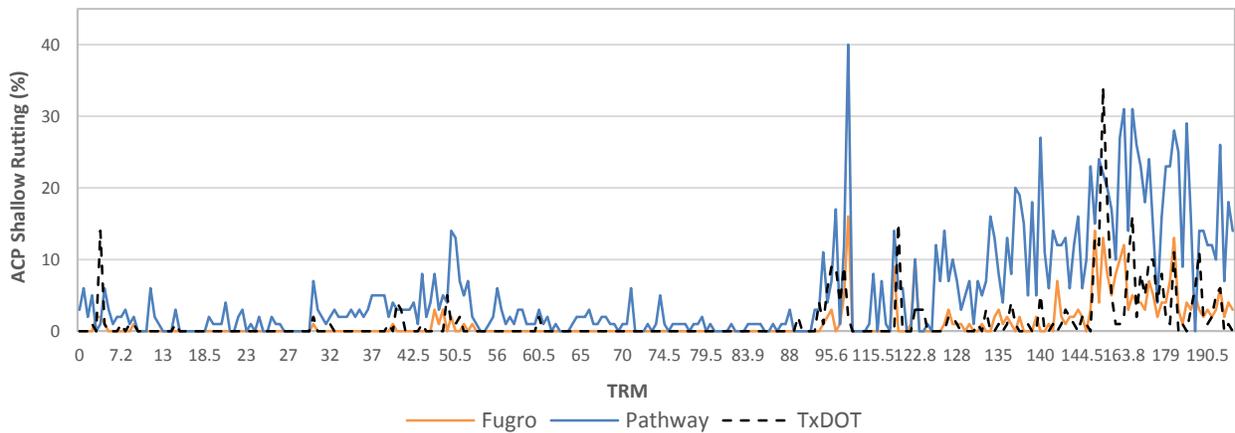
Figure 3.24: Distribution of Shallow Rutting for ACP in Houston

In addition, from comparing the districts, it is observed that Fugro had a close match to PMIS data for both districts, whereas Pathway Services differences were greater for the sections in the Bryan District. This difference in performance between districts may be attributed to factors such as having used different survey vans at each district or having different pavement characteristics (e.g., irregular rut shapes, which are more typically found on rural highways) within the two districts.

More detailed information on shallow rutting is shown in Figures 3.25 and 3.26. These figures show the percentage of shallow rutting in PMIS (green) and the corresponding values produced by Fugro (orange) and Pathway Services (blue) for a section of IH 45. Two lanes are shown: one on the main road (above) and one on the frontage road (below). It is clear that the differences grow as the percentage of shallow rutting increases. This is an indicator of the lack of accuracy and repeatability of the five-point algorithm for calculating rutting.



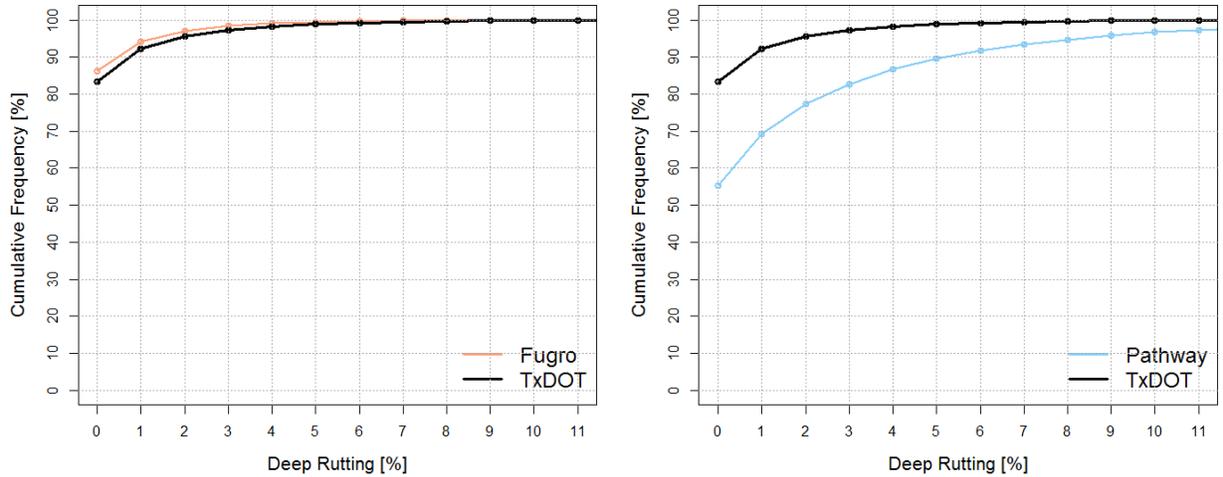
*Figure 3.25: Shallow Rutting along IH-45 for Main Lane L*



