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Office of Research

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Replacement of SDDOT's Roadway Evaluation System

Study SD2018-02

Final Report

Prepared by

SDDOT Office of Research

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DISCLAIMER

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16. Abstract

The South Dakota Department of Transportation (SDDOT) Office of Transportation Inventory Management operates a road and pavement evaluation system consisting of a vehicle equipped with roadway evaluation equipment and computers at the SDDOT central office to process data collected by the vehicle. This system acquires roadway and pavement images, pavement roughness, cracking, rutting, and faulting values. Data is used by the SDDOT for the Pavement Management System (PMS) and the Highway Performance Monitoring System (HPMS). The roadway evaluation system purchased from FUGRO Roadware has been in operation since 2013. Because sensor technology has improved and the vehicle has over 162,000 miles on it, the SDDOT needed to replace the FUGRO roadway evaluation system after the 2019 collection year. The goals of this research project were to acquire a new roadway evaluation system based upon the needs of the SDDOT and then validate that system. To accomplish these goals, the researcher invited vendors to the SDDOT to present their systems and make technical presentations to the technical panel. Interviews were conducted with the users of the FUGRO roadway evaluation system or data provided by the system to define functional requirements for the new system. Purchasing specifications were created and a request for procurement for a new roadway evaluation system was issued. After acquiring a new system from Pathway Services, Inc., acceptance testing was performed to verify the functionality and accuracy of the data generated by the system. The new roadway evaluation system was able to pass the requirements of the acceptance testing and was used by the Office of Transportation Inventory Management for the 2020 collection year.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TABLE OF ACRONYMS

Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
DQMP	Data Quality Management Program
EVOC	Emergency Vehicle Operator Course
FHWA	Federal Highway Administration
HPMS	Highway Performance Monitoring System
IRI	International Roughness Index
JCP	Jointed Concrete Pavement
LCMS	Laser Crack Measurement System
MRM	Mileage Reference Marker
NHS	National Highway System
PCC	Portland Cement Concrete
PMS	Pavement Management System
SDBIT	South Dakota Bureau Information and Telecommunications
SDDOT	South Dakota Department of Transportation

1.0 EXECUTIVE SUMMARY

1.1 Introduction

The SDDOT's first known application of automated roadway evaluation equipment—to measure pavement roughness using a response-type test vehicle—dates back to the late 1960's. The relative movement between the axle and body of the test vehicle generated an electrical signal that was recorded on a paper roll chart recorder. Later, office workers manually digitized the peaks and valleys of the recorded ink traces. The digitized values were keypunched to Hollerith card, read into a mainframe computer, and converted to a roughness index based on root-mean-square power. Although the process was slow, and the measured roughness was dependent on the characteristics and condition of the test vehicle's suspension, this effort moved the Department toward an automated, objective assessment of pavement condition.

Since these early beginnings, SDDOT has increasingly relied on automated collection of roadway condition information. Reliance on automated methods can be expected to grow as equipment capabilities improve and as federal data reporting requirements and the need for information to support business decisions increase.

1.2 Problem Description

The SDDOT Office of Transportation Inventory Management operates a road and pavement evaluation system consisting of a vehicle equipped with roadway evaluation equipment and computers at the SDDOT central office to process data collected by the vehicle. This system acquires roadway and pavement images, pavement roughness, cracking, rutting, and faulting values. Data is used by the SDDOT for the Pavement Management System (PMS) and the Highway Performance Monitoring System (HPMS). The roadway evaluation system purchased from FUGRO Roadware has been in operation since 2013. Because sensor technology has improved and the vehicle has over 162,000 miles on it, the SDDOT needed to replace the system after the 2019 data collection year.

1.3 Research Objectives

The main goal of this project was to acquire and certify a new roadway evaluation system. The objectives of this research are as follows:

- Objective 1: Identify SDDOT's needs for a roadway evaluation system
- Objective 2: Define a specification for an optimal roadway evaluation system
- Objective 3: Validate the roadway evaluation system performance

1.4 Task Descriptions

To acquire and certify a new roadway evaluation system, the researcher performed the following tasks:

- Task 1: Review Project Scope
- Task 2: Assess the Current State of Art and Practice
- Task 3: Define Users' Needs
- Task 4: Interview Personnel within SDDOT and SDBIT

- Task 5: Define Functional Requirements
- Task 6: Develop and Submit a Purchase Specification and Detailed Testing Plan
- Task 7: Issue a Request for Proposal for Procurement of a Roadway Evaluation System
- Task 8: Evaluate Roadway Evaluation System Acceptability
- Task 9: Recommend Changes to the SDDOT Data Quality Management Program
- Task 10: Prepare Final Report
- Task 11: Make Executive presentation

1.5 Findings and Conclusions

Upon delivery of the new roadway evaluation system from Pathway Services, Inc., the researcher along with staff from the Office of Research and Transportation Inventory Management conducted certification testing to verify the functionality of the new system. Certification included comparing measurements taken with the roadway evaluation system to manual measurements taken for roughness, rutting, faulting, and cracking.

For roughness certification, a SurPRO 3500 walking profiler was used to provide a baseline profile for comparison to the profiles generated by the roadway evaluation system. As part of the certification process, the repeatability of the passes made with the roadway evaluation system and the cross-correlation of each of the passes of the roadway evaluation system with the baseline profile were analyzed. The roadway evaluation system passed the requirements for repeatability and cross-correlation as specified in AASHTO R-56.

Rut depth measurements were collected manually and with the roadway evaluation system on a 528' section of US HWY 14 east of Pierre. According to the SDDOT Data Quality Management Program (DQMP), the average rut value of each of the five runs on the test section with the roadway evaluation system must be within +/- 0.06 inches of the baseline rut value measured manually. In addition, the repeatability of the five runs with the roadway evaluation system must be within +/-0.06 inches. The manually collected rut depth measurements averaged 0.06" for the left wheel path and the roadway evaluation system measured 0.07". For the right wheel path, the manually collected rut depth measurements averaged 0.09", which was also the same measured by the roadway evaluation system. The repeatability of the five runs for the roadway evaluation system were within +/-0.06 inches. Therefore, the roadway evaluation easily passed the rut certification.

Faulting measurements were collected manually and with the roadway evaluation system on a 528' section of US HWY 14 through Blunt. Baseline measurements were taken with a Georgia Faultmeter at 18, 28, 38, 48, and 57 inches from the lane edges on every joint. The faulting measurements were averaged for each wheel path. As specified in the DQMP, the average fault value of the five runs with the roadway evaluation system on the concrete test section are required to be within +/- 0.06 inches of the baseline fault value measured manually. The manual measurements were within 0.06 inches of the measurements taken by the roadway evaluation system.

Crack measurements were collected on a 528' test section of asphalt concrete at the Emergency Vehicle Operator Course (EVOC) near Pierre. The test section was divided into ten 50' sections with one 28' section. Longitudinal cracks identified within the 39" left and right wheel paths were measured and mapped onto paper. All the cracks measured manually were identified by the roadway evaluation system. The roadway evaluation system identified significantly more crack length for each section than was manually measured. This was especially noticeable for the left wheel path. Close to 30% more crack length was identified by the roadway evaluation system.

1.6 Recommendations

1.6.1 Documentation for Operating Roadway Evaluation System

Provide training documentation for operating roadway evaluation system

Develop a document outlining operation procedures by building upon resources provided by Pathway Services, Inc. Items included in the document should cover starting up the system equipment, operating the system software, and addressing common reoccurring issues. The training document should be clear enough that someone who has never operated the system will be able to after reviewing the document.

1.6.2 Documentation for Processing and Reporting Data

Provide training documentation for processing and reporting data generated by roadway evaluation system

Create a document outlining the step by step process for extracting and processing data from the roadway evaluation system. The document should include where the data is to be stored on the computers in the SDDOT central office. Guidance should be provided for generating reports to be used for the SDDOT Pavement Management System (PMS) and the Highway Performance Monitoring System (HPMS).

