
VIRGINIA TECH

# WEBINAR SERIES 1 – CIRCULAR

## TPF-5(385) Pavement Structural Evaluation with Traffic Speed Deflection Devices

### TASK 7: ORGANIZE AND DELIVER WORKSHOPS AND TRAINING MATERIAL

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## Introduction

The Transportation Pooled Fund (TPF-5(385)) is a collaborative effort between the state highway agencies and the Federal Highway Administration (FHWA). The pooled fund started in 2018 and offers the state members the possibility of collecting data using the Traffic Speed Deflectometer Devices (TSDDs). In addition, it allows sharing knowledge and experience regarding the use and application of the TSDDs collected data among state highway agencies.

As part of this sharing experience, the pooled fund organized a series of webinars. A total of six webinars were organized between August 2020 and December 2021 with a total of eight presentations. This document summarized the presentations delivered throughout those six webinars. The summary is presented in chronological order with date, title and presenters of the webinars provided in Table 1. The main topics addressed by each of the six webinars are:

- Webinar 1 topic: Processing of TSD data (1 presentation)
- Webinar 2 topic: Segmentation of TSD data (1 presentation)
- Webinar 3 topic: Integration of TSD data into the pavement management system (2 presentations)
- Webinar 4 topic: Case study implementation of TSD in Idaho (1 presentation)
- Webinar 5 topic: Consultants perspective on analysis of TSD data (2 presentations)
- Webinar 6 topic: Consultant perspective on analysis of TSD data (1 presentation)

**Table 1: Transport Pooled Fund Program [TPF-5(385)] _Summary Webinars**

| Webinar No. | Date | Title | Presenter(s) | Presenter(s) Organisation(s) |
|---|---|---|---|---|
| 1 | 08/17/2020 | Demonstration of TSD Data Extraction and Processing Tool | Senthil Thyagarajan Ph.D., P.E. | Transportation Engineer. Maintenance Division. TxDOT |
| 2 | 10/29/2020 | Pavement Data Segmentation | Samer Katicha Ph.D., P.E. | Virginia Tech Transportation Institute |
| 3.1 | 03/17/2021 | Network Level TSD Implementation Case Studies. Review of current status from TxDOT | Jenny Li Ph.D., P.E. | Texas DOT |
| 3.2 | 03/17/2021 | Traffic Speed Deflectometer Device (TSDD) Data In Pavement Management System | Charles Pilson; Eric Perrone; Aaron Gerber | The Kercher Group |
| 4 | 05/19/2021 | Implementation of Traffic Speed Deflectometer in Idaho | Ken Maser, Infrasense<br>Nick Weitzel, NCE<br>Samer Katicha, VTTI<br>Jim Poorbaugh, ITD | Infrasense / NCE / VTTI / ITD |
| 5.1 | 08/25/2021 | Comparison of TSDD and FWD Interstate 64 Westbound. James City and York Counties, VA | Amy Simpson, Ph.D., P.E. | Wood |
| 5.2 | 08/25/2021 | New Mexico TSD. Data Analysis Results | Linda Pierce, PhD, PE<br>Nick Weitzel, PE | NCE |
| 6 | 12/08/2021 | Implementation of Traffic Speed Deflectometer Data into the Pavement Management System | Amir Arshadi, PhD, PE<br>Mirkat Oshone, PhD, PE Gerhard du Toit, PE | AECOM |

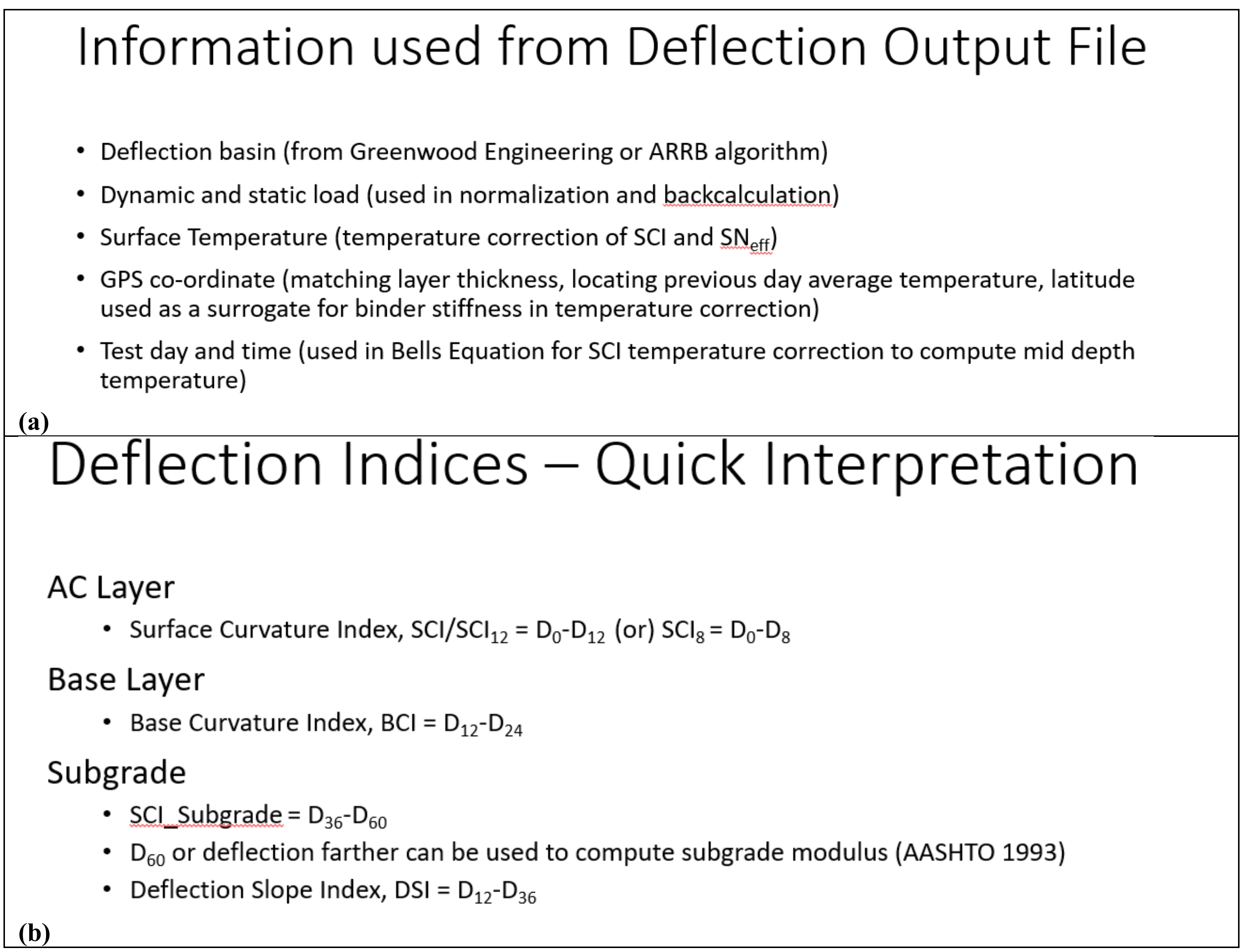
## Demonstration of TSD Data Extraction and Processing Tool


**Senthil Thyagarajan, Ph.D., P.E.**

Transportation Engineer. Maintenance Division. TxDOT


Dr. Thyagarajan's presentation demonstrated, using a case study, the use of an excel spreadsheet tool to analyse TSD data. The tool has a graphical interface to import TSD measurements and Ground Penetrating Radar (GPR) data and matches the two datasets based on GPS coordinates. The tool can then be used to perform temperature correction of the deflection measurements, and calculate: 1) pavement deflection indices, 2) pavement effective structural number (SNeff), and 3) layer moduli using the WesLEA software (see Figure 1).

Three different deflection basin indices are calculated: $SCI_{12} = D_0 - D_{12}$ to characterize the strength of the asphalt layer, $BCI = D_{12} - D_{24}$ to characterize the strength of the base layer, and SCI_Subgrade = D36 – D60 to characterize the strength of the subgrade. The effective structural number is estimated using the Rhode equation calibrated for TSD measurements. The tool also calculates the required structural number (SNreq) for a design period of 20 years using the AASHTO 1993 method, based on truck traffic information provided as an input. Finally, using the SNeff and SNreq, the tool calculates the structural condition index defined as the relationship of SNeff/SNreq [see Figure 1, from (a) to (f)].



# Temperature Corrected, $SCI_{12}$

$$\lambda = \frac{SCI_{Ref}}{SCI_{TSD}} = \frac{10^{-0.05014T_{Ref}+0.019049T_{Ref}log(h_{AC})log(\varphi)}}{10^{-0.05014T+0.019049Tlog(h_{AC})log(\varphi)}}$$

where

$\lambda$ = Temperature adjustment factor

$SCI_{TSD}$ = SCI computed from TSD and normalized to standard load

$SCI_{Ref}$ = Adjusted $SCI_{TSD}$ at reference temperature

$T_{Ref}$ = Reference temperature, ° C

$T$= Mid-depth AC layer temperature at time of measurement, ° C
(computed using Bells equation code available in https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/98085/tempred.cfm)

$h_{AC}$= Asphalt Concrete layer thickness, mm

$\Phi$ = Latitude of measurement location (within 30 to 50 degrees) as a surrogate for asphalt stiffness

Required Additional Inputs:

- Previous day average temperature to find mid-depth temperature using Bells Equation and surface temperature (https://gis.ncdc.noaa.gov/maps/ncei/summaries/daily)
- AC layer thickness

From Nasimifar, M., Chaudhari, S., Thyagarajan, S., & Sivaneswaran, N. (2018) Temperature adjustment of Surface Curvature Index from Traffic Speed Deflectometer measurements, International Journal of Pavement Engineering, DOI: 10.1080/10298436.2018.1546858

**(c)**

# Effective Structural Number (Rhode Equation)

$SN_{eff} = C_1 SIP^{C_2} H_p^{C_3}$ $(Recalibrated\ from\ Rhode\ equation\ for\ FWD)$

SIP = structural index of pavement (µm) from TSD data;

$SIP = D_0 - D_{1.5H_P}$

- $D_0$ = peak deflection under a standard 40-kN (9,000-lb) FWD load;
- $D_{1.5Hp}$ = surface deflection measured at offset of 1.5 times $H_p$ under standard 40-kN (9,000-lb) FWD impulse load.
- $H_p$ = total pavement thickness (mm); and
- $C_1 = 0.4369$; $C_2 = -0.4768$; $C_3 = 0.8182$

Required Additional Inputs:

- Total pavement thickness, $H_p$ above subgrade
- Temperature correction for $D_0$ to 68F

from Nasimifar, M., Thyagarajan, S., Chaudhari, S., & Sivaneswaran, N. (2019). Pavement Structural Capacity from Traffic Speed Deflectometer for Network Level Pavement Management System Application. Transportation Research Record, 2673(2), 456–465. https://doi.org/10.1177/0361198118825122

**(d)**

# Temperature Adjustment Factor for $D_0$

From AASHTO 1993,

- Reference temperature 68°F
- Curves converted to equation

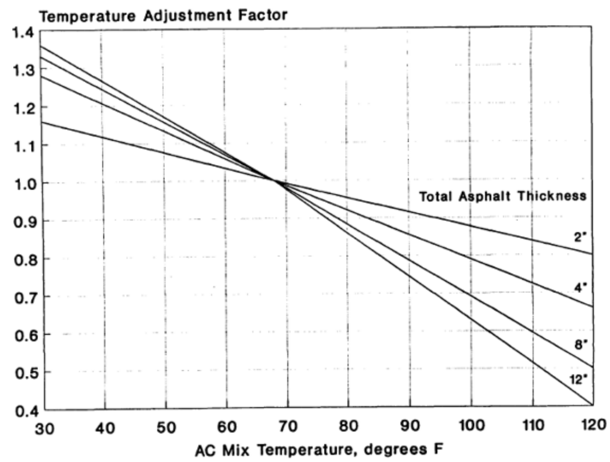



Figure I.5.4. $d_0$ Adjustment for AC Mix Temperature for Granular and Asphalt-Treated Base Pavements

**(e)**

# TxDOT Structural Condition Index

$$structural\ condition\ index, SCI = \frac{SN_{Eff}}{SN_{Req}}$$

- $SN_{eff}$ from recalibrated Rhode's equation
- $SN_{Req}$ based on
  - estimated 20-year Equivalent Single Axle Loads (ESALs) for the route, and
  - subgrade modulus ($M_R$)
- Subgrade Modulus computed from $D_{72}$ using AASHTO 1993

**Required Additional Inputs:**

Estimation of

- 20-year ESALs
- Mr
- SNreq

**(f)**

**Figure 1: Input Deflection Data and Deflection Indices Interpretation**

Dr. Thyagarajan used a sample TSD data file to illustrate the use of the excel spreadsheet tool. Before extracting the data to the Excel workbook, the format is verified, and all required changes are conducted (see Figure 2a and 2b).