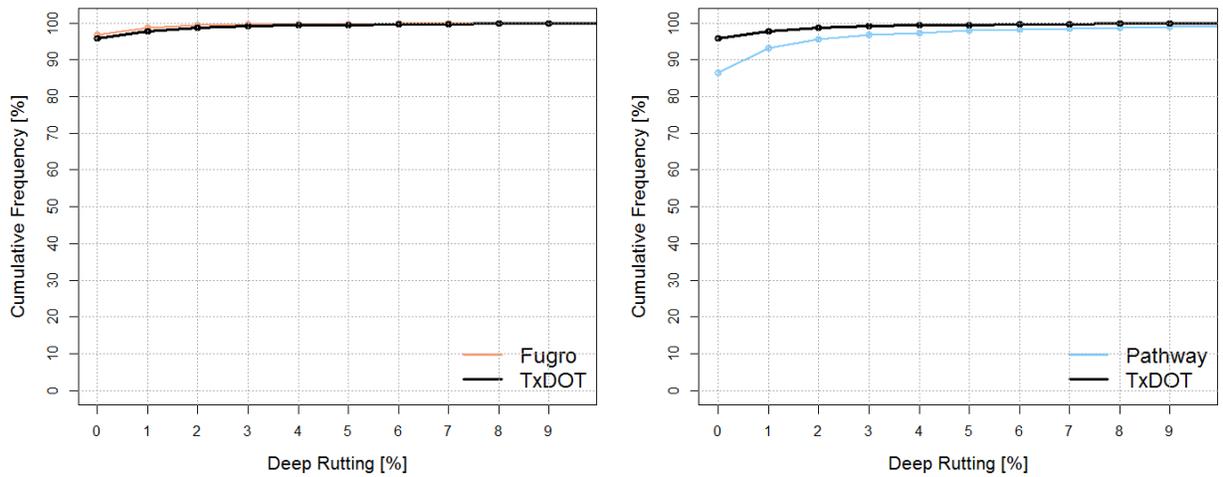
*Figure 3.26: Shallow Rutting along IH-45 for Frontage Road A*

ACP – Deep Rutting (Percentage of Rutting between 1/2” and 1”)

Figures 3.27 and 3.28 show the differences in deep rutting for flexible concrete pavements (ACP sections) in Bryan and Houston, respectively. As was the case for shallow rutting, Fugro’s data are in close agreement with PMIS data while Pathway Services’ data presented much larger discrepancies. However, in this case the differences are smaller and may be attributed to shortcomings in calculating rutting based on the five-point algorithm and not to inaccuracies in the raw data collected. In addition, as observed for shallow rutting, Pathway Services’ differences with PMIS were larger in Bryan than in Houston.



*Figure 3.27: Distribution of Deep Rutting for ACP in Bryan*



*Figure 3.28: Distribution of Deep Rutting for ACP in Houston*

ACP – Alligator Cracking

Figures 3.29 and 3.30 show the cumulative distribution of alligator cracking in flexible pavement sections (ACP) in the Bryan and Houston districts, respectively. In this case, the differences between Fugro and PMIS are significant for both districts. Interestingly, as observed for rutting and other distresses, Pathway Services’ performance was not consistent between the two districts. From the analyses of the sections at Houston, while Fugro tended to detect more

alligator cracking than visual windshield surveys, Pathway Services tended to detect less cracking. For the case of the sections at Bryan, Pathway Services observations match PMIS closely while Fugro captures significantly more alligator cracking.