1.6.3 Improve 3D Automated Crack Rating

Improve the logic used by the 3D automated crack detection system

Set up a procedure to check cracks identified by the 3D automated crack detection system. This should include manually rating cracks and comparing the manual ratings to ratings provided by the automated crack rating system. Collaboration should also occur with Pathway Services, Inc. to refine algorithms used to identify and rate cracks.

1.6.4 Annual Certification Sites

Continue to use the same annual certification sites for Roughness, Faulting, and Rutting

EVOC should continue to be used for certifying roughness. Due to the challenges with setting up a testing site for the SurPRO, the site at EVOC has worked very well for roughness certification and should continue to be used. US HWY 14 east of Pierre and through Blunt should continue to be used for rutting and faulting certification. These sites are easy to access from Pierre and data from year to year can be compared. Since there was difficulty measuring cracks at EVOC and new pavement will be installed at EVOC in 2022, the site for cracking certification should be relocated after 2022.

1.6.5 Update Data Quality Management Program

Update the Data Quality Management Program resulting from replacement of the roadway evaluation system

The recommend changes to the DQMP caused by the replacement of the Pathway roadway evaluation system are the following:

- Measurement spacing for rutting verification should be changed to 33 ft. in the longitudinal direction as specified in AASHTO R 48-10 for the 3.1.7 Rutting Data Validation section.
- The mention of FUGRO's Pave3D system should be changed to 3D system in the 3.1.8 Faulting Data Validation section.
- The mention of LCMS should be changed to 3D system in the following sections:
  - 3.1.3 Annual On-Site Preventative Maintenance
  - 3.1.8 Faulting Data Validation
  - 3.1.10 Images
  - 3.1.11 Summary of Equipment Certification/Quality Control

2.0 PROBLEM DESCRIPTION

The FUGRO roadway evaluation system used at the SDDOT employed instrumentation, cameras, computer hardware, and software to acquire data used in various analyses of roadways. This system acquired roadway and pavement images, pavement roughness, cracking, rutting, and faulting values. The collected data was referenced spatially through global positioning and linearly to roadway centerlines using the SDDOT Mileage Reference Marker (MRM) system.

Because the FUGRO roadway evaluation system vehicle had logged more than 162,000 miles, the system needed replacement. Technological advances made since the equipment was purchased in 2013 were reviewed for inclusion with the replacement system. These included the following:

- Higher resolution roadway images
- Higher resolution pavement images showing rumble strips, raveling, sealed cracks, colored contour lines, patching, bleeding, water entrapment depth, and man-made objects (manhole covers & storm-drains)
- 3D modeling of roadway using Lidar
- Improved automated crack detection and rating
- Asset extraction using photogrammetry or Lidar
- Improved accuracy of positional system for collecting vehicle position, velocity, altitude, track, speed, and dynamics of a moving vehicle
- Ground penetrating radar

3.0 RESEARCH OBJECTIVES

Three objectives are defined for this study.

3.1 Identify SDDOT's Needs for a Roadway Evaluation System

Identify SDDOT's needs for a roadway evaluation system through assessments internal to the Department, reviews of similar equipment presently in use at other states and Canadian provinces, and appraisals of newly emerging equipment and technology.

To determine the capabilities needed in new equipment, the researcher did the following:

- Identified SDDOT's current needs
- Assessed their value and importance
- Assessed their potential for automation by the current generation of roadway evaluation equipment

This vital information was secured through reviews of SDDOT's business functions and interviews with staff who currently use or could potentially use new roadway evaluation equipment. Through review of technical information from vendors, discussions with users of their equipment, and equipment demonstrations, the capabilities of currently available equipment were determined and matched against SDDOT's identified needs.

3.2 Define a Specification for an Optimal Roadway Evaluation System

Develop a specification for an optimal roadway evaluation system configuration based on departmental needs and functional requirements and testing criteria that can be used to validate equipment performance before final acceptance.

After SDDOT's needs and relevant equipment capabilities were identified, a high-level specification of equipment capabilities was possible. The high-level specification identified the major subsystems to be included in the new roadway evaluation system.

After approval of the high-level specifications, a detailed procurement specification was developed. The specification covered the host vehicle, vehicle-mounted roadway evaluation equipment, and office-based equipment for processing or analyzing data acquired by the roadway evaluation equipment. The specification addressed physical, functional, and performance requirements. It also defined criteria for acceptance and payment. The specification was used by the Office of Research for use in the State of South Dakota's procurement process.

3.3 Validate the Roadway Evaluation System Performance

Validate the roadway evaluation system performance to ensure compliance with specifications.

Verifying all the specifications required a combination of activities by the vendor and SDDOT. The vendor was required to certify conformance with AASHTO R 56-14 Standard Practice for Certification of Inertial Profiling Systems upon delivery of the roadway evaluation system. This required the vendor to pass certification at an established facility prior to delivery. The researcher and Pathway Services, Inc. performed the remaining certification identified in the procurement specification for acceptance and payment.

4.0 TASK DESCRIPTIONS

The research objectives were attained by executing eleven distinct tasks.

4.1 Review Project Scope

Meet with the project's technical panel to review the project scope and work plan.

The researcher met with the project's technical panel on October 10, 2018 to review the technical approach and activities proposed in the work plan and to gain deeper understanding of the panel's concerns and insights.

4.2 Assess the Current State of Art and Practice

Through review of technical documentation and vendor demonstration, assess the current state of art and practice regarding capabilities, use, and cost of roadway evaluation systems.

To acquire information for his own consideration and the consideration of the technical panel, the researcher did the following:

- The researcher collected technical information from vendors' websites, published product literature, and personal contacts.
- The researcher invited vendors to present their systems to the technical panel. Pathway Services, FUGRO, Mandli Communications, and International Cybernetics Company presented their systems to the technical panel. The presentations enabled the researcher and technical panel to become familiar with the latest available roadway evaluation technology.
- The researcher collected information, including equipment specifications and assessments of equipment performance, from other state transportation departments that had recently acquired and deployed roadway evaluation equipment.

4.3 Define Users' Needs

Examine documentation and interview appropriate personnel within SDDOT to define users' needs for data that is or could potentially be collected by a roadway evaluation system.

To identify and characterize SDDOT's need for data that already was or could be collected by an automated roadway evaluation system, the researcher relied on review of relevant documents and interviews with current and potential users of the system.

Because of the broad interest and potential application of the equipment, interviews were arranged and conducted with nearly all offices of the SDDOT, as shown in Table 1. In each case, the researcher discussed current and possible uses of data that was already collected or that could be collected with currently available equipment.

Table 1: SDDOT OFFICES INTERVIEWED

<table>
<tr><th>Division</th><th>Offices</th><th>Potential Applications</th></tr>
<tr><td>Planning & Engineering</td><td>Transportation Inventory Management
Project Development Administration
Materials & Surfacing
Bridge Design
Roadway Design
Right of Way</td><td rowspan="3">Longitudinal Profile
Network Pavement Roughness
Transverse Profile & Rutting
Pavement Surface Texture
Roadway Surface Images
Pavement Distress (cracking)
Grade & Cross-Slope
Horizontal & Vertical Curvature
Roadway and Right of Way Images
Pavement Marking Condition
Roadside Asset Location
Roadside Asset Condition</td></tr>
<tr><td>Operations</td><td>Operations Support
Region Operations
Area Engineering</td></tr>
<tr><td>Secretariat</td><td>Air, Rail, & Transit</td></tr>
</table>

Those interviewed were asked to comment on:

- roadway data needs, including:
    - types of data needed
    - data definitions
    - temporal frequency of measurement (annual or other)
    - spatial frequency of measurement
    - location accuracy needed
    - attribute accuracy needed
    - anticipated future needs
    - seasonal limitations for data collection
    - processing and analysis needs
- current data collection methods and cost
- adequacy of currently collected data
- convenience of current data access
- data importance and value

4.4 Interview Personnel within SDDOT and SDBIT

Review documentation and interview appropriate personnel within SDDOT and the SD Bureau of Information and Telecommunications to define operational requirements and constraints.