## Workbook Outline

- ‘Input’ – main worksheet that contain the command button to extract and analyze data. Also contains input default values.
  - Make changes as required.
- ‘OutputFormat’ – contains outline of the calculations. The code will copy the content of this worksheet to the imported deflection worksheet.
  - Changes are required only if additional indices/parameters are appended
- ‘Defl_File_Format’ – Contains the location reference for the required data in the TSD deflection file.
  - Update the column location if the TSD deflection file format changes.
- ‘LEA’ – contains backcalculation worksheet.
  - Changes are not required.

**(a)**

## Pre-analysis Check

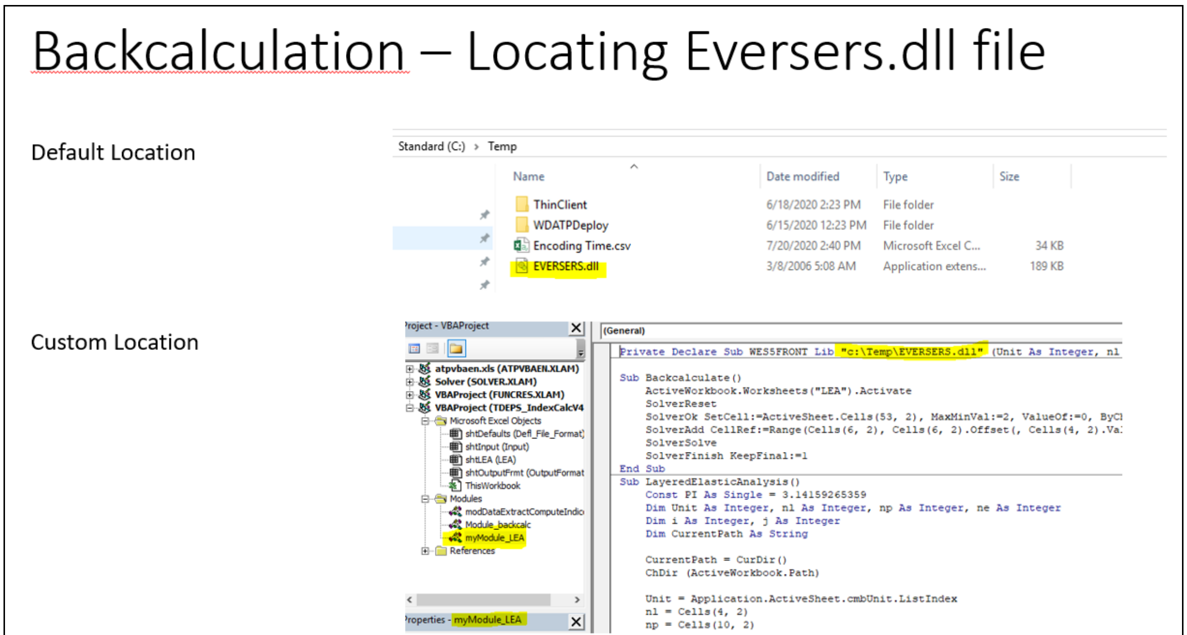
Before extracting data,

- Verify the deflection worksheet is the first worksheet.
- Verify the data format and make any required changes to the “Defl_File_Format” worksheet.
  - Verify if the column numbers next to each column in ‘Defl_file_format’ worksheet match the column location for the key variables in the deflection file.
- Extract previous day average temperature for the test route from https://gis.ncdc.noaa.gov/maps/ncei/summaries/daily.
- The DLL file ‘EVERSERS.dll’ required for backcalculation should be placed in c:\Temp\EVERSERS.dll

**(b)**

**Figure 2: Excel workbook outline and pre-analysis checks**

Figure 3a shows the backcalculation Visual Basic Module that connects the Eversers.dll file, the input worksheet (Figure 3b), the approach followed to obtain the previous day average temperature needed to perform temperature correction (Figure 3c), and the deflection file format (Figure 3d). Figure 4a, 4b and 4c, detailed the process of how the backcalculation can be performed, and Figure 5 shows the interface worksheet to perform the backcalculation.




**(a) Visual Basic Module to Connect Eversers.dll File**

## Input Worksheet

| | | | |
|---|---|---|---|
| **Deflection File** | C:\Users\STHYAGAR\Documents\TSD\TSD_Deflection_Sample_File.xlsx | Select and Import Deflection Data | Clear All |
| **GPR File Full Name** | C:\Users\STHYAGAR\Documents\TSD\GPR-sample file.xlsx | Select and Import GPR | Export TSD_Data |

| | | | Layer Thickness | |
|---|---|---|---|---|
| **Other Inputs** | Reference Temperature, C | 25.00 | GPR reported Spacing, mile | 0.2 |
| | UTC to Local time conversion, hr | 0.00 | Default AC Layer Thickness, in | 5.0 |
| | Previous day Average Temperature, C | 12.50 | Default Base Thickness, in | 9.0 |
| | Static Dual Tire Load, lb | 9000.00 | Default Subbase1 Thickness, in | 0.0 |
| | Reported Dyn Load, lb (Enter 1 for dual tire load, 2 for total axle load) | 1 | Default Subbase2 Thickness, in | |
| | TSD Tire Pressure, psi | 120.00 | Matching Field: Chainage 1, GPS 2 | 1.0 |
| | ESALS | 3,000,000 | | |

GPR reported spacing: If the deflection chainage and closest layer thickness chainage are farther than this GPR reported spacing, the current/default thickness value will be retained.

**(b) Input Worksheet**

## Extracting previous day average temperature

Used in SCI temperature correction (Nasimifar et al. 2018)

1) Go to the website https://gis.ncdc.noaa.gov/maps/ncei/summaries/daily
2) Enter GPS coordinate, previous day (date) of testing and press update map
3) Obtain the previous day average temperature from the station closer to the testing route

**(c) Temperature Correction**

## Defl_File_Format Worksheet

Sample TSD Deflection Worksheet

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 1 | ROAD_SECTION_ID | ROAD_ID | BLOCK_ID | DIRECTION | ROUTE | HEADING | FROM | TO | SECTION_SUB_CHAINAGE_FROM (mi) | SECTION_SUB_CHAINAGE_TO (mi) | SCI_8 | SCI_12 | SCI_SUBGRADE | D0 (mils) | D8 (mils) | D12 (mils) | D18 (mils) |
| 2 | 0183N001 | 0183N | 1 | F | US 183 | NB | SH 80 | TRM 554 | 0.000 | 0.010 | | | | | | | |
| 3 | 0183N001 | 0183N | 1 | F | US 183 | NB | SH 80 | TRM 554 | 0.010 | 0.020 | 2.3 | 3.9 | -1.8 | -13.2 | -10.7 | -9.2 | -7.5 |
| 4 | 0183N001 | 0183N | 1 | F | US 183 | NB | SH 80 | TRM 554 | 0.020 | 0.030 | 2.1 | 3.6 | -1.4 | -11.6 | -9.3 | -7.9 | -6.3 |

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | | | Column Location of column headers in deflection worksheet | | | | |
| 2 | Deflection File | SECTION_SUB_CHAINAGE_FROM (mi) | SECTION_SUB_CHAINAGE_TO (mi) | SCI_8 (mils) | SCI_12 (mils) | SCI_SUBGRADE (mils) | D0 (mils) | D8 (m |
| 3 | | 9 | 10 | 11 | 12 | 13 | 14 |
| 4 | | | | | | | |

Input | TSD_Data | OutputFormat | Defl_File_Format | LEA

Ready

**(d) Deflection File Format**

**Figure 3: Worksheet Configuration**

## Procedure

1. Verify and update the input values in the 'input' worksheets.
2. Use 'Select and Import Deflection Data' command button to Select the deflection file.
    a) The code will copy all the worksheets from the selected file to this workbook.
    b) The first worksheet will the renamed "TSD_Data" and second worksheet will be renamed "Data_Dictionary".
    c) All calculations will be done only in the "TSD_Data" worksheet. The tool computes the indices with default values entered the "input" worksheet when required.
    d) The tool post the relevant computation formula in the worksheet. Thus the user has the option (if preferred) of changing the layer thicknesses and previous day average temperature for each/subgroup of record after data extraction and index computation.

**(a)**

## Layer Thickness

1. The tool uses the default layer thickness (entered in "input" worksheet).
2. Use 'select and import GPR' to import layer thickness from separate workbook
    - thickness data can be either at the interval of the reported deflections or in flexible intervals
    - code will find matching chainage or GPS co-ordinates within distance provided in 'GPR reported spacing'
3. Layer thickness can also be entered manually

**(b)**

## Backcalculation

- WesLEA layered elastic solution
- Optimization uses Excel's Generalized Reduced Gradient (GRG) non-linear method

**(c)**

**Figure 4: Backcalculation Methodology**

## Backcalculation

**BackCalculation**

| | Backcalculation | AC Layer | Base Layer | Subbase Layer | Subgrade | Stiff Layer |
|---|---|---|---|---|---|---|
| **BackCalculation** | Seed Moduli, ksi | 500.00 | 50.00 | 20.00 | 10.00 | 1000.00 |
| | Poison Ratio | 0.35 | 0.40 | 0.40 | 0.40 | 0.25 |

| | | |
|---|---|---|
| **BackCalculation: Data Range** | Minimum Layer Modulus, ksi | 3 |
| | Minimum subgrade Layer Thickness, inch | 12.00 |
| | BackCalculation Interval, every reported value | 500 |
| | Default Subgrade thickness (will be backcalculated), inch | 96.0 |
| | Minimum Stiff layer modulus, ksi | 1000.00 |

AutoBackcalculate | Clear Backcalculated Results

- Last two layers are assumed as
    - both subgrade or
    - subgrade and stiff layer.
- If subbase thickness is provided, the tool combines subbases in to one layer

**Figure 5: Excel workbook Processing Tool for Backcalculation**

The excel workbook processing tool is available at the Pooled Found web site, and Dr. Thyagarajan encouraged all participants to use the spreadsheet and come back to him if there is any question.

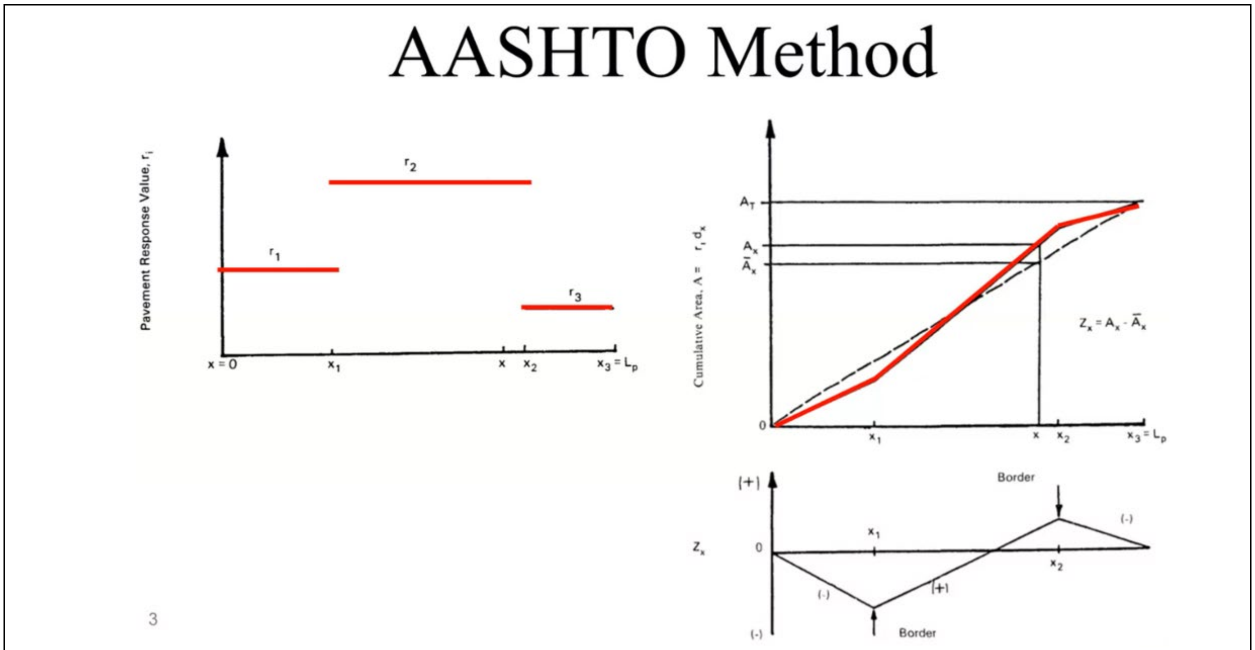
**Samer Katicha, Ph.D., P.E.**

Virginia Tech Transportation Institute (VTTI)

Dr. Katicha presented a MATLAB data segmentation tool, that is based on the AASHTO 1993 cumulative sum (CUSUM) segmentation procedure (also called cumulative difference approach [CDA]). The CUSUM procedure, as described in the AASHTO 1993 guide, selects the locations of changes in the sign of the slope of the CUSUM as the locations defining the boundaries of uniform sections. This leads to the following three drawbacks:

1. The procedure, as described in the AASHTO 1993 guide, fails to differentiate between consecutive homogeneous sections that have an average that is higher or lower than the total average of the data. This is because these consecutive sections will have the same sign for the slope – positive if their average is higher than the overall average and negative if their average is lower than the overall average.
2. Changes in the sign of the slope are very sensitive to small noise-like changes in the data. This results in the AASHTO procedure potentially wrongly identified homogenous sections.
3. The third drawback is a direct consequence of the first two. Because of missing sections that have the same slope sign and the high sensitivity to noise-like features, the AASHTO 1993 procedure is generally used as graphical segmentation procedure. Therefore, it is not suitable for large datasets as these result in narrowly spaced data with relatively smaller sections not visible to the human eye.