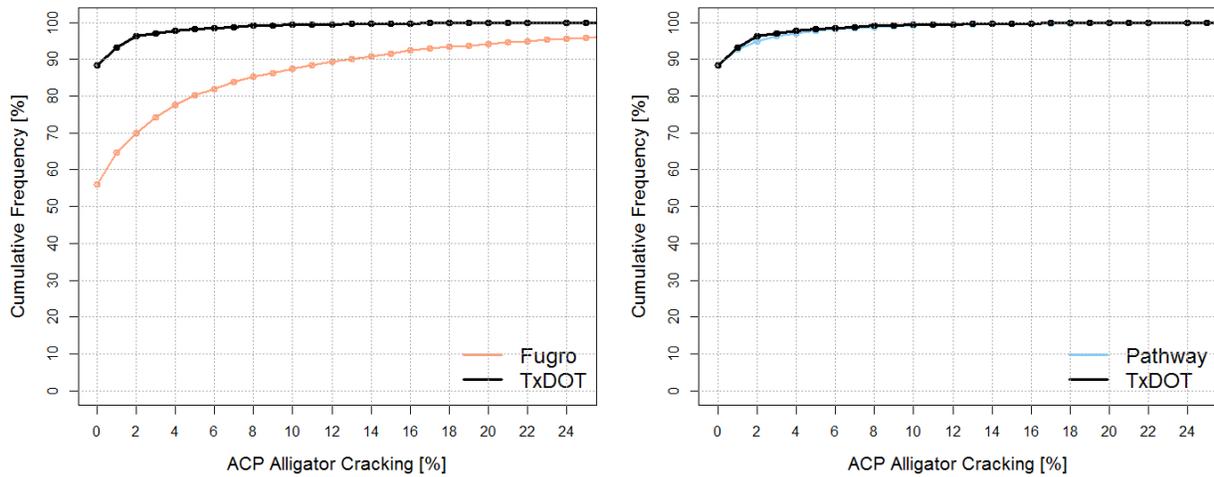


Figure 3.29: Distribution of Alligator Cracking for ACP in Bryan

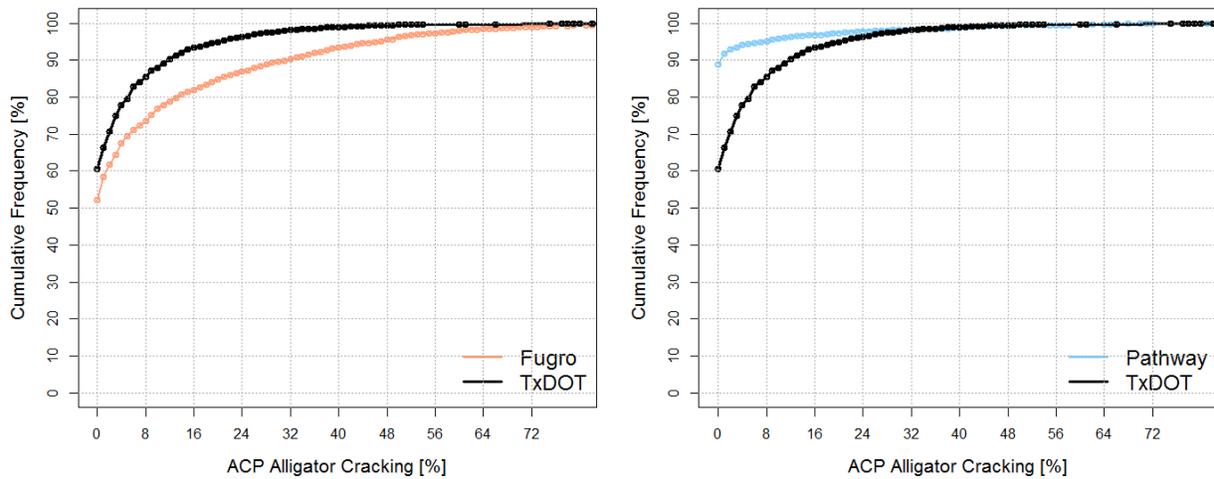
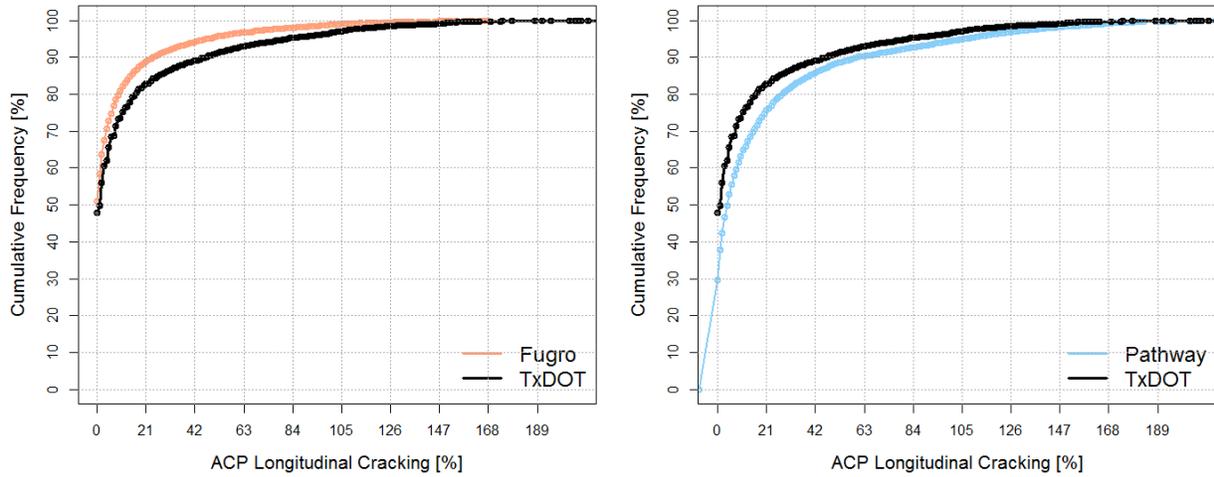


Figure 3.30: Distribution of Alligator Cracking for ACP in Houston

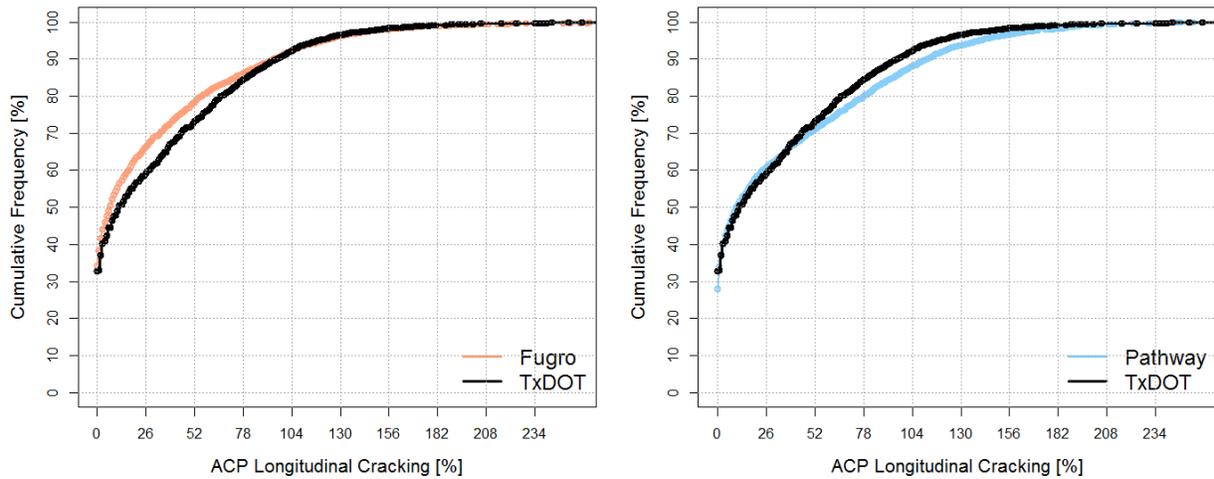
### ACP – Longitudinal Cracking

Figures 3.31 and 3.32 show the cumulative distribution of longitudinal cracking in flexible pavements in the Bryan and Houston districts, respectively. In general, there is a relatively close agreement for the amount of longitudinal cracking that was detected by the vendors and that contained in PMIS. It is interesting to note, however, that in both districts Fugro observed less longitudinal cracking than PMIS while Pathway Services observed more.