The researcher identified operational requirements and constraints primarily through discussions with staff of the Office of Transportation Inventory Management who currently operate SDDOT's roadway evaluation equipment and staff of the Bureau of Information and Telecommunications knowledgeable of information systems needed to support the equipment. Staff of the Office of Transportation Inventory Management was able to describe requirements relating to operation of the mobile data collection equipment, vehicle, and workstations used to process collected data. Staff of the Bureau of Information and Telecommunications was able to describe requirements relating to information architecture, system hosting, data storage, and communication to outlying SDDOT offices.

4.5 Define Functional Requirements

Based on the findings of SDDOT data needs, equipment capabilities, operational requirements and constraints, and estimated costs, define and submit for review and approval of the project's technical panel functional requirements for replacement of the roadway evaluation system.

Upon completion of Tasks 2-5, the researcher summarized high-level functional requirements in a presentation to the project's technical panel on January 31, 2019. The presentation described the state of art and practice in roadway evaluation, defined SDDOT's identified data collection needs, and identified operational requirements and constraints for new equipment.

The researcher offered recommendations for inclusion of major subsystems—such as profile measurement, automated distress rating, roadway images, etc. The researcher and panel also discussed subsystems to consider such as Lidar, Ground Penetrating Radar (GPR), and 360^{o} camera. It was decided by the technical panel to include the major subsystems used by the existing roadway evaluation system and forego new systems such as Lidar, GPR or 360^{o} camera.

4.6 Develop and Submit a Purchase Specification and Detailed Testing Plan

Upon the technical panel's approval of the functional requirements, develop and submit for review and approval of the project's technical panel a complete purchase specification and a detailed testing plan for acceptance of the roadway evaluation system and comparison to SDDOT's current system.

After the technical panel approved the functional requirements, the researcher developed a complete and detailed specification for procurement of the roadway evaluation system. The specification conformed to requirements of the SD Bureau of Administration's Office of Procurement Management.

To develop the specification, the researcher relied on the specification used to procure SDDOT's previous roadway evaluation system and recent specifications used by other states to procure similar equipment. The specifications covered the test vehicle, hardware, software, installation and configuration, applicable standards, warranty, training, and all other system requirements. The specification also included criteria—including physical requirements, certification requirements, and performance requirements—for accepting the equipment upon delivery and for final acceptance and payment after the equipment was put into service. The researcher provided the specifications for consideration and approval of the project's technical panel.

4.7 Issue a Request for Proposal for Procurement of a Roadway Evaluation System

In collaboration with the technical panel, issue a Request for Proposal for procurement of a roadway evaluation system, critically evaluate proposals received, select and negotiate with the successful vendor, and acquire the system using standard state procurement procedures.

To procure the roadway evaluation system, the researcher did the following:

- Issued request for proposal (4/2/19)
- Addressed questions that occurred during the proposal period
- Evaluated vendors' proposals with the technical panel (5/10/19)

- Negotiated with the successful vendor (Pathway Services, Inc.)
- Acquired the system (5/11/20)

4.8 Evaluate Roadway Evaluation System Acceptability

Upon delivery of the roadway evaluation system, evaluate its acceptability and compare its performance to the performance of the current roadway evaluation system using the detailed acceptance testing plan.

Prior to delivery of the Pathway roadway evaluation system, the researcher developed a test plan for evaluating the delivered equipment against the acceptance and payment criteria defined in the procurement specification. The plan detailed the procedures involved in the evaluation and the responsibilities of those involved. Since the FUGRO roadway evaluation system had a faulty Laser Crack Measurement System (LCMS) unit, only pavement roughness was compared between the FUGRO and Pathway systems.

After delivery of the Pathway system, the researcher worked collaboratively with staff of the Office of Transportation Inventory Management to conduct the evaluations necessary for final acceptance and payment. In addition to verification of basic functionality and feasible accuracy checks of measured data, acceptance criteria included 20 days of successful operation of the system. Results of the equipment evaluations are documented in Chapter 5 of this report.

4.9 Recommend Changes to the SDDOT Data Quality Management Program

Recommend changes to the SDDOT Data Quality Management Program resulting from replacement of the roadway evaluation system.

The Data Quality Management Program (DQMP) contains protocols and processes for collecting and reporting network level pavement data. According to the DQMP, the vendor of the new profiler is required to certify, prior to delivery, the longitudinal profile and roughness measurement at an independent testing facility. The SDDOT also conducts an initial verification of the functionality of the roadway evaluation system. Annual on-site preventive maintenance is to be performed by the vendor. Daily, weekly, and monthly equipment checks are to be performed by SDDOT personnel. The IRI, Rutting, Faulting, and Cracking data is required to be tested weekly and certified annually.

The recommend changes to the DQMP caused by the replacement of the Pathway roadway evaluation system are the following:

- Measurement spacing for rutting verification should be changed to 33 ft. in the longitudinal direction as specified in AASHTO R 48-10 for the 3.1.7 Rutting Data Validation section.
- The mention of FUGRO's Pave3D system should be changed to 3D system in the 3.1.8 Faulting Data Validation section.
- The mention of LCMS should be changed to 3D system in the following sections:
    - 3.1.3 Annual On-Site Preventative Maintenance
    - 3.1.8 Faulting Data Validation
    - 3.1.10 Images
    - 3.1.11 Summary of Equipment Certification/Quality Control

4.10 Prepare Final Report

In conformance with Guidelines for Performing Research for the South Dakota Department of Transportation, prepare a final report summarizing the research methodology, findings, conclusions, and recommendations.

The researcher documented the work done in the project in a final report summarizing the project motivation, objectives, tasks, findings, and conclusions. The final report conforms to SDDOT's *Guidelines for Performing Research for the South Dakota Department of Transportation* and includes implementation recommendations concerning use of the roadway evaluation system.

4.11 Make Executive Presentation

Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

The researcher prepared and gave a presentation to SDDOT's Research Review Board on April 26, 2021. Presentations to other groups will be offered at the direction of the project's technical panel.

5.0 FINDINGS AND CONCLUSIONS

5.1 Pavement Roughness, Rutting, Cracking, and Faulting Certification

Figure 1 shows the different components of the Pathway roadway evaluation system. The roadway evaluation vehicle's inertial profiling system, which is based on vertical accelerometers and laser height sensors, measures longitudinal profile in the left and right wheel paths. The inertial profiling system sensors are located at the rear of the vehicle for both the left and right wheel paths and spaced at 66 inches apart. The 3D Pavement Condition Data Acquisition System, which consists of the 3D camera and two lasers also at the rear of the vehicle, is used to acquire rutting, faulting, and cracking data.