The AASHTO Method is shown in Figure 1a and its limitations are illustrated in Figure 1b to 1g.




**(a)**

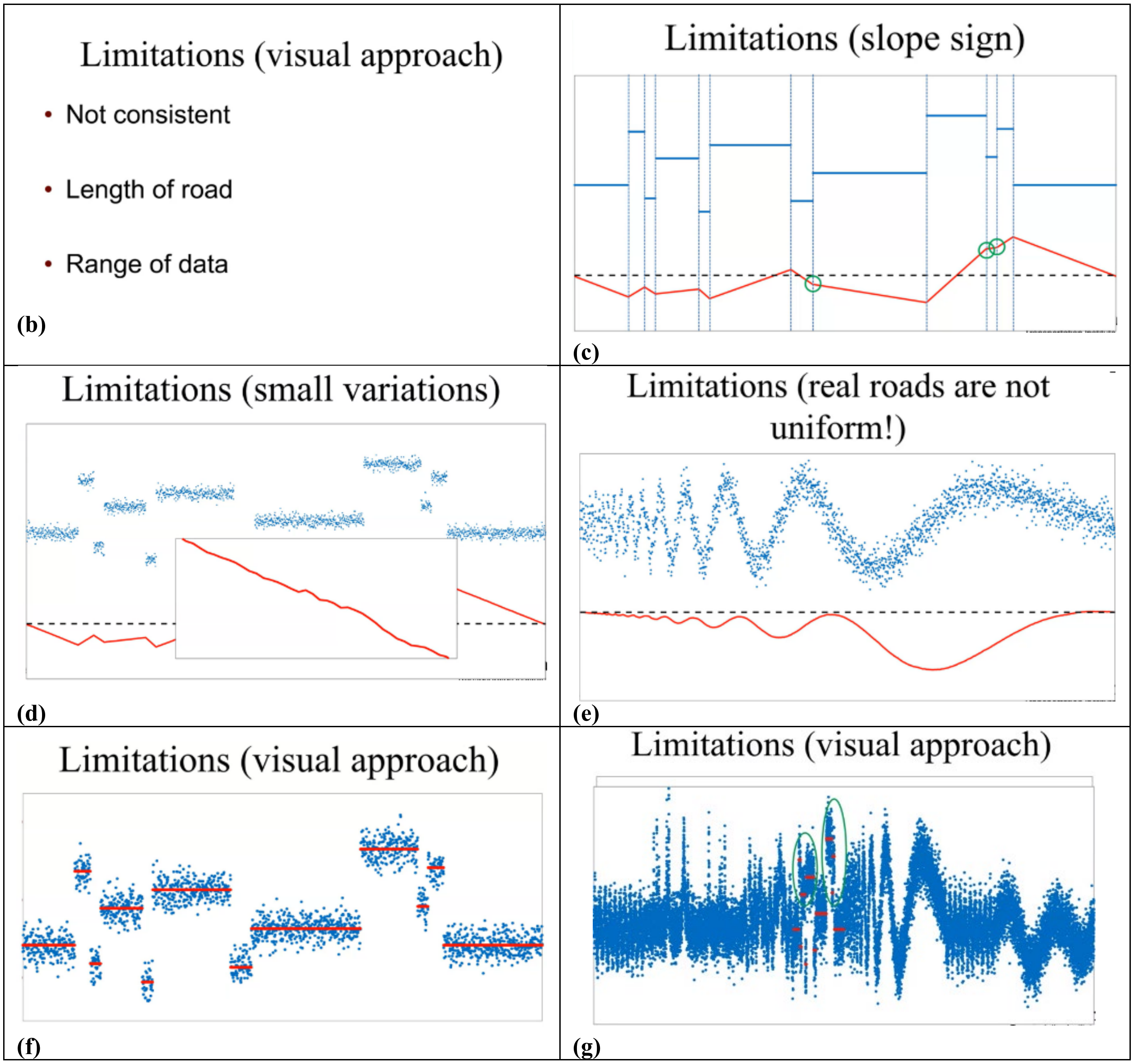



**Figure 1: Method AASHTO-93, CUSUM Analysis. Constraint and Limitations**

Dr. Katicha proposed an iterative procedure that, at each step of the iteration, defines the new segment based on the maximum absolute value of the difference between the CUSUM and the current segmentation. At the first iteration, the whole road being analysed is treated as one segment. The iterative procedure is illustrated in Figure 2a to 2d. In Figure 2c the CUMSUM is shown in the blue solid line and the segmentation in the black dashed line. The black dashed line shows that at this stage of the iteration, four segments are defined. The next point that defines the new section will be the location where the difference between the blue full solid line and the black dashed line is at its maximum. The user can define the total number of iterations to be performed along with two optional parameters which are the minimum segment length and the minimum difference between adjacent sections. If any of the two optional parameters is defined, then the parameter can be used as the stopping criterion rather than the total number of iterations.

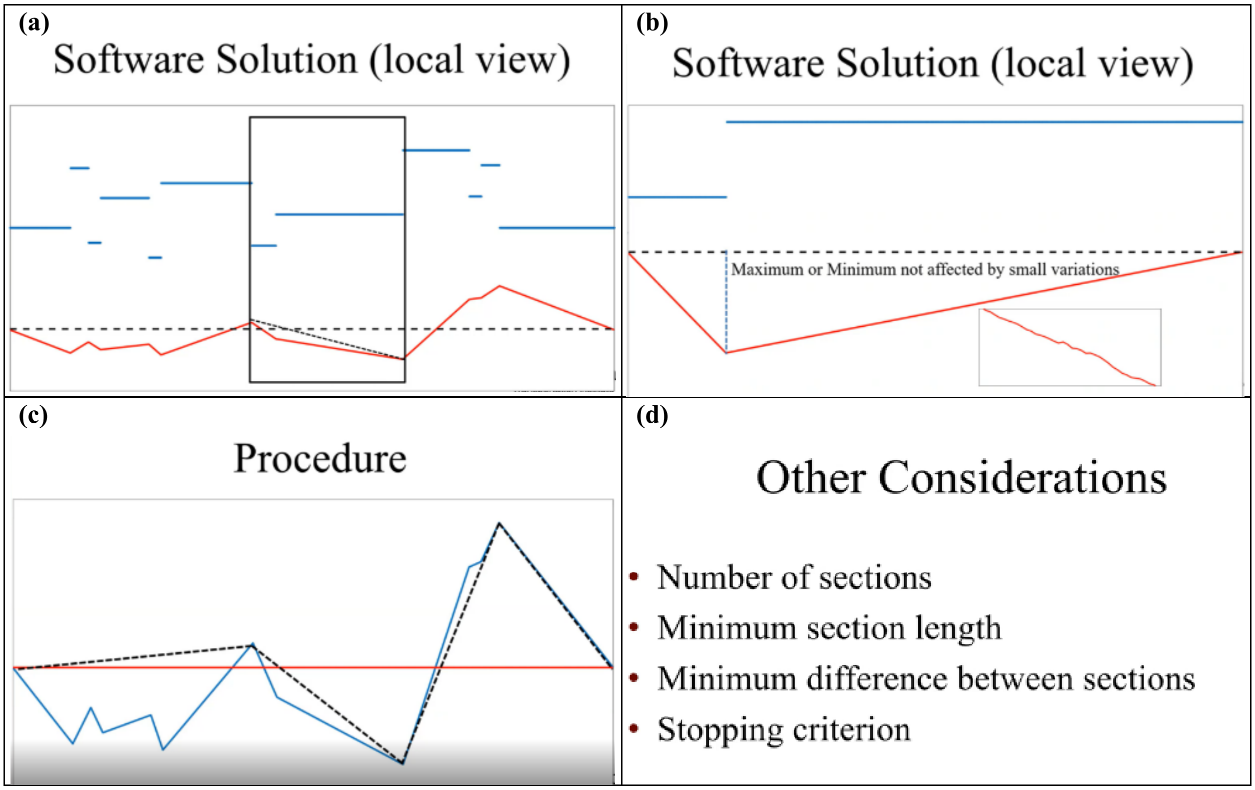
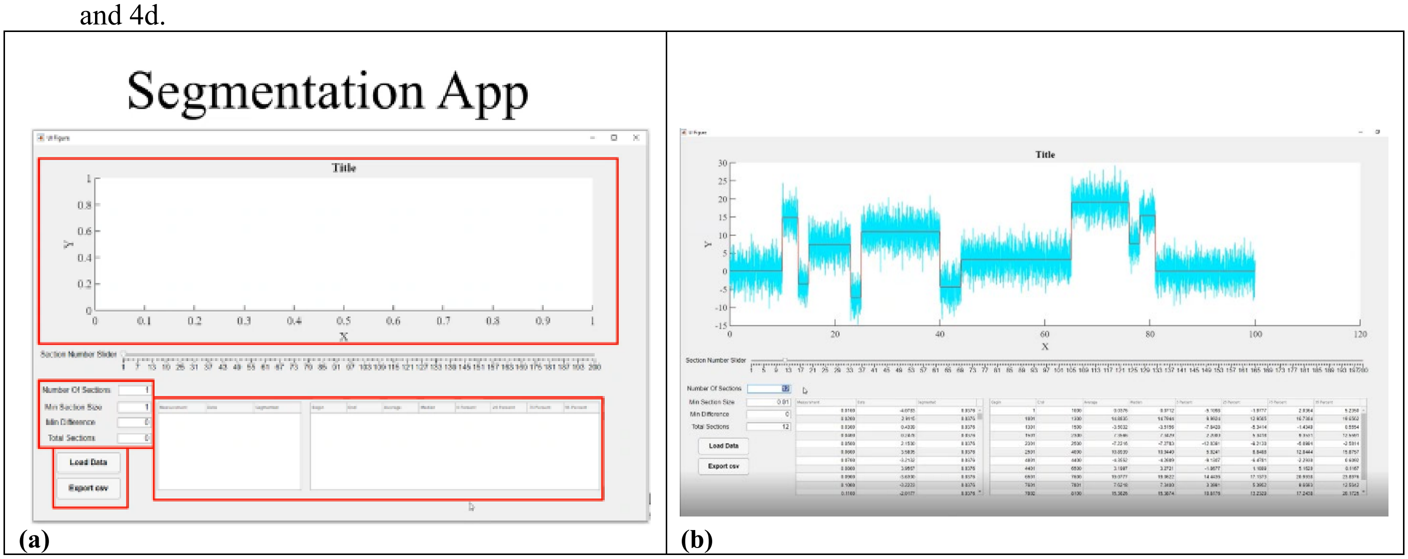
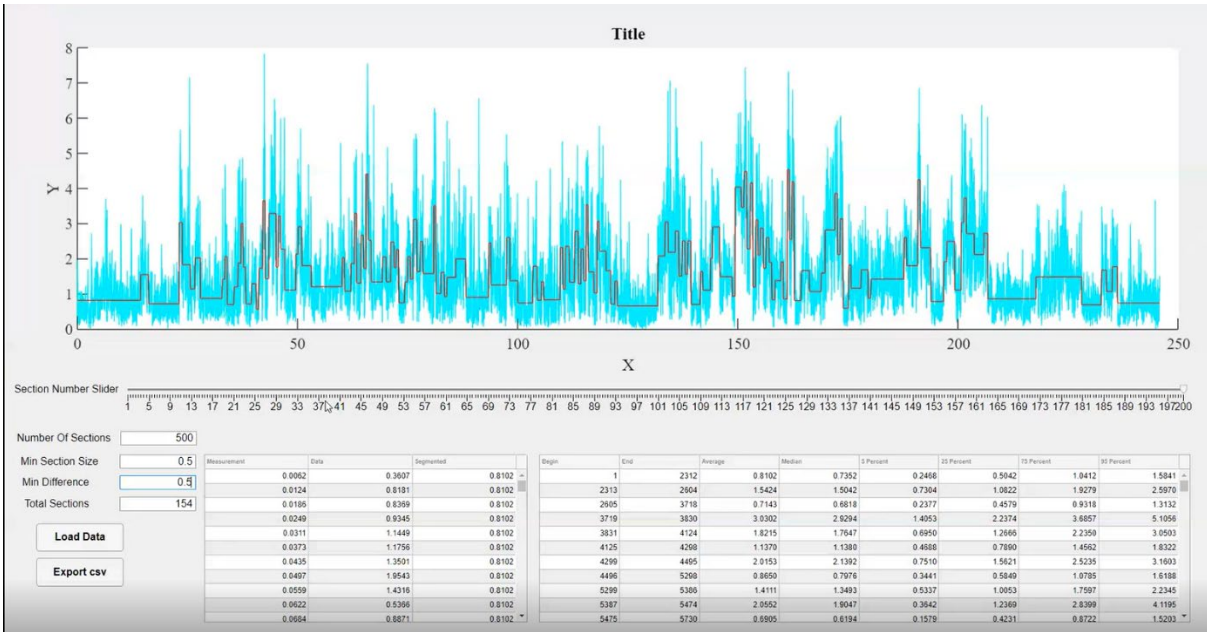



**Figure 2 Segmentation Procedure and Considerations**

Finally, Dr. Katicha presented segmentation results of the tool using simulated examples (see Figure 4a and 4b) and examples of Traffic Speed Deflectometer (TSD) data collected in Virginia and Idaho (Figure 4c and 4d.