The observed greater amount of alligator cracking and the lower amount of longitudinal cracking reported by Fugro with respect to PMIS might be explained, in part, by differences in interpreting whether a crack developing in the wheel path is classified as alligator or longitudinal cracking.



*Figure 3.31: Distribution of Longitudinal Cracking for ACP in Bryan*



*Figure 3.32: Distribution of Longitudinal Cracking for ACP in Houston*

JCP – Failures

Figure 3.33 shows the cumulative distribution of failures for the JCP sections in Houston. As observed from the figure, Pathway Services presented significantly large differences with PMIS whereas Fugro data was in much closer agreement. The large discrepancies between Pathway and PMIS may be explained in part by differences in interpretation of TxDOT definition of JCP failure, which suggests the need for adjusting their measurements systems’ algorithms for the identification of distresses.

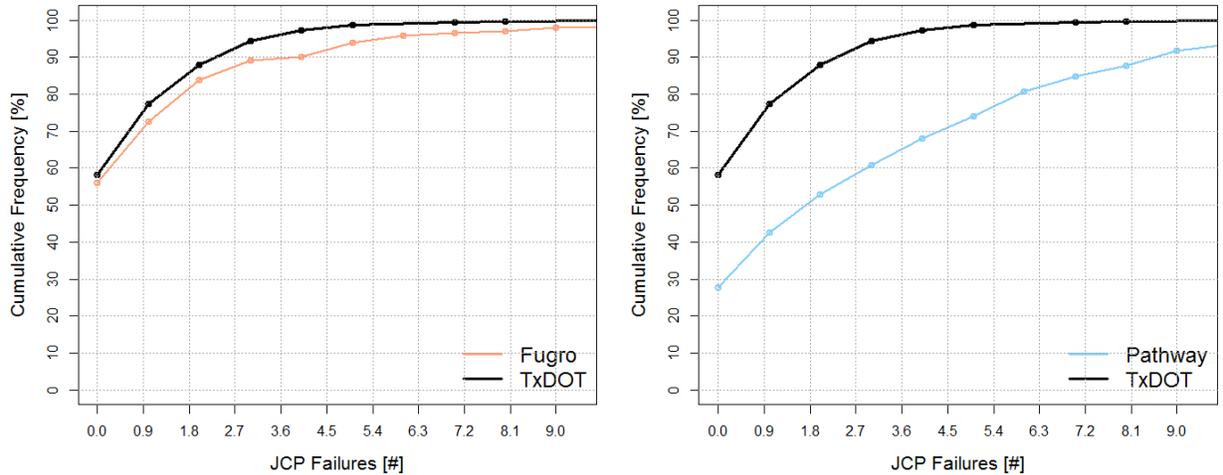


Figure 3.33: Distribution of Failures for JCP Sections in Houston

JCP – Failed Joint Cracks

Figure 3.34 shows the cumulative distribution of failed joint cracks for JCP sections in Houston. Similarly to the observations for JCP failures, Pathway Services data show significant differences with PMIS while Fugro’s distribution match PMIS data much closely. Interestingly, the differences between Pathway Services and PMIS are larger for sections with larger number of failed joint cracks than for sections with less failed joint cracks

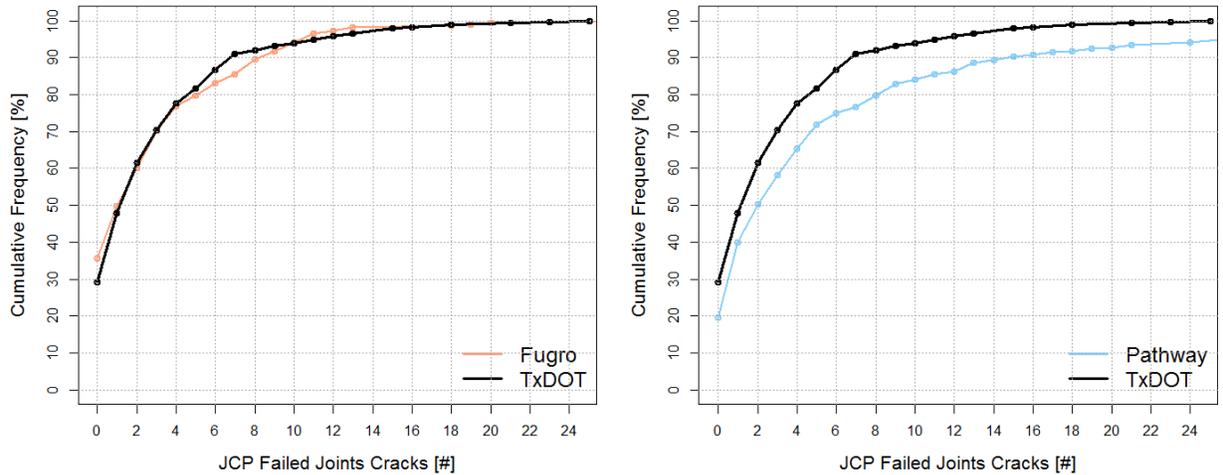


Figure 3.34: Distribution of Failed Joint Cracks for JCP Sections in Houston

JCP – PCC Patches

Figure 3.35 shows the cumulative distribution of PCC patches for JCP sections in the Houston District. For this particular case the differences between PMIS data and both vendors’ distributions were similar. Both Fugro’s and Pathway Services’ distributions curve lie below PMIS’s, and therefore, detected more PCC patches than the visual raters. However, the differences between PMIS and Pathway Services for this particular distress were not as pronounced as for the case of JCP failures and failed joint cracks.