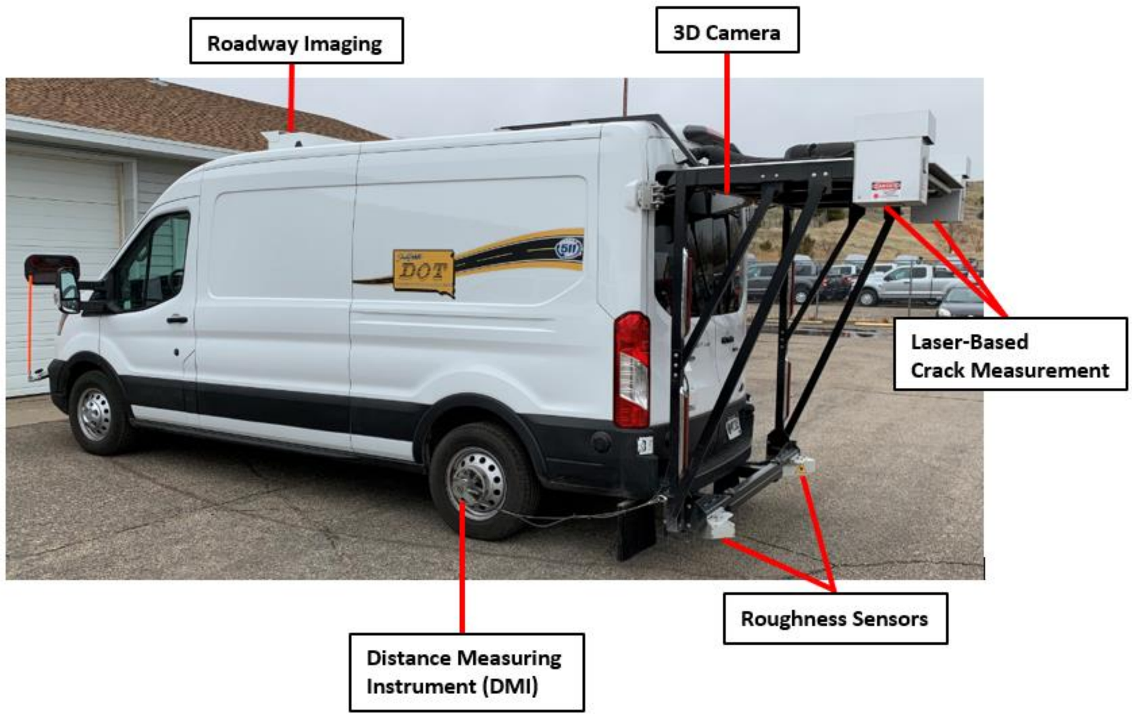

Figure 1: PATHWAY ROADWAY EVALUATION SYSTEM

5.1.1 Pavement Roughness Certification

Figure 2: ROUGHNESS MEASUREMENTS WITH SURPRO

The Emergency Vehicle Operator Course (EVOC) located near Pierre was the site used to perform roughness certification. This is the same site that was used in 2018 and 2019 for the pavement roughness certification of the FUGRO roadway evaluation system. A 528' test section on the course was measured and marked before testing. The SurPRO pavement profiler was used as the IRI baseline to compare to both the new (Pathway) and old (FUGRO) roadway evaluation systems. For both the right and left wheel paths, five passes were made with the SurPRO. The profiles generated by the SurPRO were loaded onto ProVAL 3.61 and filtered with a Butterworth High Pass Filter with a 300' cut off wavelength. Ten passes were made with the Pathway roadway evaluation system at 55 mph and five passes were made at 35 mph. Five passes were made with the FUGRO roadway evaluation system at 55 mph. The profiles for the SurPRO and the Pathway roadway evaluation system can be found in Appendix A.

According to the SDDOT Data Quality Management Program, the average IRI value of the five runs on a test section must be within 5% of the baseline IRI value. In addition, the repeatability of the five runs must be within 5%. Also, according to AASHTO R-56, concerning equipment repeatability and for IRI values less than 150 in./mi, an agreement score of 92% is required. For equipment accuracy, an agreement score of 90% is required for the cross-correlation of ten profiles to the baseline profile.

As shown in Figure 3, the lowest repeatability between any of the two runs for the left wheel path of the Pathway system was 94.54% and the accuracy of the cross-correlation of the Pathway system with the SurPRO was greater than 90% for all ten runs with the Pathway roadway evaluation system.

Profiler Certification: Summary Results

Statistics

Statistic	Repeatability - Left	Repeatability - Right	Accuracy - Left
Comparison Count	45	45	10
% Passing	100.00	100.00	100.00
Mean	97.49	96.36	92.49
Minimum	94.54	93.54	91.13
Maximum	99.17	98.87	93.80
Standard Deviation	0.9	1.6	0.9
Grade	Passed	Passed	Passed

Accuracy

Run	Left
1	92.99
2	92.77
3	92.63
4	91.14
5	93.80
6	92.37
7	91.89
8	91.13
9	92.55
10	93.63

Repeatability - Left Correlations (%)

Run	2	3	4	5	6	7	8	9	10
1	97.72	98.60	97.08	97.85	96.21	98.16	97.99	97.06	96.63
2		97.76	96.88	97.62	97.74	97.58	95.58	97.60	97.57
3			98.40	98.61	96.30	99.17	97.99	97.78	97.38
4				98.26	96.27	98.19	97.83	98.21	97.84
5					96.90	97.92	97.26	97.90	98.20
6						96.72	94.54	97.53	98.12
7							97.59	98.14	97.60
8								96.38	96.08
9									98.47

Repeatability - Left Offsets (ft)

Run	2	3	4	5	6	7	8	9	10
1	-0.2	-0.2	-0.2	0.0	0.0	-0.3	-0.1	-0.1	-0.1
2		-0.1	0.0	0.0	0.0	-0.1	0.0	0.0	0.0
3			0.0	0.1	0.1	-0.1	0.0	0.0	0.0
4				0.0	0.0	-0.1	0.0	0.0	0.0
5					0.0	-0.3	-0.1	-0.1	-0.1
6						-0.3	-0.1	-0.1	-0.1
7							0.1	0.1	0.1
8								0.0	0.0
9									0.0

Repeatability - Right Correlations (%)

Run	2	3	4	5	6	7	8	9	10
1	97.49	98.84	95.93	98.34	93.74	96.54	97.36	93.96	94.44
2		97.16	94.64	97.52	94.23	96.30	95.38	94.04	95.15
3			96.83	98.87	93.78	97.56	97.78	94.66	94.95
4				97.59	95.63	98.40	97.69	96.80	96.96
5					94.58	97.88	98.38	95.56	96.04
6						96.29	93.54	97.94	97.97
7							96.99	97.24	97.31
8								94.71	94.98
9									98.41

Repeatability - Right Offsets (ft)

Run	2	3	4	5	6	7	8	9	10
1	-0.1	-0.2	-0.1	0.0	0.0	-0.2	-0.1	-0.1	-0.1
2		0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0
3			0.0	0.0	0.1	0.0	0.0	0.0	0.0
4				0.0	0.0	-0.1	0.0	0.0	0.0
5					0.0	-0.2	-0.1	0.0	-0.1
6						-0.2	-0.1	-0.1	-0.1
7							0.0	0.1	0.0
8								0.0	0.0
9									0.0

Figure 3: SURPRO AND PATHWAY SYSTEM AT 55 MPH CROSS-CORRELATION (LEFT WHEEL PATH)

As shown in Figure 4, the lowest repeatability between any of the two runs for the right wheel path of the Pathway system was 93.54% and the accuracy of the cross-correlation of the Pathway system with the SurPRO was greater than 90% for all ten runs with the Pathway roadway evaluation system.

Profiler Certification: Summary Results

Statistics

Statistic	Repeatability - Left	Repeatability - Right	Accuracy - Right
Comparison Count	45	45	10
% Passing	100.00	100.00	100.00
Mean	97.49	96.36	92.88
Minimum	94.54	93.54	90.60
Maximum	99.17	98.87	94.65
Standard Deviation	0.9	1.6	1.4
Grade	Passed	Passed	Passed

Accuracy

Run	Right
1	91.37
2	94.05
3	93.56
4	94.65
5	92.06
6	94.25
7	90.60
8	93.52
9	92.97
10	91.76

Repeatability - Left Correlations (%)

Run	2	3	4	5	6	7	8	9	10
1	96.63	97.57	97.38	97.84	98.20	98.12	97.60	96.08	98.47
2		97.72	98.60	97.08	97.85	96.21	98.16	97.99	97.06
3			97.76	96.88	97.62	97.74	97.58	95.58	97.60
4				98.40	98.61	96.30	99.17	97.99	97.78
5					98.26	96.27	98.19	97.83	98.21
6						96.90	97.92	97.26	97.90
7							96.72	94.54	97.53
8								97.59	98.14
9									96.38

Repeatability - Left Offsets (ft)

Run	2	3	4	5	6	7	8	9	10
1	0.0	0.0	-0.1	0.0	0.0	0.0	-0.2	0.0	0.0
2		-0.2	-0.2	-0.2	0.0	0.0	-0.3	-0.1	-0.1
3			-0.1	0.0	0.0	0.0	-0.1	0.0	0.0
4				0.0	0.1	0.1	-0.1	0.0	0.0
5					0.0	0.0	-0.1	0.0	0.0
6						0.0	-0.3	-0.1	-0.1
7							-0.3	-0.1	-0.1
8								0.1	0.1
9									0.0

Repeatability - Right Correlations (%)