**(c) I-81_Virginia TSD Data**


**(d) I-84_Idaho TSD Data**

**Figure 4: Segmentation Tool Application. Sample Data, I-81 (Virginia) and I-84 (Idaho) TSD Data**

## Network Level TSD Implementation Case Studies. Review of current status from TxDOT

**Jenny Li, Ph.D., P.E.**

Texas DOT

Dr. Li presented the current status of TxDOT's efforts to incorporate TSD data into the network-level Pavement Management Information System (PMIS) decision-making process. The presentation was structured in three parts: 1) the reasons to incorporate deflection data into the PMS, 2) how the TSD data was evaluated, and 3) the preliminary implementation of the TSD data into their current PMS tool. Case studies were presented for data comparison and analysis. Different structural indices were considered and a comparison between TSD and FWD data was included. Some limitations and challenges with regards to the availability of FWD and GPR data were discussed, as well as network and project level analyses. Dr. Li ended the presentation showing future challenges and R&D projects for this year.

TxDOT owns and operate 7 FWD units located in 5 regional data collection centers, El Paso and Bryan districts (see Figure 1). These 7 FWD units are used to collected project level FWD data. Network level structural condition data is currently not collected by TxDOT. Therefore, the TxDOT PMIS decision making process is currently based on surface condition data (IRI, rutting, cracking). However, since the early 1990's, the application that TxDOT uses for its PMS is capable of incorporating structural condition data, if such as data is collected. This is shown in Figure 2a for the mainframe used in 1991, and the more recent AgileAsset software adopted in 2016 (Figure 2b).

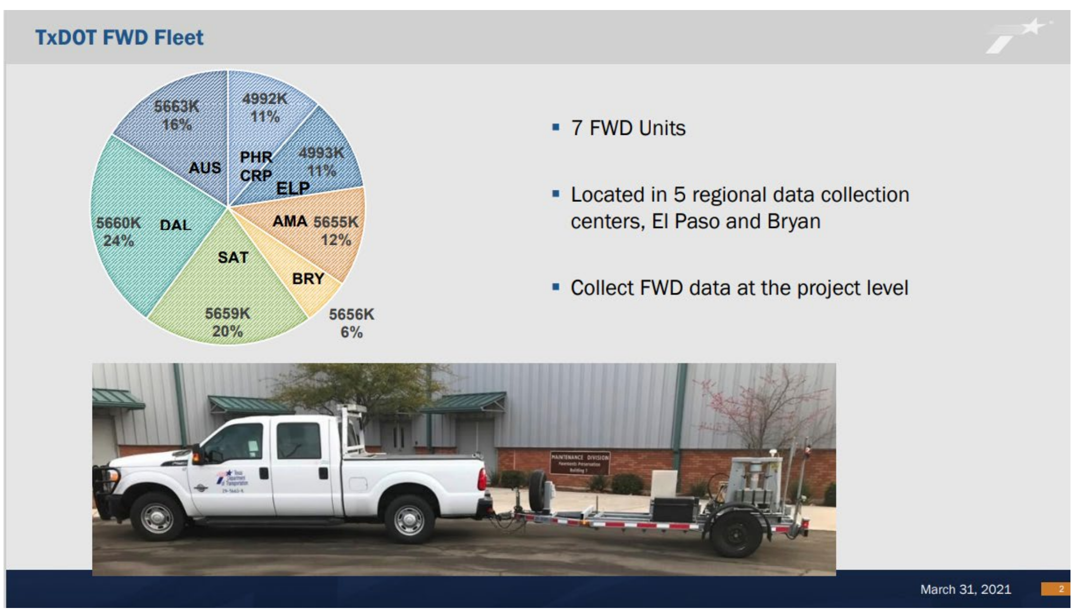



**Figure 1: TxDOT FWD Fleet and District Regions in Percentage**

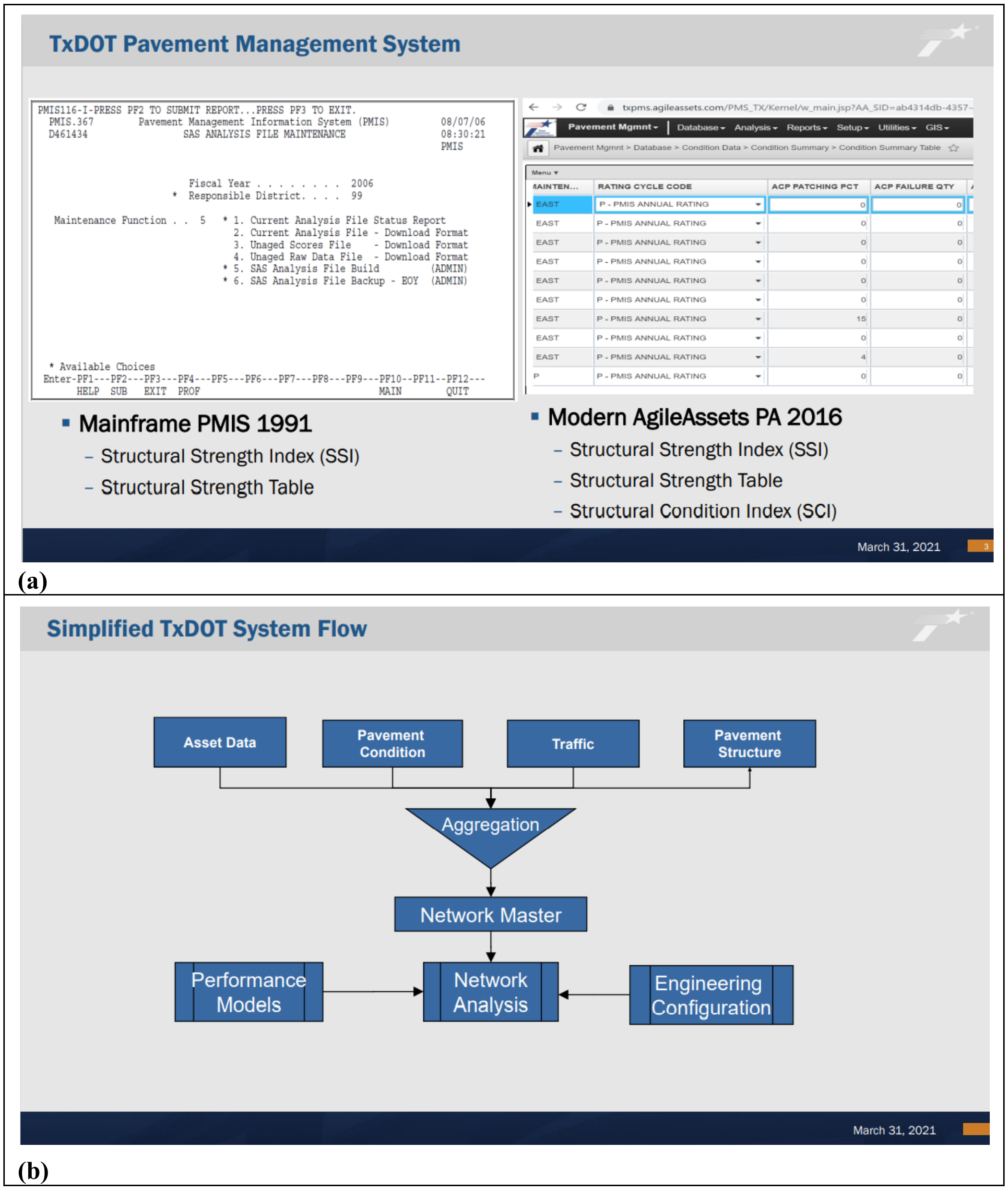



**Figure 2: TxDOT PMIS and Simplified System Flow**

Dr. Li presented a summary of the TSD data collected in four districts along Texas region (1600 miles), with Dallas district scheduled for collection this year (see Figure 3a and 3b). A case study of 22 miles Farm to Market (FM) road highway were selected. The objective of the case study was a data comparison of the pavement deflection using TSD and FWD data along different pavement condition (see Figure 3c). GPR imaging data and surface pavement types were also collected.


**Figure 3: TxDOT District TSD Data Collected Summary and Applied Technology for Data Collection**

Based on the results, Dr. Li concluded that FM Highway exhibited similar trend between the FWD and TSD collected data (see Figure 4). In addition, the condition scores (CS and DS) were consistent with the deflection measurements, especially at the start of the section where the pavement condition was good (see Figure 4).

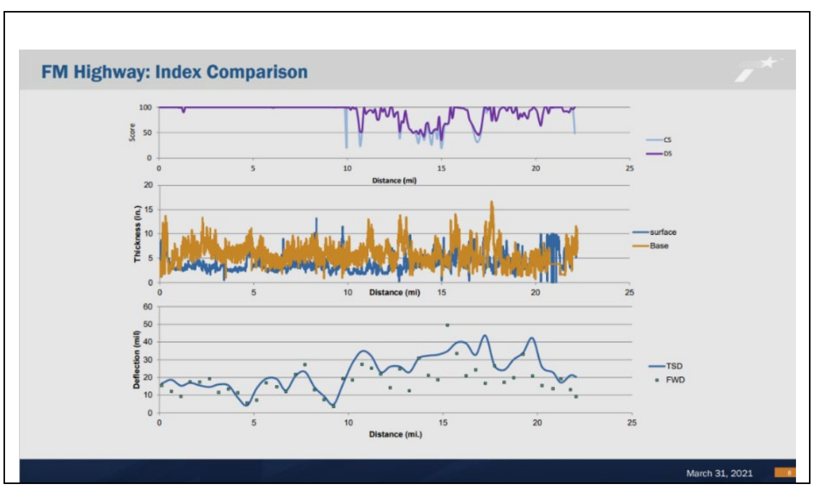



**Figure 4: Case Study. Deflection Comparison between TSD and FWD Data, Thickness and Condition Scores (FM Highway)**

In order to increase the level of confidence of deflection measurement using TSD devices, additional data comparison was conducted using a State Highway (SH) road. It showed similar trend as can be seen in Figure 5 below.

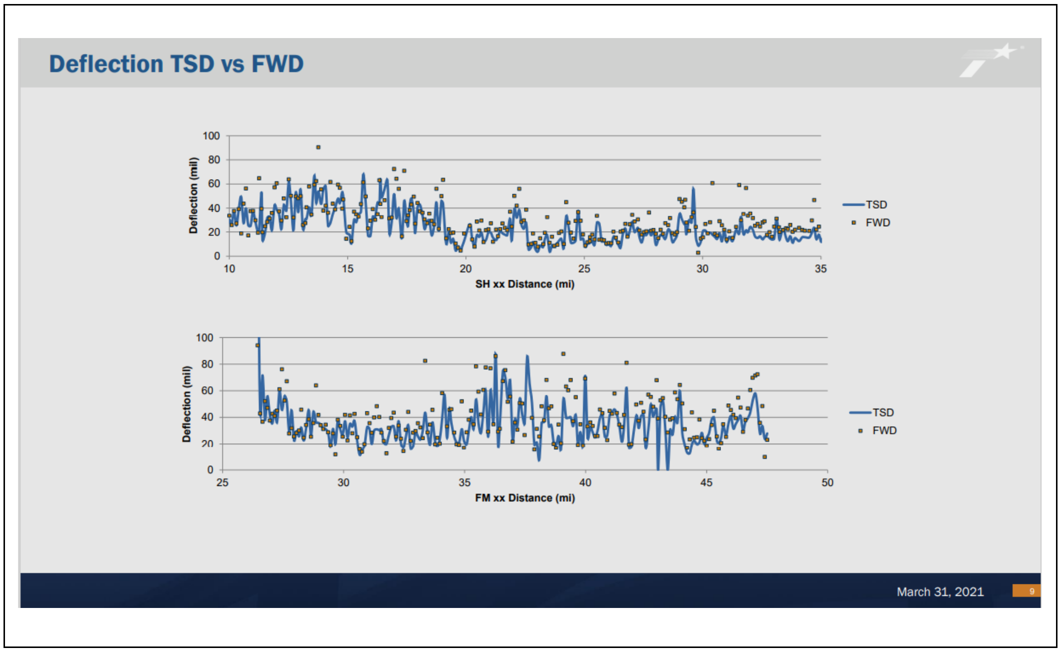



**Figure 5: SH Highway and FM Highway. Deflection Comparison between TSD and FWD Data**

Considering the positive results of the data comparison, the TSD data and FWD data collected along the districts were loaded into the TxDOT PMIS tool (see Figure 6).