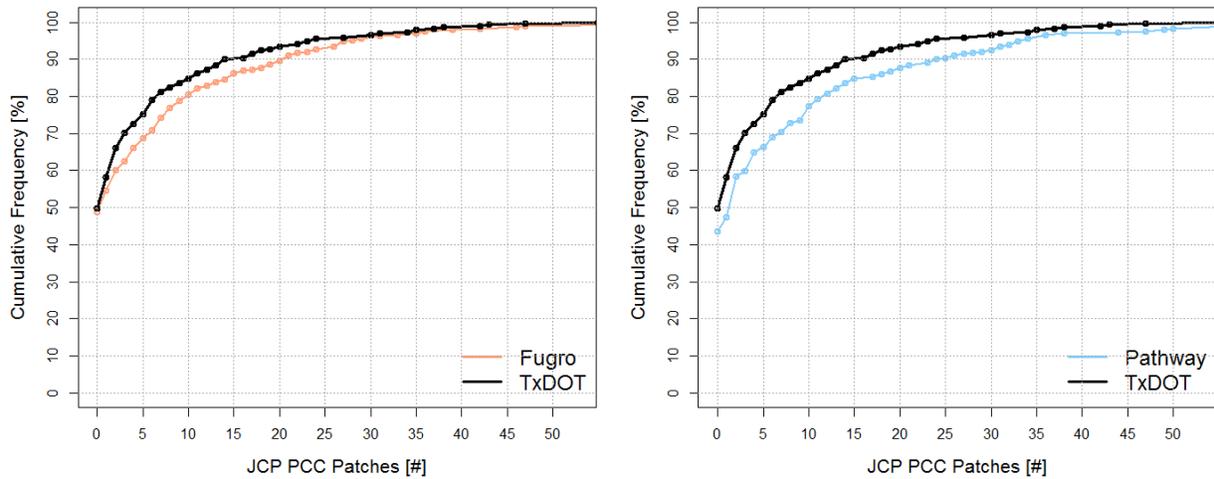


Figure 3.35: Distribution of PCC Patches for JCP Sections in Houston

CRCP – Punchouts and Spalled Cracks

Figures 3.36 and 3.37 show the cumulative distribution of punchouts and spalled cracks respectively, for the CRCP sections in the Houston District. As observed from these two figures, both vendors’ distributions matched PMIS data closely for the two distress types. As previously noted from the comparison of DS by surface type, both Fugro and Pathway Services presented relatively small differences with PMIS for this pavement type.

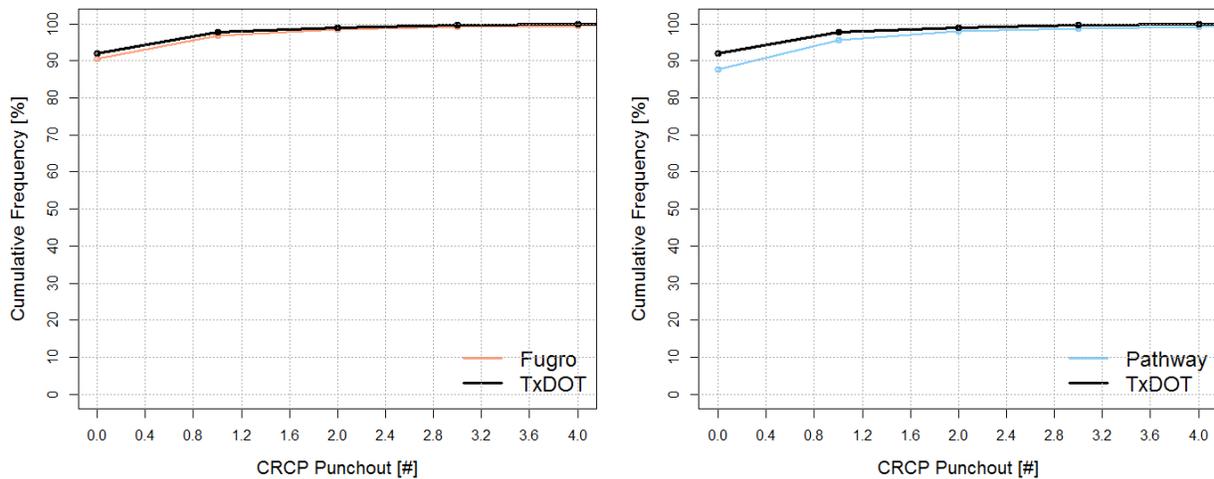
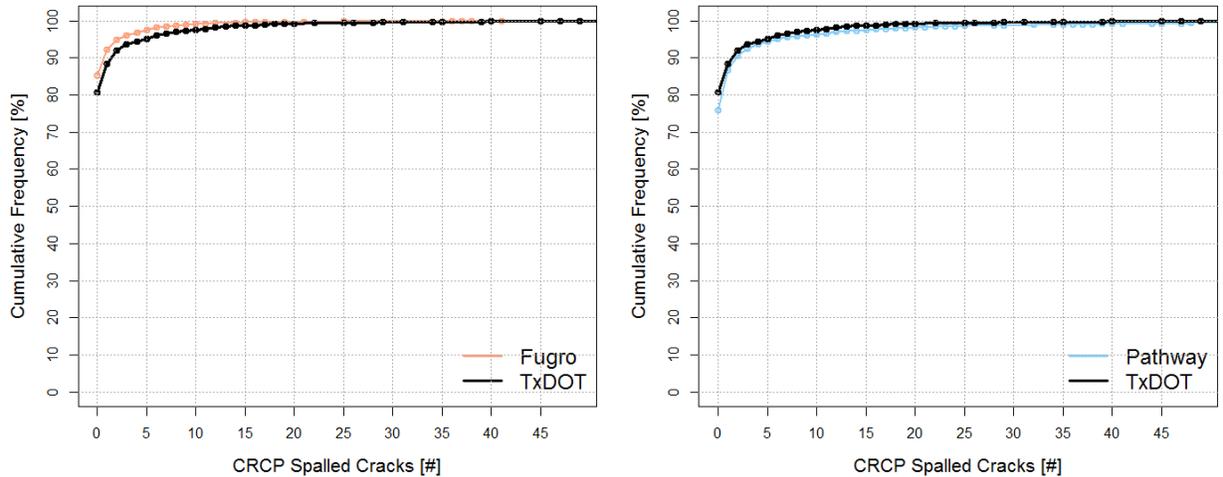