Run	2	3	4	5	6	7	8	9	10
1	94.44	95.15	94.95	96.96	96.04	97.97	97.31	94.98	98.41
2		97.49	98.84	95.93	98.34	93.74	96.54	97.36	93.96
3			97.16	94.64	97.52	94.23	96.30	95.38	94.04
4				96.83	98.87	93.78	97.56	97.78	94.66
5					97.59	95.63	98.40	97.69	96.80
6						94.58	97.88	98.38	95.56
7							96.29	93.54	97.94
8								96.99	97.24
9									94.71

Repeatability - Right Offsets (ft)

Run	2	3	4	5	6	7	8	9	10
1	0.0	0.0	-0.1	0.0	0.0	0.0	-0.1	0.0	0.0
2		-0.1	-0.2	-0.1	0.0	0.0	-0.2	-0.1	-0.1
3			0.0	0.0	0.0	0.0	-0.1	0.0	0.0
4				0.0	0.0	0.1	0.0	0.0	0.0
5					0.0	0.0	-0.1	0.0	0.0
6						0.0	-0.2	-0.1	0.0
7							-0.2	-0.1	-0.1
8								0.0	0.1
9									0.0

Figure 4: SURPRO AND PATHWAY SYSTEM AT 55 MPH CROSS-CORRELATION (RIGHT WHEEL PATH)

As shown on Table 2, the average IRI for the ten runs at 55 mph with the Pathway roadway evaluation system is within 3.75% of the average IRI from the SurPRO. The average IRI for the best five runs with the Pathway system is within 2.89% of the average IRI from the SurPRO.

Table 2: IRI CERTIFICATION FOR LEFT WHEEL PATH

	2020 Certification IRI LWP Values						
	LWP @ 35mph				LWP @ 55mph		
Runs	SurPRO	Pathway	FUGRO		SurPRO	Pathway	FUGRO
1	146.87	146.26	150.67		145.10	138.62	154.79
2	145.33	144.72	150.61		146.87	140.52	156.29
3	144.76	143.90	152.56		145.33	138.85	156.58
4	144.89	144.74	153.52		144.76	138.97	153.30
5	145.10	146.59	153.65		144.89	139.96	158.69
6						142.28	
7						138.50	
8						138.53	
9						141.37	
10						141.84	
Average	145.39	145.24	152.20		145.39	139.94	155.93
% Diff compared to SurPRO		-0.10%	4.69%			-3.75%	7.25%
5 Best						141.19	
% Diff of Best 5 runs						-2.89%	
Pathway compared to FUGRO		-4.57%				-10.25%	

As shown in Table 3, the average IRI for the ten runs at 55 mph with the Pathway roadway evaluation system is within 5.07% of the average IRI from the SurPRO. The average IRI for the best five runs with the Pathway system is within 4.23% of the average IRI from the SurPRO.

Table 3: IRI CERTIFICATION FOR RIGHT WHEEL PATH

	2020 Certification IRI RWP Values						
	RWP @ 35mph				RWP @ 55mph		
Runs	**SurPRO**	**Pathway**	**FUGRO**		**SurPRO**	**Pathway**	**FUGRO**
1	**160.93**	**152.39**	**170.27**		**160.93**	**155.97**	**165.33**
2	**162.68**	**155.09**	**169.25**		**162.68**	**154.94**	**163.04**
3	**162.61**	**155.22**	**166.62**		**162.61**	**156.16**	**162.52**
4	**163.63**	**156.97**	**167.37**		**163.63**	**154.70**	**165.57**
5	**163.47**	**154.01**	**166.13**		**163.47**	**156.25**	**163.62**
6						**151.60**	
7						**154.21**	
8						**155.60**	
9						**153.01**	
10						**151.78**	
Average	**162.66**	**154.74**	**167.93**		**162.66**	**154.42**	**164.02**
% Diff compared to SurPRO		**-4.87%**	**3.24%**			**-5.07%**	**0.83%**
5 Best						**155.78**	
% Diff of Best 5 runs						**-4.23%**	
Pathway compared to FUGRO		**-7.86%**				**-5.85%**	

The Pathway roadway evaluation system met the requirements as specified in the DQMP and also AASHTO R-56. The IRI values for the Pathway system are slightly lower than the SurPRO and the IRI values for FUGRO system are slightly higher than the SurPRO. It is unknown the reason for this and according to Pathway Services, Inc., this is in line with their previous testing experiences.

5.1.2 Pavement Rutting Certification

Figure 5: RUT MEASUREMENTS WITH LEVEL AND CALIPER

For the pavement rutting certification, the rut depths for the left and right wheel paths were measured every 33’ along a 528’ asphalt concrete test section as specified in AASHTO R 48-10. This test section was located on US HWY 14 east of Pierre and was also used to perform the rutting certification in 2019 with the FUGRO roadway evaluation system. To obtain the baseline rut depth measurements, a 6’ level, caliper, and flat steel piece were used. The flat steel piece was used as a flat surface for the end of the depth gauge on the caliper to rest on in order to measure the distance between the top of the level and the flat surface as shown in Figure 5. The width of the level and thickness of the flat steel piece were subtracted from the measured height to give the depth of rutting.

According to the DQMP, the average rut value for each of the five runs on the test section must be within +/- 0.06 inches of the baseline rut value. In addition, the repeatability of the five runs must be within +/-0.06 inches. As shown on Table 4, the average manually collected rut depth measurements using the straightedge method for the left wheel path depth was 0.06” and the rut depth measured with the roadway evaluation system was 0.07”, which is within +/-0.06”. For the right wheel path, the rut depth measured manually and with the roadway evaluation system was 0.09”. The repeatability of the five runs for the roadway evaluation system were within +/-0.06 inches. Therefore, the system easily passed the rutting certification.

Table 4: RUTTING CERTIFICATION WITH PATHWAY SYSTEM

	LRUT_WIRE	RRUT_WIRE	LRUT_SE	RRUT_SE
Average	0.112	0.119	0.072	0.089
Tolerance +/-	0.060	0.060	0.060	0.060
Standard Deviation	0.006	0.004	0.005	0.005
Average	*0.112*	*0.119*	*0.072*	*0.089*
Number	10	10	10	10
Min	0.098	0.114	0.061	0.081
Max	0.117	0.126	0.075	0.100
Equipment Average =	**0.11**	**0.12**	**0.07**	**0.09**
Manually Collected Average =	**0.06**	**0.09**	**0.06**	**0.09**
	Passed	**Passed**	**Passed**	**Passed**

NOTE: WIRE rutting is used for reporting.

5.1.3 Pavement Faulting Certification

Figure 6: FAULT MEASUREMENTS WITH GEORGIA FAULTMETER

For the pavement faulting certification, a 528' section of jointed concrete pavement (JCP) at Blunt was used. Baseline measurements were taken with a Georgia Faultmeter at 18, 28, 38, 48, and 57 inches from the lane edges on every joint. The faulting measurements were averaged for each wheel path. As clarified in the DQMP, the average fault value of the five runs on the concrete test section are required to be within +/- 0.06 inches of the baseline fault value. As shown on Table 5, the manual measurements were within 0.06 inches of the measurements taken by the system.

Table 5: FAULTING CERTIFICATION WITH PATHWAY SYSTEM

Baseline Average of 36 Joints Height in inches									
Left WP					Right WP				
18	28	38	48	57	57	48	38	28	18
0.025	0.014	0.013	0.011	0.011	0.013	0.021	0.008	0.008	0.011

Equipment Average =	**0.040**	**0.031**
Manually Collected Average =	**0.012**	**0.013**
	Passed	**Passed**

5.1.4 Pavement Cracking Certification

Figure 7: CRACK MEASUREMENTS WITH CALIPER

For pavement cracking certification, a 528' test section of asphalt concrete at EVOC was used. The test section was divided into ten 50' sections with one 28' section. Longitudinal cracks identified within the 39" left and right wheel paths were measured and mapped onto paper as shown in Figure 8.

Tables 6 & 7 give the overall crack lengths and average crack width per 50' section measured manually and with the Pathway roadway evaluation system on the test section at EVOC. All the cracks measured manually were identified by the roadway evaluation system. The roadway evaluation system identified significantly more crack length than manually measured. This was especially noticeable for the left wheel path. Close to 30% more crack length was identified by the roadway evaluation system. After reviewing the pavement images, more crack length should have been measured manually. Due to the pavement condition of the test section at EVOC, it was difficult to determine the cracks. A new site for crack certification should be identified.