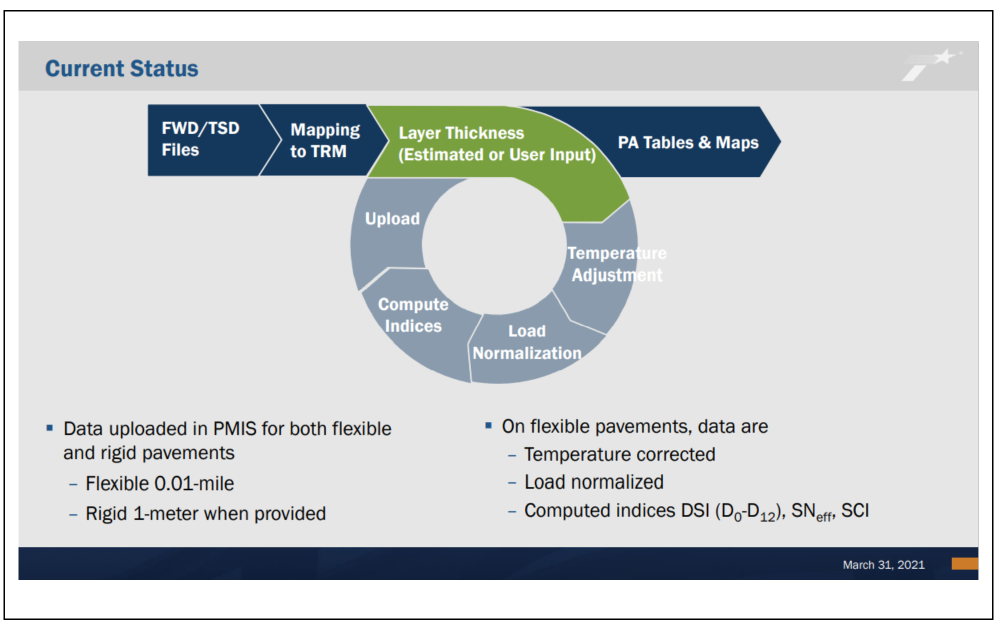
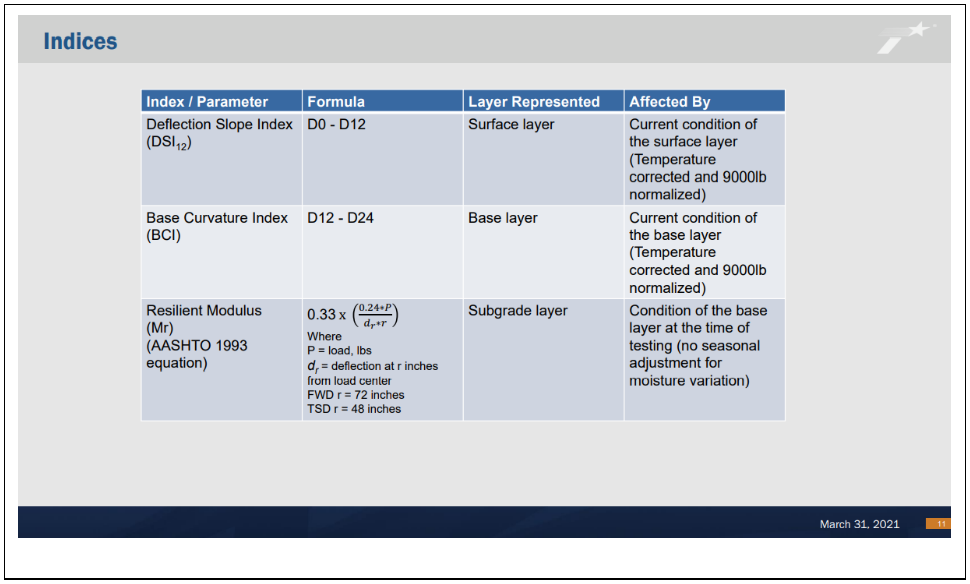



**Figure 6: TSD Data integration into TxDOT PMIS.**

Different indices were computed in order to compare both set of data (TSD and FWD), as well as structural indices of the existing pavement condition. The following Figure 7 shows the structural indices included in the TxDOT PMIS tool, presented by Dr. Li.




| Index / Parameter | Formula | Layer Represented | Affected By |
|---|---|---|---|
| Deflection Slope Index ($DSI_{12}$) | D0 - D12 | Surface layer | Current condition of the surface layer (Temperature corrected and 9000lb normalized) |
| Base Curvature Index (BCI) | D12 - D24 | Base layer | Current condition of the base layer (Temperature corrected and 9000lb normalized) |
| Resilient Modulus (Mr) (AASHTO 1993 equation) | $0.33 \times \left(\frac{0.24 * P}{d_r * r}\right)$ Where P = load, lbs $d_r$ = deflection at r inches from load center FWD r = 72 inches TSD r = 48 inches | Subgrade layer | Condition of the base layer at the time of testing (no seasonal adjustment for moisture variation) |

**Figure 7: TxDOT Structural Indices**

In addition, Dr. Li showed the Structural Condition Index (SCI) calculated as the ratio of the effective and required AASHTO 1993 Structural Numbers (SCI = SNeff/SNreq). This index was included in order to define weak areas and eventually the required overlay thickness. The effective SN was estimated using the recalibrated Rhode equation. The required SN was based on the estimated 20 years design traffic using the AASTHO 1993 equation (see Figure 8).

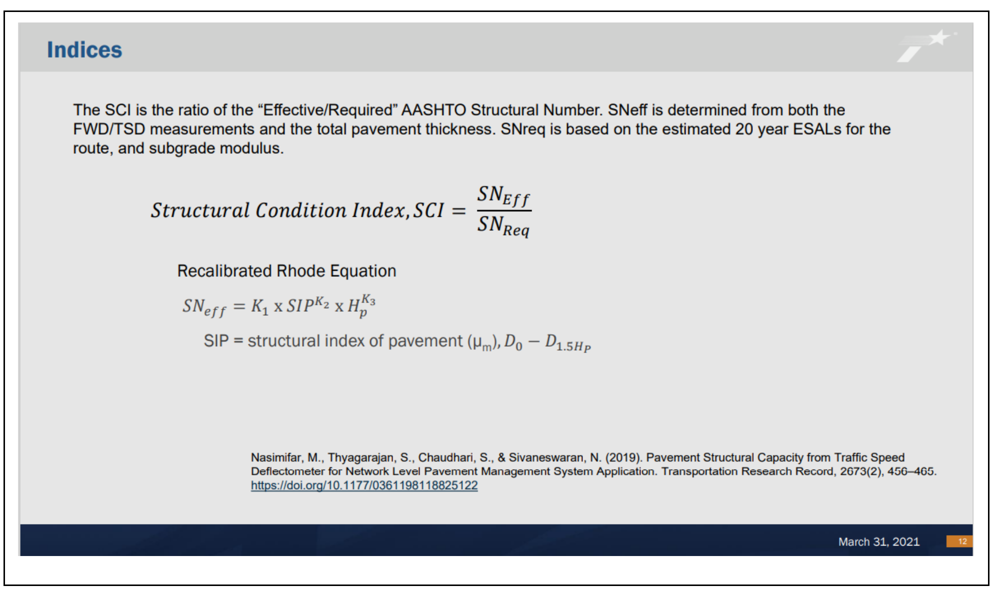
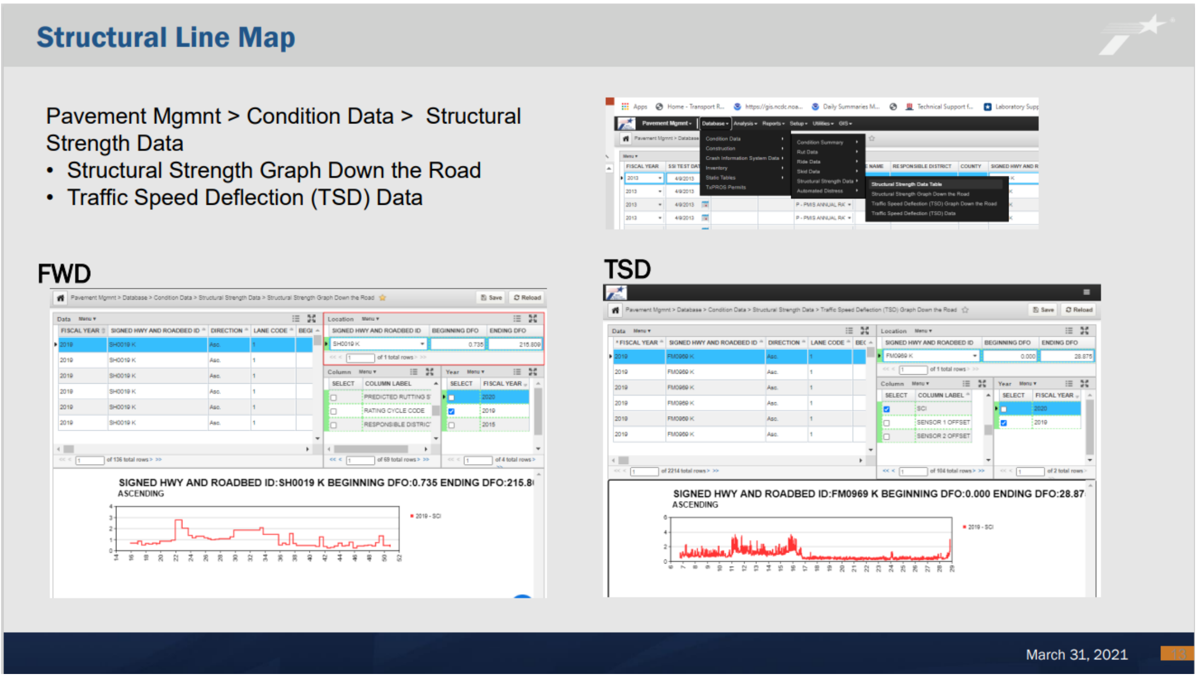
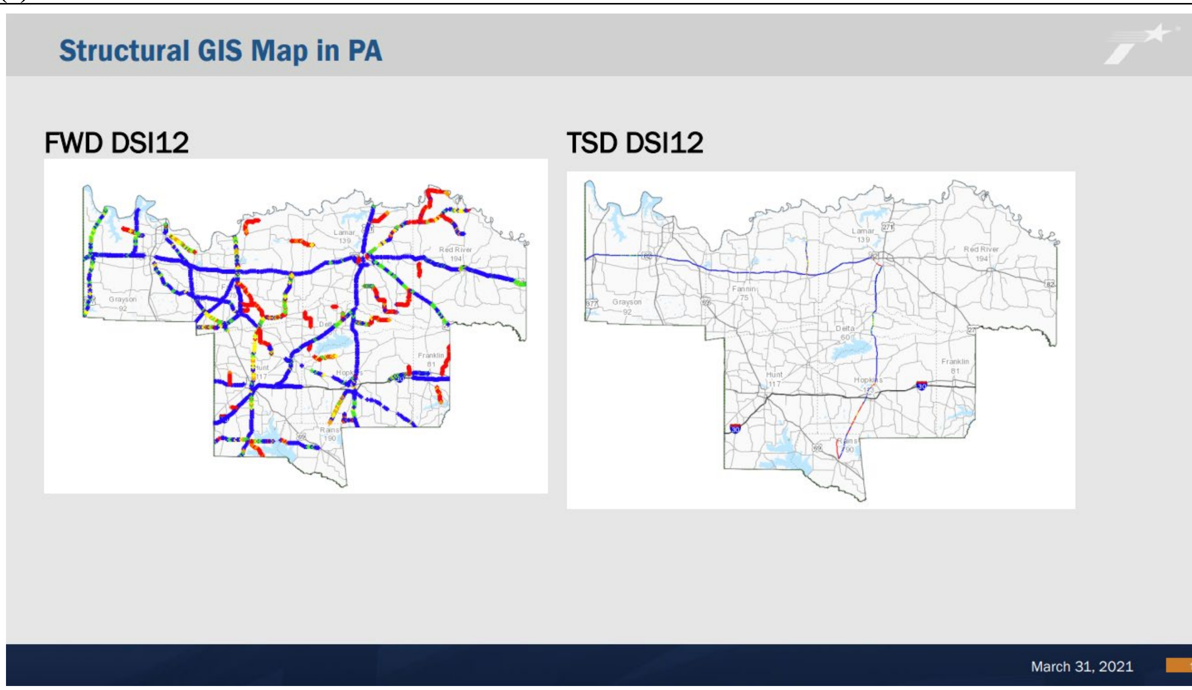



**Figure 8: TxDOT Structural Condition Index (SCI)**

Dr. Li presented the results in graphical format, as well as GIS map representation using the PMIS tool (see Figure 9a and 9b). In general, the TSD and FWD structural data compares well, showing a consistent trend between the two set of data.