Figure 3.36: Distribution of CRCP Punchouts in Houston



*Figure 3.37: Distribution of CRCP Spalled Cracks in Houston*

### Main Observations Based on Specific Distresses

Based on the data evaluated in this study, it is apparent that the differences in DSs for AC pavements between Pathway Services and PMIS are primarily due to differences in shallow rutting and deep rutting. While Pathway Services reported more rutting and the difference was higher for the Bryan District, Fugro’s rutting data were very similar to PMIS. This observation is different in terms of cracking. It is apparent that the differences in DSs for AC pavements between Fugro and PMIS are mainly explained by differences in the amount of alligator cracking. While Fugro reported more alligator cracking than PMIS, Pathway Services reported less. It is also interesting to note that Pathway Services’ differences for alligator cracking are more pronounced in Houston, while Fugro’s differences are more pronounced in Bryan.

In the case of Pathway Services, it is apparent that differences in DSs for JCPs are mainly explained by differences in failures. It should be noted that the definition of failures is particular to Texas and some calibration of the algorithms to estimate failures will be required.



## **Chapter 4. Phase III Summary and Conclusions**

### **4.1 Summary**

TxDOT initiated a pilot study with two semi-automated visual distress data collection vendors to collect PMIS data in the Bryan and Houston districts. TxDOT PMIS data was used as the baseline for comparison and was collected using guidelines established by the Maintenance Division to ensure that the PMIS and vendor data was collected on the same routes and in the same roadbeds and travel lanes.

The vendor's systems are considered "semi-automated" since visual distress algorithms used by the vendors to identify and rate cracking and other types of distresses are supplemented by human raters that correct, add, or remove distresses to arrive at what the vendor considers to be more accurate results. This means that there can be a lag of several weeks between data collection and delivery. Of course, the time lag will be related to the vendor staffing and equipment resources available and the associated cost to pay for these resources.

The amount of time required for the vendors to collect and post-process the data, and for TxDOT to process and format the vendor's data so that it could be uploaded to the PMIS database, exceeded the original time line established for this study. However, the research team thinks that the experience and knowledge gained through the pilot study will better inform our understanding of this process, and thus will definitely improve future efforts and reduce the potential for delays in data delivery in the required formats.

In addition, the research team thinks that important lessons were learned about contract language and other visual aids used in the original RFP, providing extremely valuable take-aways. Important lessons were learned that will help ensure that potential future RFPs can be written "not just so the language can be understood, but so there is no way the language can be misunderstood."

The University of Texas at Austin's Center for Transportation Research was contracted to analyze the resulting datasets for the Bryan and Houston Districts. These datasets included visual distress, ride, and rut data collected according to standard TxDOT PMIS data collection processes conducted by experienced raters; two Fugro data collection vans; and two Pathway Services data collection vans. The following sections summarize the main observations and findings from Phase III.

#### **4.1.1 Description of Bryan's and Houston's Highway Networks**

- The number of PMIS 0.1-mile sections in each district is similar; the Houston District has a slightly larger proportion of the pilot study network (55%).
- Route types included FM (41%), SH (23%), IH main lane and frontage road (18%), US (9%), and other types (9%).
- About two-thirds (66%) of the total network evaluated (inclusive of both districts) consisted of flexible pavements, composed mainly of intermediate thickness ACP (2.5 in. to 5.5 in. thick) and surface treatments. Furthermore, almost half of the sections (46%) in the study were intermediate thickness ACP; rigid pavements comprised approximately 33% of the network, including CRCP and JCP.

- Practically all (99%) CRCP sections are in the Houston District while 96% of the surface-treated pavement sections are in the Bryan District.
- Bryan’s highway network is predominantly composed of flexible pavements (more than 95% of the sections), including ACP (59%) and surface treatments (36%).
- The Houston District is almost evenly distributed between rigid (53.3%) and flexible pavements (46.7%). The predominant rigid pavement type in Houston is CRCP (47%).

#### **4.1.2 Data Collected and Available for the Analysis**

- The total length of PMIS data for Bryan and Houston districts is 7,549.5 roadbed miles. Fugro reported 7,550.0 roadbed miles of raw data and Pathway Services reported 7,326.1 roadbed miles of raw data.
- The amount of data successfully processed, converted to ratings and exported to PMIS databases for the comparison, totaled 7,077 roadbed miles for Fugro and 6,491 roadbed miles for Pathway Services.
- A certain percentage of data reported by the vendors was not successfully processed and exported into the PMIS databases (approximately 7% for Fugro and 10% for Pathway Services) due to formatting issues, repeated measurements, and data collected on non-TxDOT highways or outside the boundaries of the two districts, among other causes.
- Although the analyzed network (the subset of successfully processed and analyzed sections) does not equal the total network, the network’s characteristics were preserved for all practical purposes.