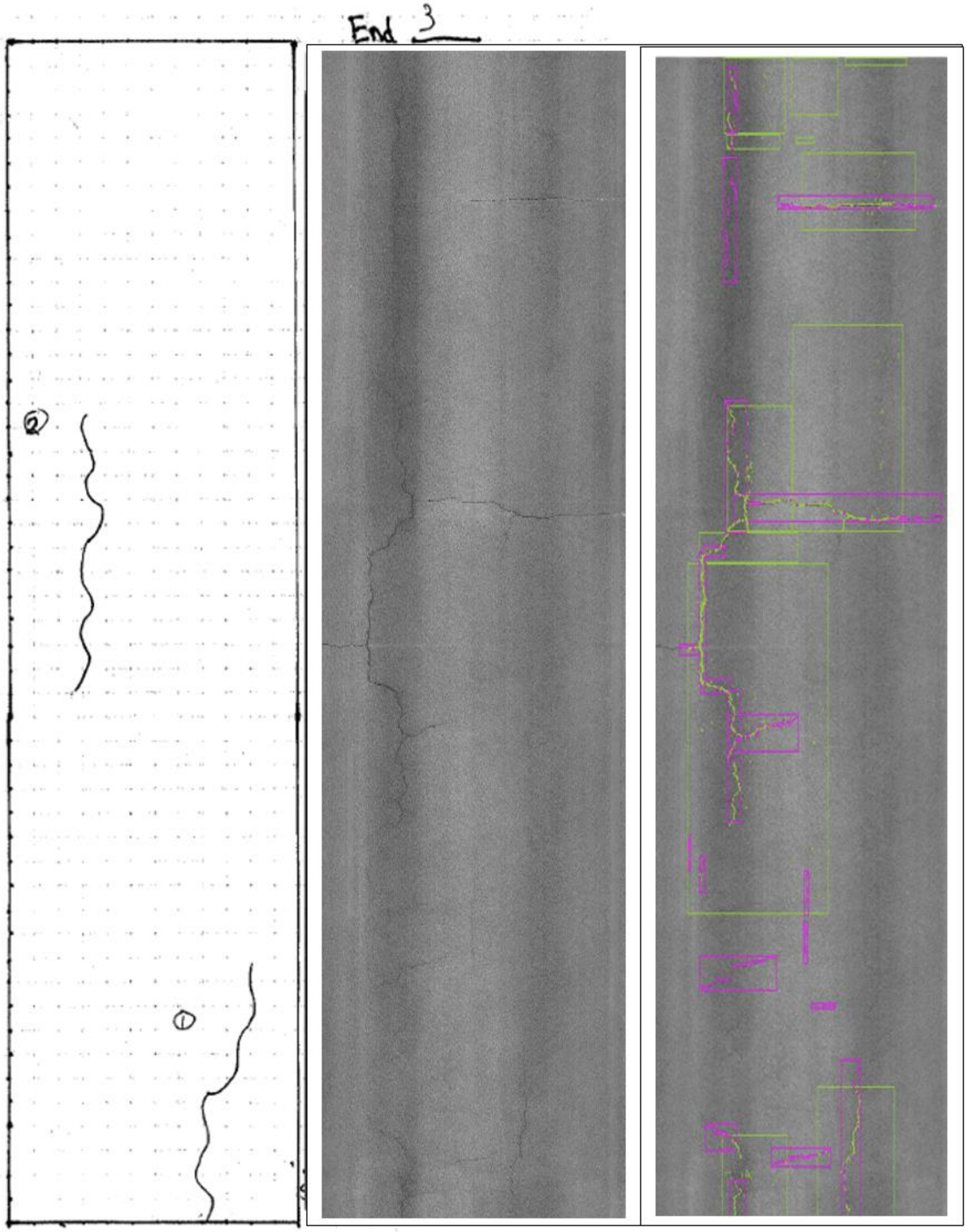

Figure 8: CRACKS COLLECTED MANUALLY VS. CRACKS COLLECTED WITH PATHWAY SYSTEM FOR SECTION 2 TO 3 AT EVOC

Table 6: CRACKS COLLECTED MANUALLY VS. CRACKS COLLECTED BY PATHWAY SYSTEM FOR LWP AT EVOC

	LWP			
	Manual		Pathway System	
Section	Crack Length (in)	Avg Crack Width (in)	Crack Length (in)	Avg Crack Width (in)
0 to 1	0	0	0	0
1 to 2	87	0.16	163.2	0.15
2 to 3	76	0.5	243.6	0.2
3 to 4	0	0	127.2	0.14
4 to 5	51	0.45	54	0.19
5 to 6	207	0.35	218.4	0.19
6 to 7	293	0.435	307.2	0.21
7 to 8	0	0	0	0
8 to 9	188	0.45	158.4	0.17
9 to 10	0	0	0	0
10 to 11	0	0	0	0

Table 7: CRACKS COLLECTED MANUALLY VS. CRACKS COLLECTED BY PATHWAY SYSTEM FOR RWP AT EVOC

	RWP			
	Manual		Pathway System	
Section	Crack Length (in)	Avg Crack Width (in)	Crack Length (in)	Avg Crack Width (in)
0 to 1	0	0	0	0
1 to 2	136	0.36	154.8	0.17
2 to 3	87	0.38	110.4	0.23
3 to 4	0	0	0	0
4 to 5	0	0	0	0
5 to 6	0	0	0	0
6 to 7	188	0.26	162	0.21
7 to 8	29	0.19	18	0.15
8 to 9	0	0	0	0
9 to 10	0	0	0	0
10 to 11	0	0	0	0

5.2 Pavement Roughness, Rutting, Cracking, and Faulting from Network Collection

Tables 8 – 12 give overall pavement ratings for the statewide network based on the data collected with the FUGRO roadway evaluation system in 2019 and the Pathway roadway evaluation system in 2020. When looking at pavement roughness, the percent of pavement considered in the "Good" category for year 2020 was higher than that for year 2019. This is reflected by what was seen during roughness certification. The FUGRO roadway evaluation system provided higher IRI values than the Pathway roadway evaluation system, which would result in more pavements being classified in the "Good" category in 2020. It was also observed that the Pathway system reported greater rut values for certification in 2020 than the FUGRO system had reported for certification in 2019. This matches why the percentage of rutting < 0.2" is lower in 2020 than 2019 for NHS Interstate. All the NHS Interstate for 2020 was collected with the Pathway roadway evaluation system. However, close to 93% of the NHS Non-interstate for 2020 was collected with the Pathway system. Some of the NHS Non-interstate reported in 2020 would have rutting values from the FUGRO system collected in 2019, which could be why the percentage of rutting < 0.2" is higher in 2020 than 2019 for NHS Non-interstate.

Table 8: NHS INTERSTATE (2019-2020) NETWORK COLLECTION FOR ASPHALT

	NHS Interstate (2019-2020)								
	Asphalt								
	IRI			Rutting			Cracking		
		2019	2020		2019	2020		2019	2020
Good	<96	90.1%	94.2%	< 0.20"	76.4%	72.7%	<5	99.2%	99.6%
Fair	96 to 170	8.8%	5.3%	0.20 to 0.40"	23.2%	25.5%	5 to 20	0.5%	0.4%
Poor	> 170	0.8%	0.5%	> 0.40"	0.0%	0.2%	> 20	0.0%	0.0%
No Data		0.3%			0.3%	1.6%		0.3%	0.0%

Table 9: NHS INTERSTATE (2019-2020) NETWORK COLLECTION FOR JCP

	NHS Interstate (2019-2020)								
	Concrete - Jointed								
	IRI			Faulting			Cracking		
		2019	2020		2019	2020		2019	2020
Good	<96	81.0%	80.1%	< 0.10"	99.8%	99.9%	<5	99.6%	99.7%
Fair	96 to 170	17.7%	19.4%	0.10 to 0.15"	0.2%	0.1%	5 to 15	0.4%	0.3%
Poor	> 170	1.2%	0.6%	> 0.15"	0.0%	0.0%	>15	0.0%	0.0%
No Data		0.1%	0.0%		0.0%	0.0%		0.1%	0.0%