(a)




(b)

**Figure 9: Comparison TSD and FWD Data. Data Mapping Representation**

Dr. Li prepared a demonstration to the districts comparing the structural indices, surface distress scores, and the deflection measurements (see Figure 10a and 10b). The results showed areas with poor surface condition. However, the deflection values were low and the SCI was less than 1, showing good structural capacity.

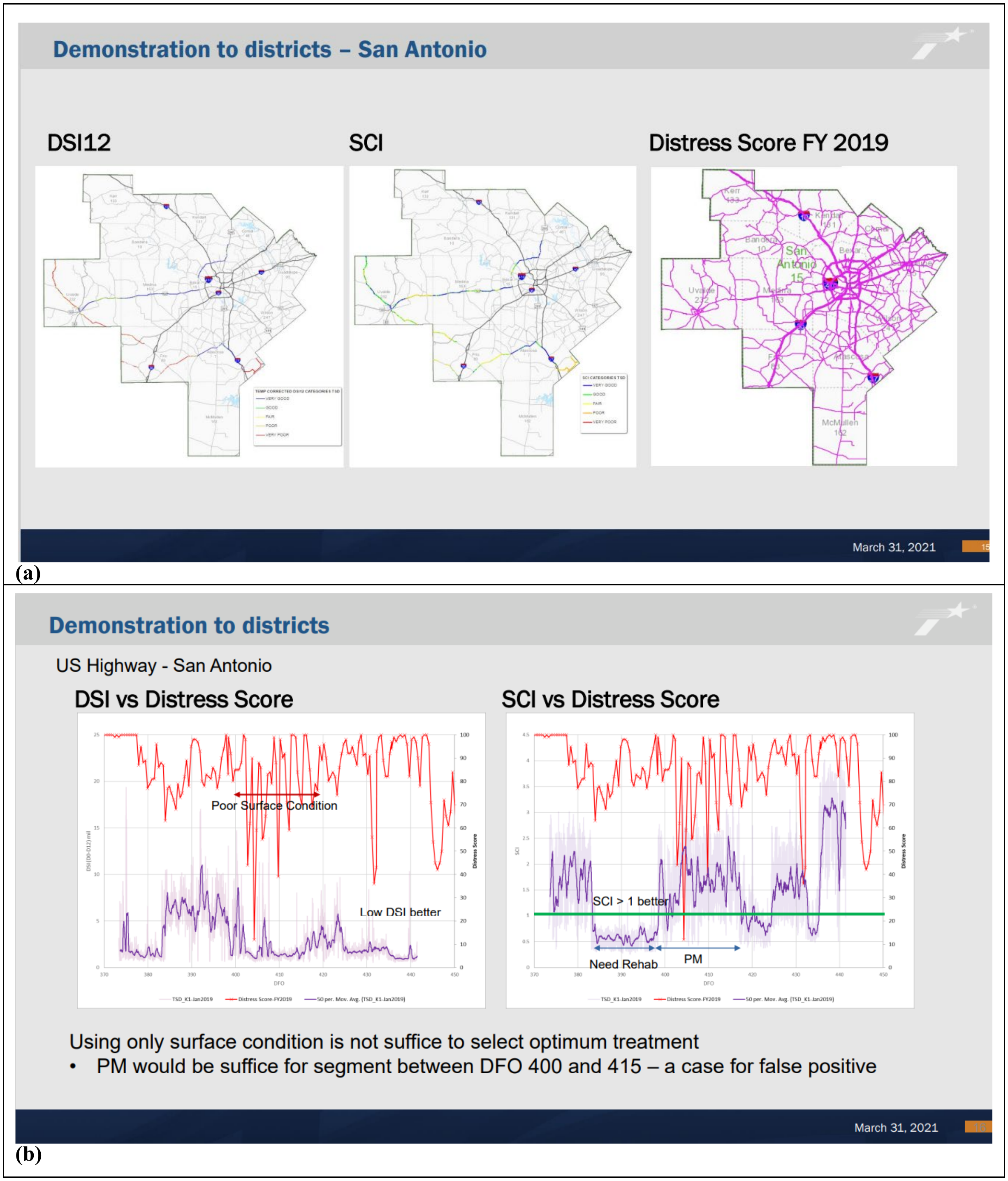



**Figure 10: Demonstration to Districts. Comparison Surface and Structural Indices (US Highway-San Antonio)**

Dr. Li concluded that using only the surface pavement distresses is not sufficient to select the optimum pavement treatment, and structural data is required (see Figure 11a and 11b for additional comparison).

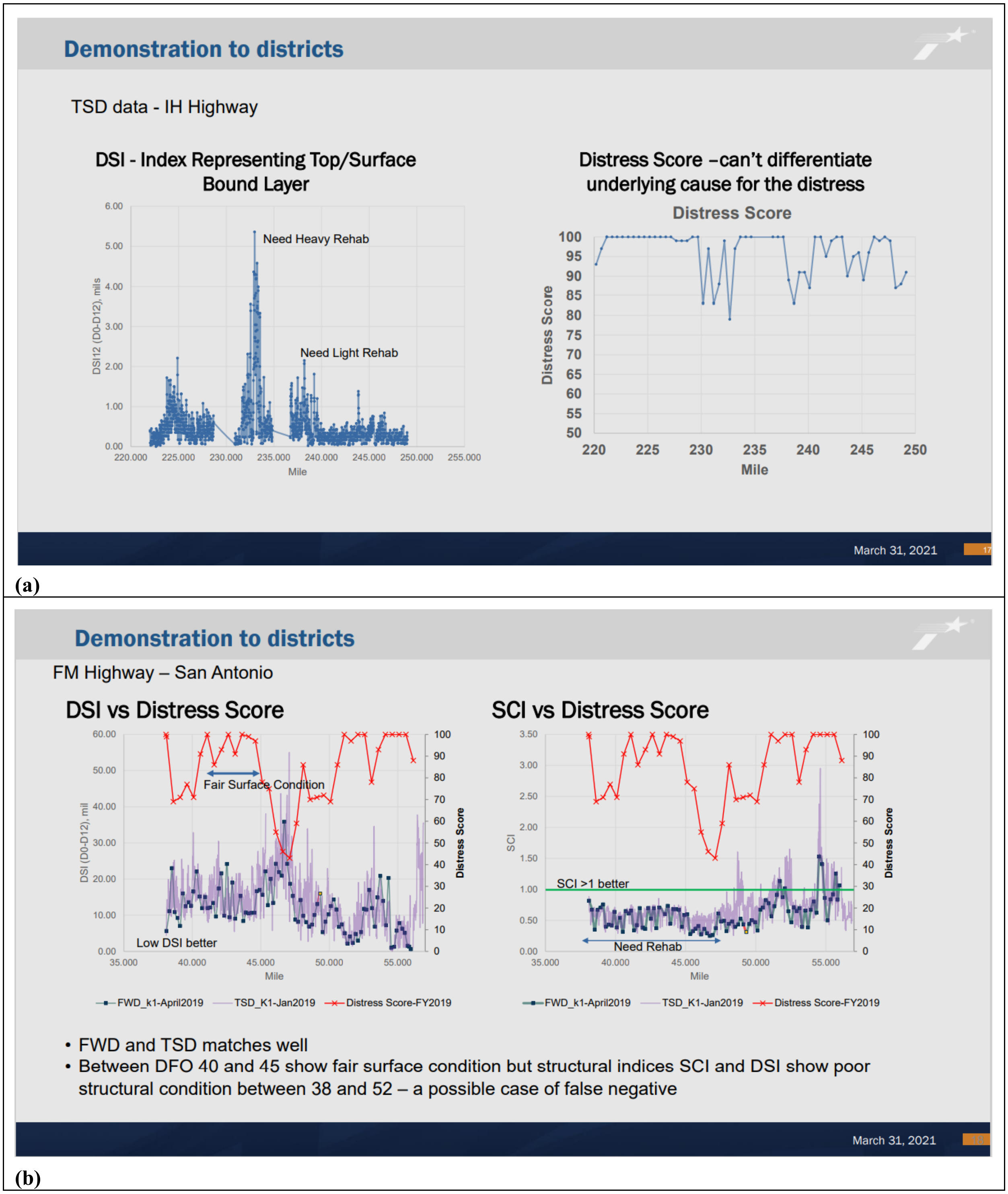



**Figure 11: Demonstration to Districts. Additional Comparison Surface and Structural Indices (IH and FM Highway-San Antonio)**

Dr. Li summarized some challengers regarding the lack of asset inventory information (layer thicknesses, material type and characteristics). In addition, there was a lack of as-built information and work history along the network roads. It has negative impact on developing accurate deterioration models based on functional and structural distresses, as well decision trees. The TSD data was considered valuable and reliable with a lot of potential. Dr. Li recommended additional efforts to apply the TSD data to a network level and close the gap between network and project level assessments. It was suggested a research to stablish structural indices thresholds for network level application, as well as QA/QC guidelines for TSD data collection verification. The following Figure 12a to 12c shows the current challenges and future research suggested by Dr. Li, and her team.

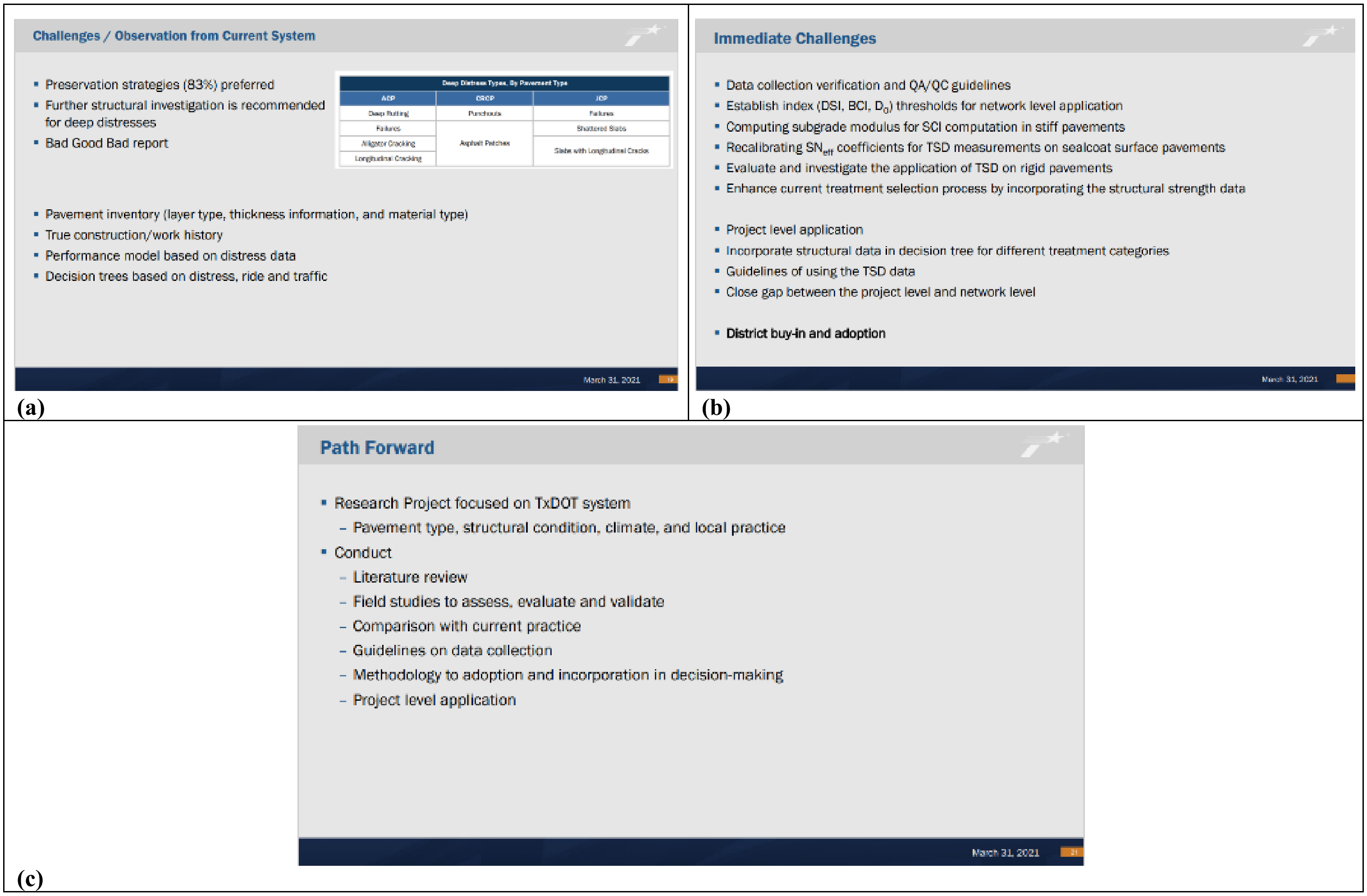



**Figure 12: Current Challengers and Future Researches**

**Traffic Speed Deflectometer Device (TSDD) Data in Pavement Management Systems**

**Charles Pilson; Eric Perrone; Aaron Gerber**

The Kercher Group

C. Pilson and A. Gerber presented on how structural information data can be included into a pavement management system (PMS). Three examples of agencies that have already incorporated structural data into their PMS were given. The three agencies were Idaho Transportation Department (ITD), City of Dallas and Montana Department of Transportation (MDT).