#### **4.1.3 Data Collection Operations**

- Pathway Services used two survey vans, “PATHRN19” and “PATHRNVa,” to collect the pavement condition data. The usage of the two vans varied, with PATHRN19 predominately collecting data during September 2013, and PAHTRNVa collecting data from early September to late October 2013.
- Fugro used two vans, “ARAN44” and “ARAN48,” to collect the requested pavement data. These two survey vans equally covered the two-month period of the data collection.
- Pathway Services collected data using one survey van per district, whereas both of Fugro’s vans collected data in both districts.
- Pathway Services van PATHRN19 collected approximately 99.9% of its data in the Houston District and PATHRNVa collected 100% of its data in the Bryan District.
- Fugro’s ARAN44 collected 30% of the data in the Houston District and 70% of the data in the Bryan District, whereas ARAN48 van collected 72% of its data in the Houston District and 28% in the Bryan District.
- The researcher team has no information regarding the repeatability or reproducibility of the two vans used by either Pathway Services or Fugro. Thus, we

cannot determine whether similar results would have been obtained had the van operations been performed differently. *Repeatability* relates to the ability of a van and operator to obtain similar results from repeated data collection runs along the same route. *Reproducibility* relates to the ability of two different vans and operators to obtain similar results along the same route.

- Currently there are no national or Texas state standards, protocols, or methods for calibrating automated visual distress data collection vehicles to ensure both repeatability and reproducibility. Both repeatability and reproducibility are crucial to ensuring that the automated visual data collected by a fleet of vans is high quality and accurate.

#### **4.1.4 Survey Van Data Collection Production Rates**

- On average, ARAN44 and ARAN48 were 82% active, while PATHRN19 and PATHRNVa were 90.5% active. The main reasons for the active percentage being less than 100 are weather effects, and potentially, malfunctions and repairs.
- The two Fugro survey vans each collected data in both districts and had similar average daily production rates.
- The Pathway Services survey van operating in the Bryan District collected more than double the miles per day than the van operating in the Houston District.
- The average production rate for the pilot study for all four vans is 103 miles per day, i.e., on average a data collection crew was able to collect 103 miles of data, each day, using one van. However, the production rates varied from van to van such that the range in data collection amounts varied from 63 miles per day to 283 miles per day. Many vendors state that the standard production rate per van is approximately 200 miles per day.

#### **4.1.5 Comparison of PMIS Data to Vendor Data**

- Both vendors agreed closely with TxDOT PMIS Ride Scores based on aggregated data for all mileage collected in both districts. However, larger differences were observed along main corridors on frontage roads.
- Both vendors captured more distresses than TxDOT PMIS visual ratings. This resulted in lower overall “Good” or better Distress and Condition Scores in both Districts and when the Score for both Districts were combined. However, it was also observed that the amount of difference varied among the Distress or Condition Score categories for each vendor.
- Compared to TxDOT PMIS Ratings, Pathway Services reported lower “Very Good” Condition and “Very Good” Distress Scores for both districts, but higher “Good” Condition Scores and “Good” Distress Scores for both districts. When the “Very Good” and “Good” Scores were summed to produce the “Good” or better Condition Score value, the lower values in the “Very Good” category partially compensate and result in a closer “Good” or better score than Fugro.

- Compared to TxDOT PMIS Ratings, Fugro reported lower “Very Good” Condition and “Very Good” Distress Scores for both districts, and lower “Good” Condition Scores and “Good” Distress Scores for both districts. Thus, when the “Very Good” and “Good” Scores were summed to produce the “Good” or better Condition Score value, there was no compensation in the values that were consistently lower for both score categories.
- It should be noted, however, that when score categories are created to sub-divide a dataset, as is done in the TxDOT PMIS System, there is always a possibility that small score differences can result in data falling into one or the other category by a matter of one or two points. The results of the pilot study highlight this issue and suggest that calibration of distress identification algorithms and increased experience in evaluating pavement distress image data could improve these results for any vendor. In addition, TxDOT may want to consider a different method for evaluating the Condition and Distress Scores such that the boundary effects of categories are eliminated.
- For Distress Scores, differences between Pathway Services and TxDOT PMIS were more significant in the Bryan District (as Figure 3.14 illustrated). To be more specific, Pathway Services showed larger differences for ACP and JCP sections, whereas Fugro showed slightly larger differences for ACP.
- For Distress Scores on ACP sections, Pathway Services Distress Scores were higher in the Houston District and lower in the Bryan District compared to TxDOT PMIS.
- As for the specific distresses, differences between Pathway Services and PMIS for ACP sections can be explained by the differences in shallow rutting and deep rutting. Pathway reported more rutting and the difference was higher for the Bryan District.
- Fugro presented very similar values for both shallow and deep rutting in both districts compared to TxDOT PMIS.
- It should be noted that past experience has shown, based on field testing in Texas and other states, that a five-point rut bar will typically underestimate the amount of rutting. However, the baseline for this study was the five-point rut bar used by TxDOT. Thus, though both vendors collected full-lane-width transverse profiles that could have been used to determine more accurate RDs in both wheel paths using proprietary algorithms, these capabilities were not used. The vendors were required to simulate a five-point rut bar using an algorithm developed for this purpose in order to calculate RDs according to the TxDOT RFP requirements. The process of applying an algorithm to simulate a five-point rut bar applied to a full-width transverse profile could potentially also introduce variability when compared to TxDOT PMIS data using an actual five-point rut bar.
- It is anticipated that if the vendors had used full-lane-width transverse profiles and a calibrated algorithm for collecting RDs for each of the TxDOT PMIS RD categories, the amount of measured rutting would have exceeded the amount of rutting measured in the pilot study based on the a five-point rut bar. This would

have resulted in lower Distress and Condition Scores than reported in the pilot study.