Table 10: NHS INTERSTATE (2019-2020) NETWORK COLLECTION FOR CRC

	NHS Interstate (2019-2020)								
	Concrete - Continuously Reinforced								
	IRI			[redacted]			Cracking		
		2019	2020					2019	2020
Good	<96	84.2%	90.9%				<5	94.9%	100%
Fair	96 to 170	15.0%	8.8%				5 to 15	3.8%	0.0%
Poor	> 170	0.5%	0.3%				>15	1.0%	0.0%
No Data		0.3%						0.3%	0.0%

Table 11: NHS NON-INTERSTATE AND NHS FFA (2019-2020) NETWORK COLLECTION FOR ASPHALT

	NHS Non-Interstate and NHS FFA (2019-2020)								
	Asphalt								
	IRI			Rutting			Cracking		
		2019	2020		2019	2020		2019	2020
Good	<96	61.2%	72.3%	< 0.20"	85.0%	90.7%	<5	85.5%	95.4%
Fair	96 to 170	31.1%	24.0%	0.20 to 0.40"	10.9%	6.0%	5 to 20	9.6%	4.0%
Poor	> 170	4.2%	3.3%	> 0.40"	0.5%	0.2%	> 20	1.4%	0.2%
No Data		3.5%	0.4		3.6%	3.0%		3.5%	0.4%

Table 12: NHS NON-INTERSTATE AND NHS FFA (2019-2020) NETWORK COLLECTION FOR JCP

	NHS Non-Interstate and NHS FFA (2019-2020)								
	Concrete - Jointed								
	IRI			Faulting			Cracking		
		2019	2020		2019	2020		2019	2020
Good	<96	54.5%	62.2%	< 0.10"	93.9%	95.8%	<5	90.9%	89.7%
Fair	96 to 170	34.7%	31.2%	0.10 to 0.15"	0.9%	1.1%	5 to 15	2.8%	2.5%
Poor	> 170	5.6%	3.5%	> 0.15"	0.1%	0.1%	> 15	1.1%	1.1%
No Data		5.2%	3.1%		5.1%	3.0%		5.2%	6.7%

5.3 Roadway and Pavement Images

Through the interviews conducted to determine the specifications for the new roadway evaluation system, it was discovered that the images taken by the FUGRO roadway evaluation system were used by several offices. Figures 9-12 were taken by the Pathway roadway evaluation system along US HWY 83 north of Herreid. Figures 9 & 10 were taken with the forward-facing cameras in the front of the vehicle. Figure 11 was taken with the side camera, which is used to see the shoulder area along the side of the road. Figure 12 contains pavement images taken with the 3D system camera. Both the light intensity image and the elevation image are of the same pavement.

Figure 9: CENTER IMAGE ROADWAY EVALUATION SYSTEM JCT US 83 NORTH OF HERREID

Figure 10: LEFT, CENTER, AND RIGHT IMAGE ROADWAY EVALUATION SYSTEM JCT US 83 NORTH OF HERREID

Figure 11: SIDE IMAGE FROM ROADWAY EVALUATION SYSTEM JCT US 83 NORTH OF HERREID

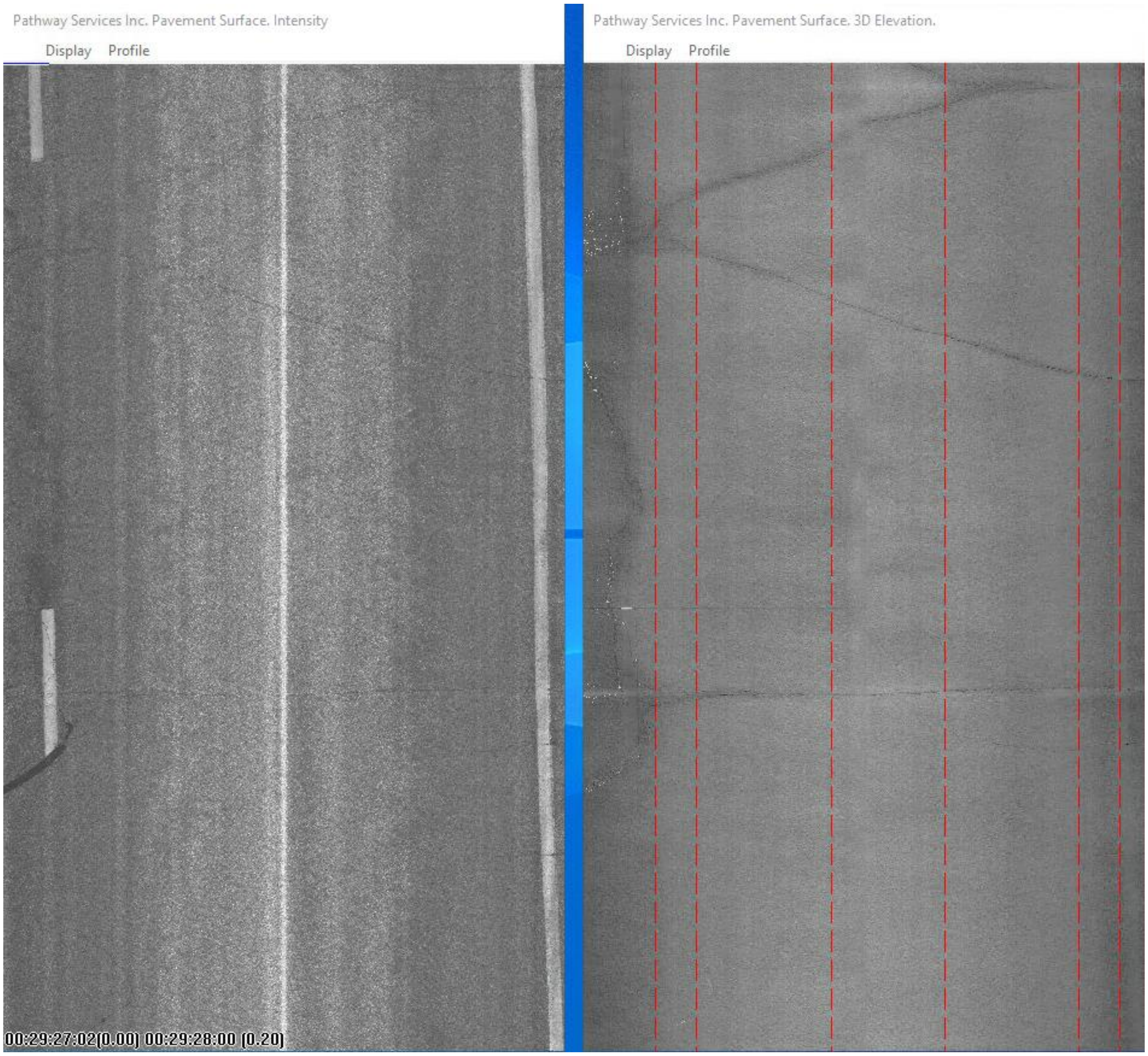

Figure 12: PAVEMENT IMAGES FROM ROADWAY EVALUATION SYSTEM JCT US 83 NORTH OF HERREID

6.0 RECOMMENDATIONS

This section presents the recommendations related to the future use of the SDDOT Roadway Evaluation System. These recommendations were developed based on the findings from Section 5.0 and issues that occurred during the first year of operation with the system.

6.1 Documentation for Operating Roadway Evaluation System

Provide training documentation for operating Roadway Evaluation System

Develop a document outlining operation procedures by building upon resources provided by Pathway Services, Inc. Items included in the document should cover starting up the system equipment, operating the system software, and addressing common reoccurring issues. The training document should be clear enough that someone who has never operated the system will be able to after reviewing the document.

6.2 Documentation for Processing and Reporting Data

Provide training documentation for processing and reporting data generated by Roadway Evaluation System

Create a document outlining the step by step process for extracting and processing data from the roadway evaluation system. The document should include where the data is to be stored on the computers in the SDDOT central office. Guidance should be provided for generating reports to be used for the SDDOT Pavement Management System (PMS) and the Highway Performance Monitoring System (HPMS).