ITD has already started investigating the use of Traffic Speed Deflectometer (TSD) data instead of the FWD data in their PMS. This has been completed using TSD data collected in the eastern region of District 6 (see Figure 1).

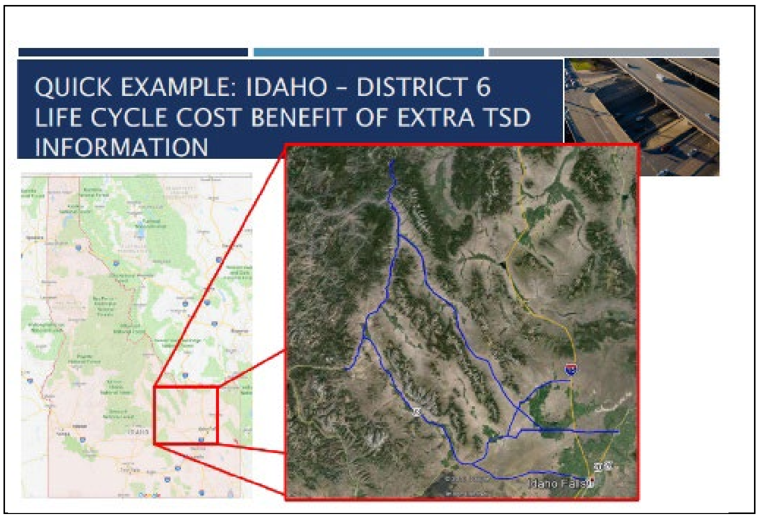



**Figure 1: Idaho-District 6 Road Network Location**

ITD used structural condition decision tree and the updated performance models based on TSD data for network level performance modelling (see Figure 2a and 2b).

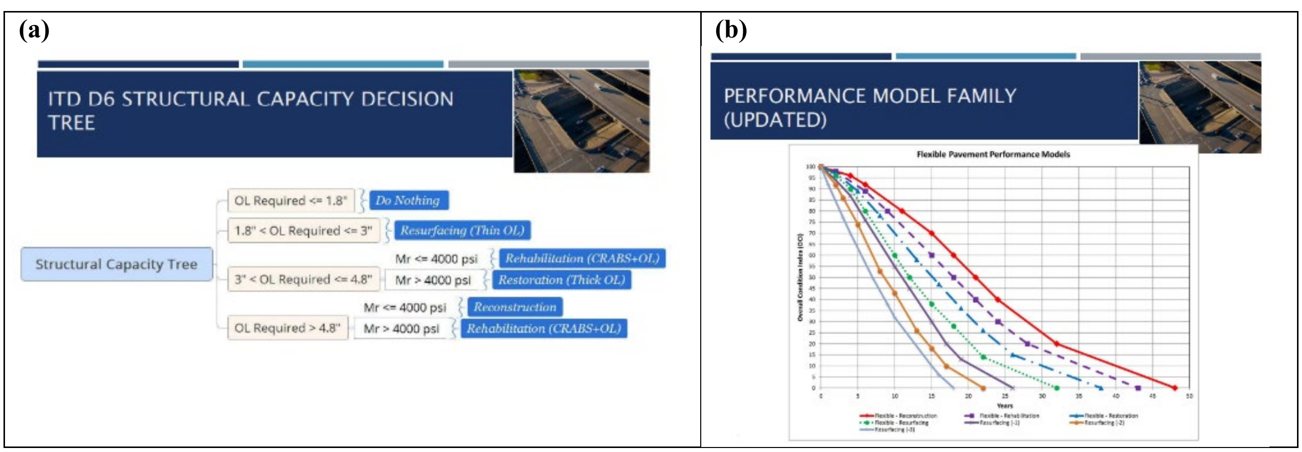



**Figure 2: ITD Structural Capacity Decision Tree and Updated Deterioration Model Using TSD Data**

The decision trees, treatment selection and updated performance models were used by ITD to perform a Life Cycle Cost Analysis (LCCA) and determine the benefits of using TSD structural information data (see Figure 3a and 3b). In summary, the analysis showed that the use of the TSD data resulted a total 50-year cost saving of $15.5 million at presented value, with a return on investment (ROI) equal to 4.2.

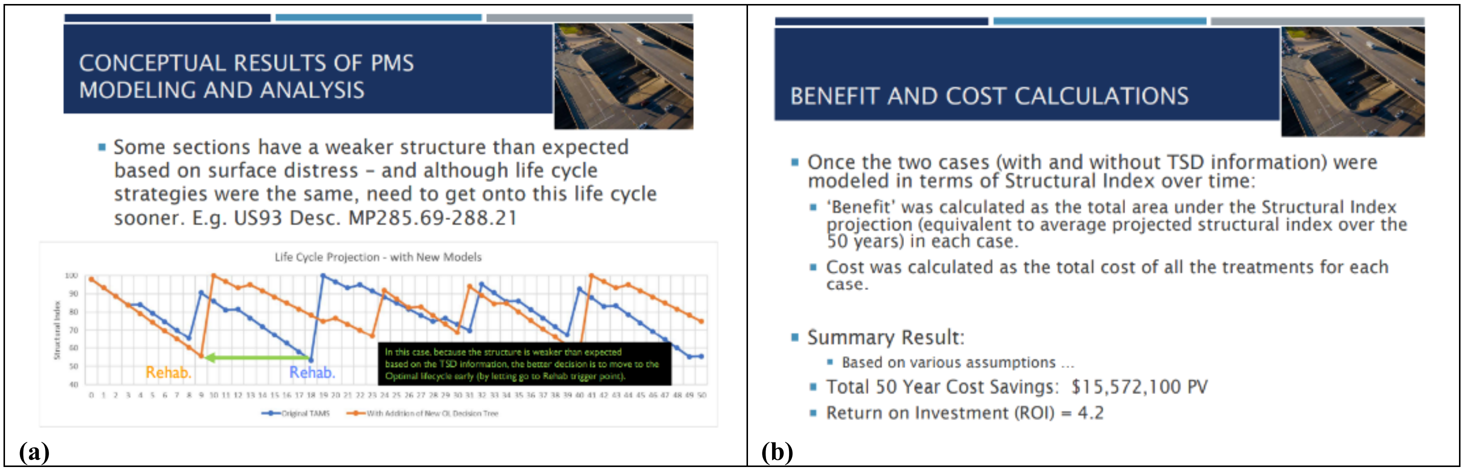



**Figure 3: LCC Analysis and Benefits and Costs Calculations**

Regarding City of Dallas and MTD, Figure 4 shows the structural decision trees used by these agencies which are similar to the one used by ITD, suggesting that similar process of incorporating TSD data can be used for both organizations.

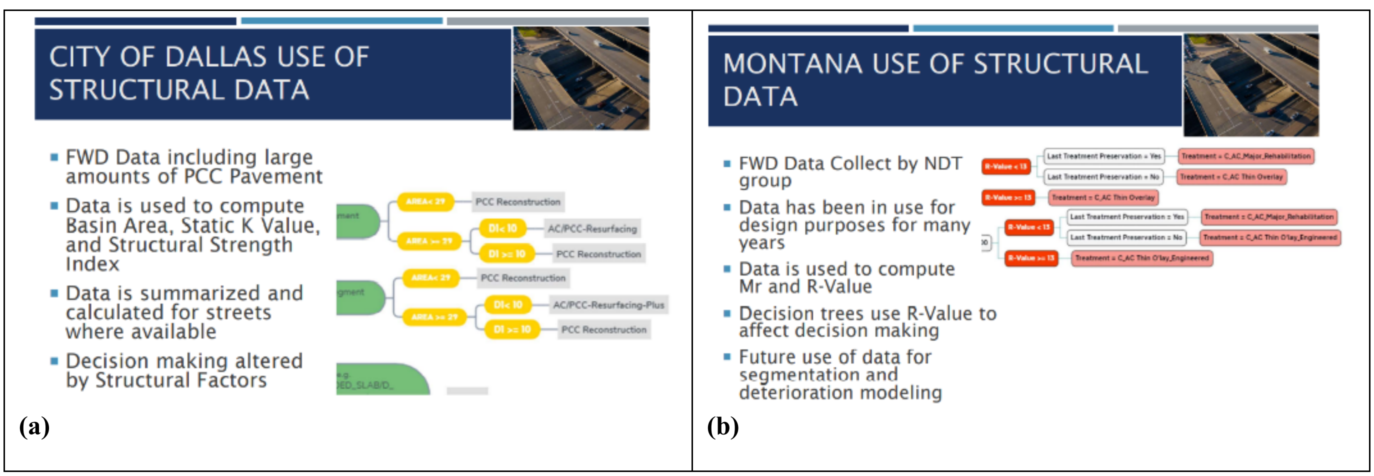



**Figure 4: City of Dallas and Montana DOTs Use of Structural Data**

Pilson and Gerber suggested that the DOTs should start using TSD data by incorporating it in three stages into their PMS as shown in Figure 5a to 5c. The first stage consists of including TSD indices into the PMS data base and decision trees. The second stage consists of adjusting the deterioration curves based on TSD data and predict deterioration curves for different treatments. Finally, the third stage consists of a comprehensive analysis that combines other distress data like cracking, roughness (IRI) and rutting in relationship with the structural data from the TSD.

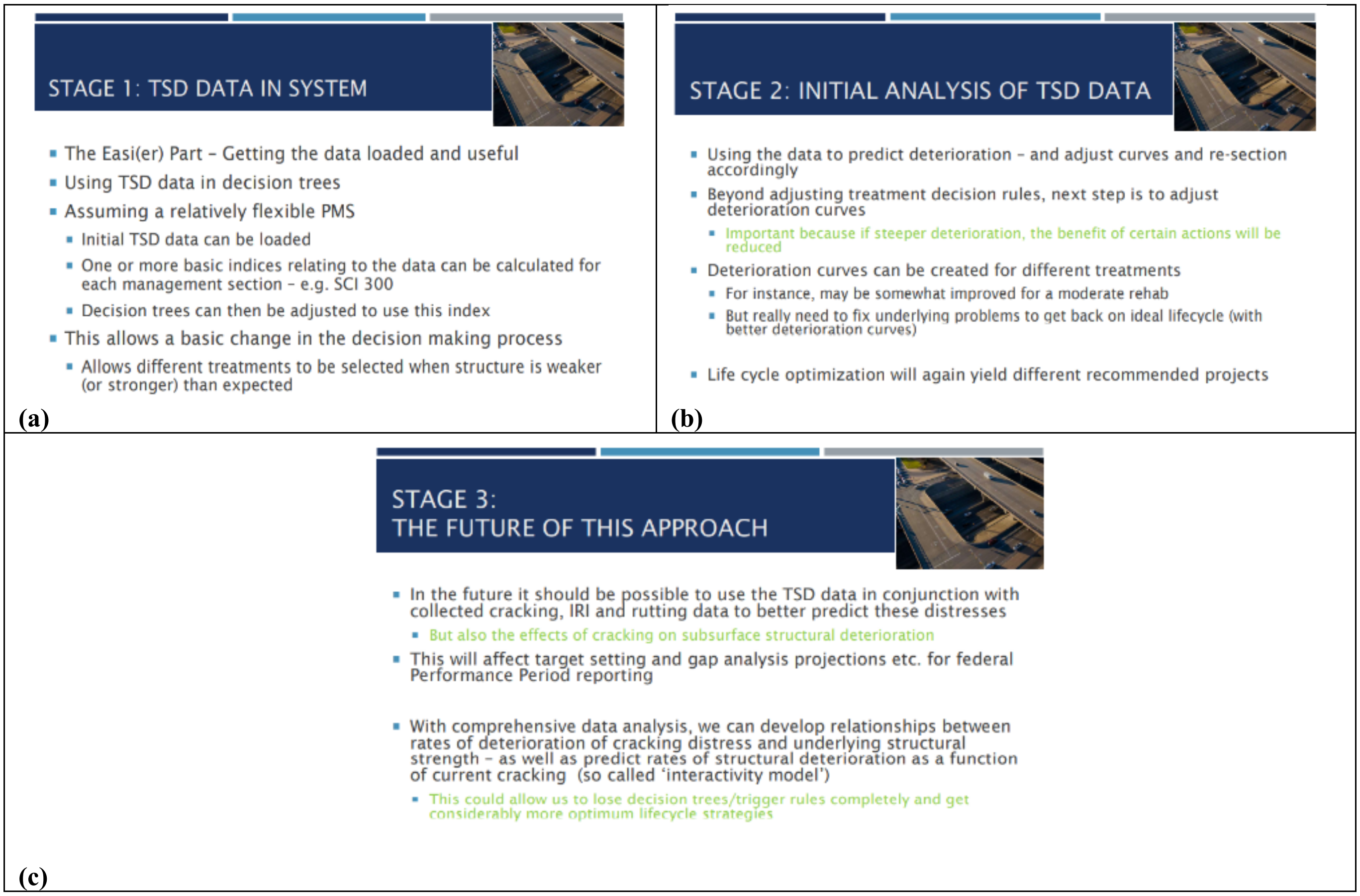



**Figure 5: Proposed General Stages for Implementing TSD Data**

Presenters showed in detail the suggested steps for implementing TSD data into the PMS tool. Steps three, four and five, related to treatment improvement, decision trees and performance models, respectively, are the steps proposed to include the TSD structural data into the PMS (See Figure 6).