- Fugro reported more alligator cracking than TxDOT PMIS, which is one of the primary reasons for the lower Distress and Condition Scores reported by Fugro. The differences between Fugro and PMIS are more pronounced in Bryan and those between Pathway Services and PMIS are more pronounced in Houston.
- Pathway Services reported less alligator cracking than TxDOT PMIS, though the differences between districts is distinctly different (Figures 3.29 and 3.30)
- When focusing on shorter segment lengths of 20 to 30 miles, the examination of individual corridor showed that the vendor data can exhibit large variations compared to TxDOT PMIS data. This finding is significant since most districts will rely on accurate PMIS data for both network- and project-level corridor evaluations to select candidate projects and evaluate initial project rankings. However, these variations could be potentially be addressed by the calibration of the vendor's algorithm.

## 4.2 Conclusions

TxDOT PMIS data and semi-automated visual distress, rutting, and ride data was collected by two vendors in the Bryan and Houston districts. Though the amount of time required to complete the pilot study exceeded original expectations, valuable lessons were learned that will improve future processes and reduce potential delays. The pilot study was successful in that a significant set of data was obtained to evaluate the potential for implementing semi-automated distress ratings to provide data for the TxDOT PMIS database.

The analysis showed trends that were expected based on the results of the Phase I and II studies. Specifically, semi-automated visual distress ratings capture more distress than manual ratings, resulting in lower Distress and Condition Scores.

In addition, if the vendors had utilized full-lane-width transverse profile measurements and calibrated algorithms to measure RDs, the research team thinks (based on 0-6663 Study Phase I results) that more rutting would have been measured compared to the five-point rut bar simulation required for this study. Increased rut measurements would have resulted in even lower Distress and Condition Scores than actually obtained by the vendors in the pilot study.

Though differences between vendor results and TxDOT PMIS data were evident for specific distresses, it is expected that TxDOT implementation of calibration procedures for automated visual distress data collection vehicles can reduce this variability. In particular calibration procedures and standards for visual distress data collection equipment and operations are needed to establish protocols as well as to identify equipment and methods to be employed by TxDOT to ensure automated visual distress data measurements are accurate and repeatable for each measurement vehicle and reproducible among a fleet of vehicles. Past experience has shown that calibration procedures alone do not necessarily ensure that reproducibility will be automatically achieved.

This pilot study is the first opportunity that vendors have had to collect a significant amount of network-level data in Texas. The researchers think that this experience is valuable for TxDOT and the vendors to identify specific distress measurements that will require calibration to Texas conditions to achieve improved measurement results. Thus, calibration of vendor

automated distress algorithms and data post-processing can reasonably be expected to achieve more accurate results.

## Chapter 5. Recommendations from Phase III

### 5.1 Recommendations

The research team considers the pilot study and resulting analysis successful in that results were obtained that can be used by TxDOT Administration and TxDOT Maintenance Division to make better informed decisions about semi-automated visual distress rating system implementation. Based on the results of the pilot study, the researchers recommend the following actions for consideration:

1. Implement automated or semi-automated visual distress data collection in place of PMIS manual visual distress data collection to:
  - a. improve safety;
  - b. provide more accurate and complete measurements of visual distress and rutting data.
2. Implement full-lane-width transverse profile measurement system(s) and rut algorithms in place of the current five-point laser rut bar system;
  - a. calibrate RD algorithms to provide data in the different rutting categories employed by TxDOT;
  - b. consider introducing a new method for determining network- or project-level RD conditions that eliminates problems associated with categories.
3. Initiate development of automated and semi-automated visual distress data collection equipment calibration standard protocols, equipment, and procedures to:
  - a. ensure both the repeatability and reproducibility of equipment;
  - b. support and encourage continued improvements in equipment capabilities;
  - c. provide services applicable for TxDOT and/or vendor supplied systems.
4. Initiate development of automated and semi-automated visual distress data collection equipment operator certification protocols, equipment and procedures to ensure that equipment operators:
  - a. are trained in proper operation of the automated systems to ensure quality data and safe operations;
  - b. can identify when systems require recalibration due to equipment repairs or replacement;
  - c. can identify systems that are out of tolerance and require recalibration.
5. Initiate development of Quality Assurance and Quality Control (QC/QA) standards for automated and semi-automated visual distress data collection processes and results to:
  - a. manage data collection processes for a fleet of vehicles operating simultaneously and autonomously in different regions of Texas;
  - b. establish procedures for sampling and assessing collected data to determine if re-collection is necessary;

- c. identify potential improvements in managing data collection, post processing, and data delivery to seek greater efficiency while maintaining data accuracy requirements.
6. Work to ensure TxDOT retains in-house subject matter experts to:
- a. maintain state-of-the art knowledge, experience, and capabilities and to continue as national leaders to champion PMIS data collection equipment development and processes;
  - b. ensure that the state of the practice is challenged to facilitate continued development and improvements in data collection equipment, procedures, methods and efficiency;
  - c. provide project-level testing and construction referee testing using state-of-the art equipment;
  - d. ensure TxDOT continues to provide districts with high quality data through expert assessment of results;
  - e. identify potential improvements in managing data collection, post processing, and data delivery to seek greater efficiency while maintaining data accuracy requirements.

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