6.3 Improve 3D Automated Crack Rating

Improve the 3D automated crack detection system that is used to identify and classify cracks

Set up a procedure to check cracks identified by the 3D automated crack detection system. This should include manually rating cracks and comparing the manual ratings to ratings provided by the automated crack rating system. Collaboration should also occur with Pathway Services, Inc. to refine algorithms used to identify and rate cracks.

6.4 Annual Certification Sites

Continue to use the same annual certification sites for Roughness, Faulting, and Rutting

EVOC should continue to be used for certifying roughness. Due to the challenges with setting up a testing site for the SurPRO, the site at EVOC has worked very well for roughness certification and should continue to be used. US HWY 14 east of Pierre and through Blunt should continue to be used for rutting and faulting certification. These sites are easy to access from Pierre and data from year to year can be compared. Since there was difficulty measuring cracks at EVOC and new pavement will be installed at EVOC in 2022, the site for cracking certification should be relocated after 2022.

6.5 Update Data Quality Management Program

Update the Data Quality Management Program resulting from replacement of the roadway evaluation system

The recommend changes to the DQMP caused by the replacement of the Pathway roadway evaluation system are the following:

- Measurement spacing for rutting verification should be changed to 33 ft. in the longitudinal direction as specified in AASHTO R 48-10 for the 3.1.7 Rutting Data Validation section.
- The mention of FUGRO's Pave3D system should be changed to 3D system in the 3.1.8 Faulting Data Validation section.
- The mention of LCMS should be changed to 3D system in the following sections:
  - 3.1.3 Annual On-Site Preventative Maintenance
  - 3.1.8 Faulting Data Validation
  - 3.1.10 Images
  - 3.1.11 Summary of Equipment Certification/Quality Control

7.0 RESEARCH BENEFITS

The anticipated benefits of this research are substantial and include:

- specification, acquisition, and validation of equipment that enables the SDDOT to continue to meet federal requirements for pavement roughness, rutting, and faulting measurements;
- specification, acquisition, and validation of equipment that can measure pavement cracking more reliably than previous equipment;
- specification and acquisition of equipment that enables continued acquisition of roadway images;
- potential improvements in the speed and convenience of processing acquired data and sharing it throughout SDDOT

Appendix A: Pathway Roadway Evaluation System vs. SurPRO Profiles

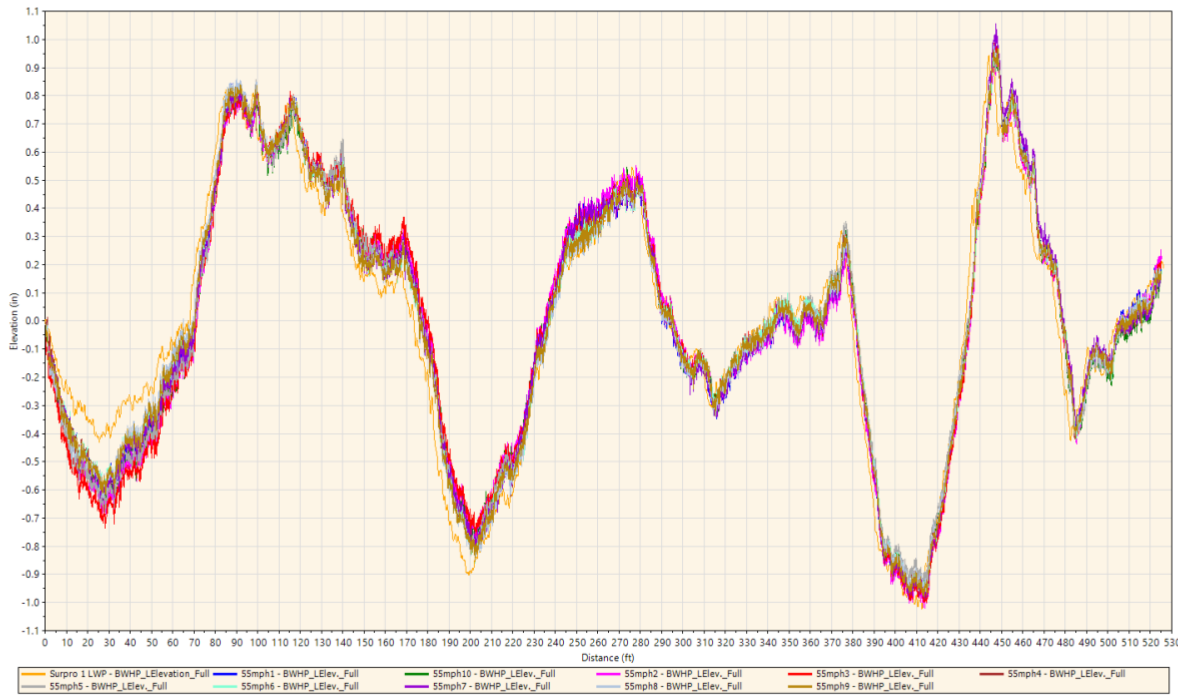

Figure 13: SURPRO VS. PATHWAY SYSTEM AT 55 MPH (LEFT WHEEL PATH)

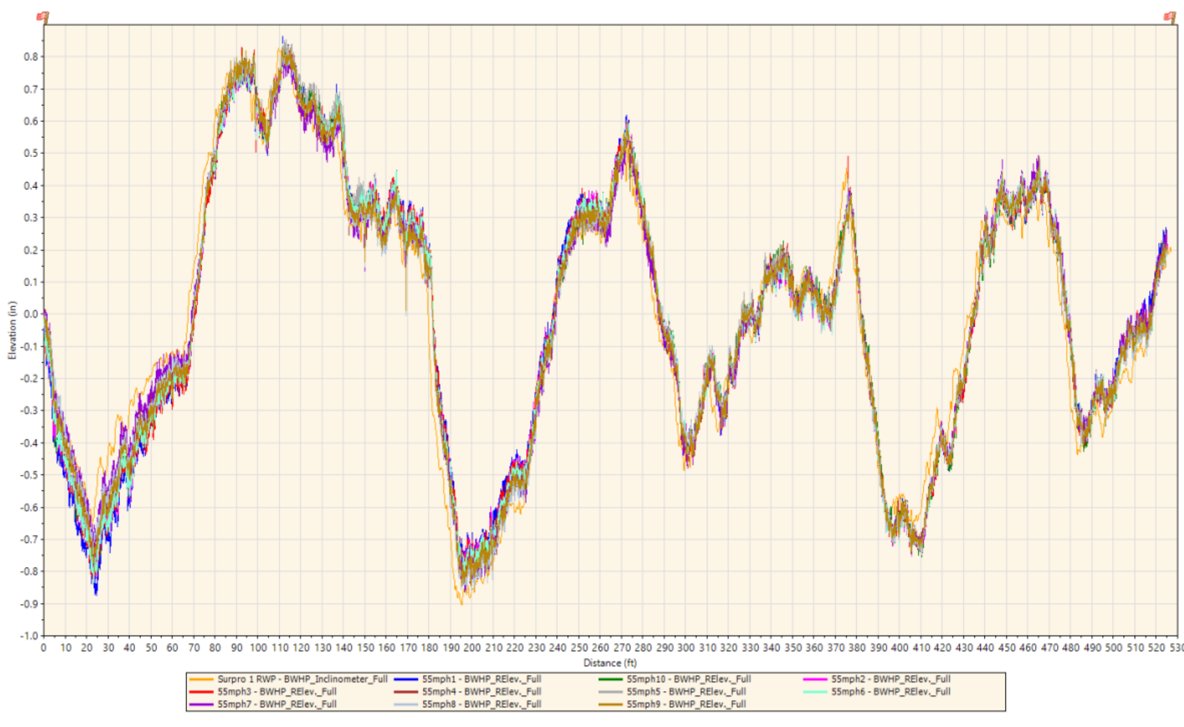

Figure 14: SURPRO VS. PATHWAY SYSTEM AT 55 MPH (RIGHT WHEEL PATH)