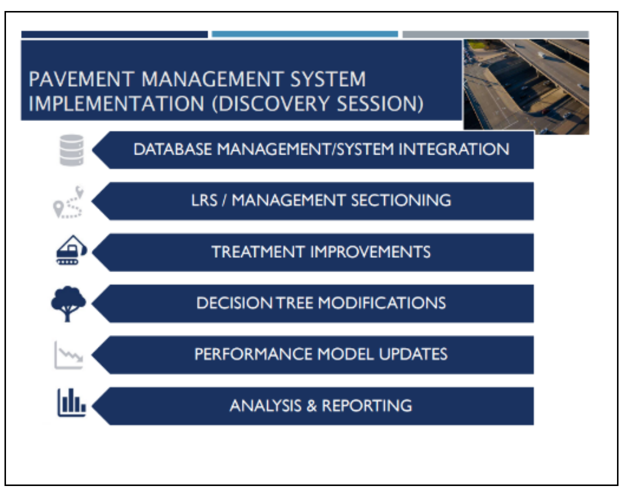



**Figure 6: TSD Data Suggested Steps for Implementing Into PMS**

Finally, the authors concluded that the industry should include structural data collected by TSD devices and start with its implementation into their PMS. Figure 7 shows a summary of the conclusions and recommendations of the presentation.

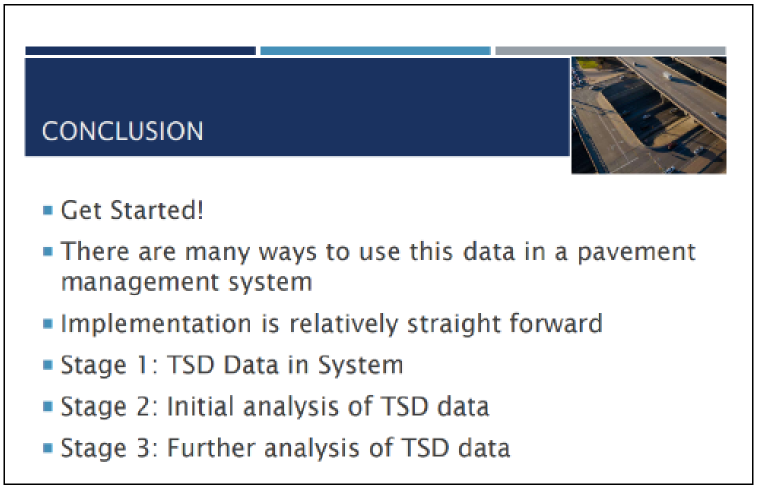



**Figure 7: Conclusions and Recommendations**

# Implementation of Traffic Speed Deflectometer in Idaho

**Ken Maser, Infrasense / Nick Weitzel, NCE / Samer Katicha, Ph.D., P.E., VTTI / James Poorbaugh, ITD**

Infrasense / NCE / VTTI / ITD

K. Maser delivered the presentation on the implementation of TSD data into Idaho Transportation Department (ITD) network asset management system. The presentation showed the advantages of having structural data, obtained from the TSD devices and layer thickness data obtained by the Ground Penetrating Radar (GPR), in calculating the required overlay thickness at the network-level. The advantages were also illustrated for project-level analysis.

Figure 1 shows a summary of the methodology to analyze the data and determine the required overlay thickness. The TSD data and GPR data are combined to determine the subgrade elastic modulus and the pavement effective structural number (SNeff). Two methods were used: 1) AASHTO-93 method, and 2) method based on backcalculation of layer moduli using EVERCALC. Method 2 was used if the RMSE of fitted deflections was less than 5%, otherwise method 1 was used as shown in Figure 1. The pavement remaining life and design overlaid were calculated using the future expected standard axle repetitions in conjunction with the calculated SNeff based on the AASHT 1993 guide (see Figure 1).

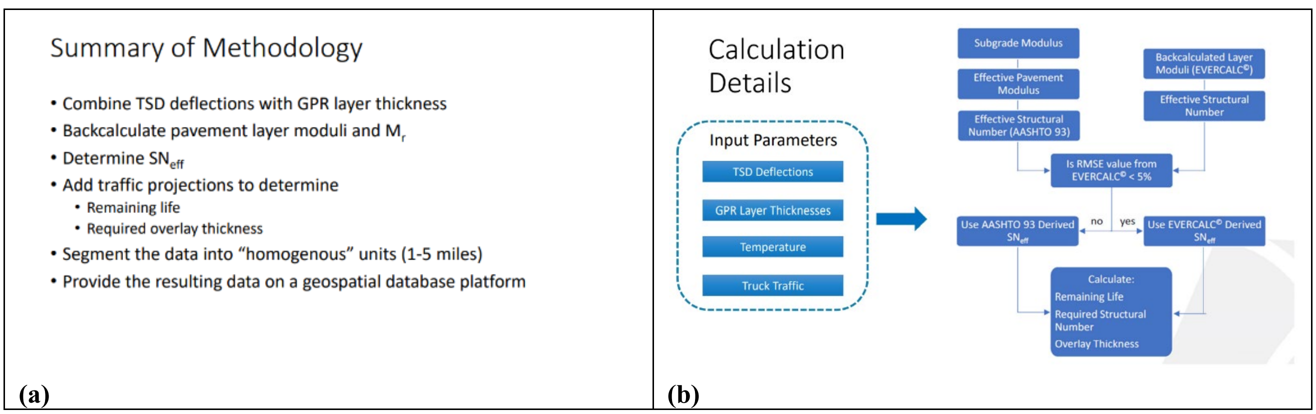



**Figure 1: Summary of the Methodology**

Figure 2a below, shows the six districts that comprised of Idaho state. The initial data was collected between 2015 and 2017 in District 6. Approximately, 1035 miles were collected using TSD and GPR equipment. Figure 2b shows the equipment for GPR data collection.

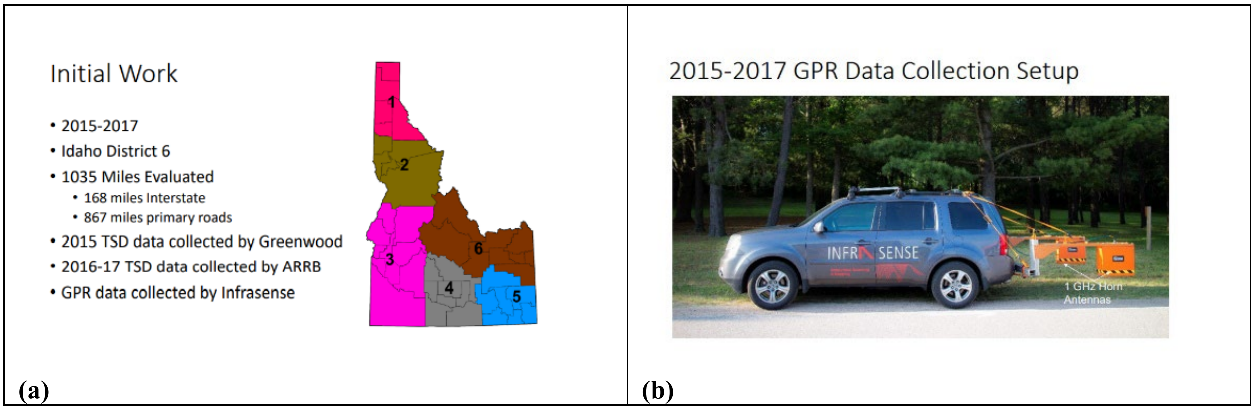



**Figure 2: Idaho Districts and GPR System for Data Collection**

The results of the initial data collection (between 2015 and 2017) were georeferenced and displayed as thematic maps. Figure 3a, 3b and 3c below shows some examples of the results considering remaining life and subgrade elastic modulus. The thematic maps were colour coded, so it was visually possible to identify weak areas. It also allowed to zoom in (See Figure 3c) and inspect particular sections and perform some data comparison.

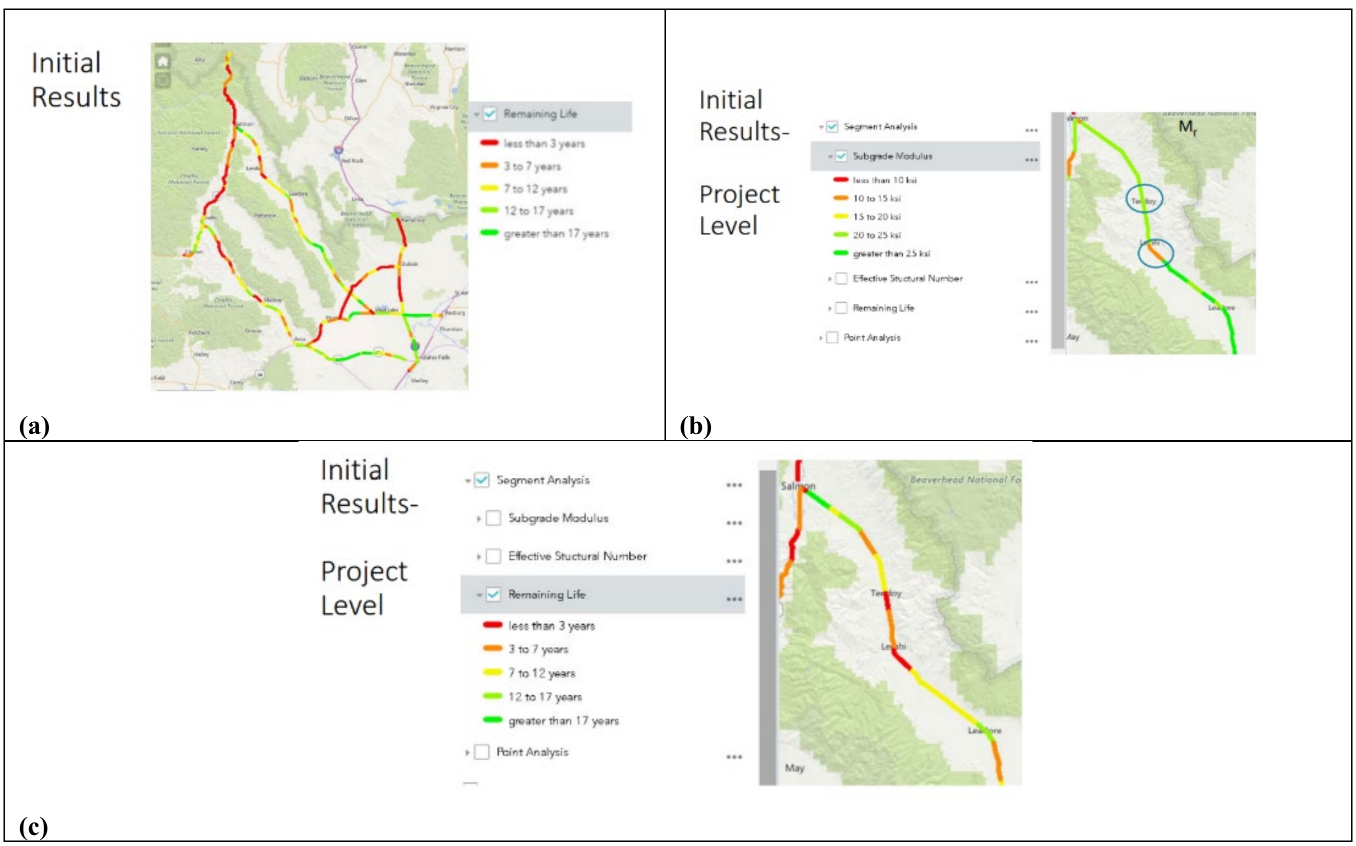



**Figure 3: Initial Results (Data Between 2015 and 2017). Project Level**

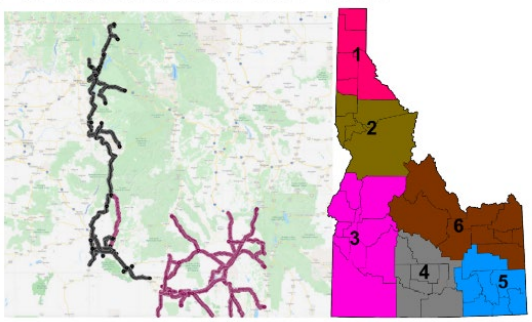
In addition to the data collected between 2015 and 2017; 1650 miles were collected in 2019 and 1870 miles in 2020. The collection covered roads along all ITD Districts. Districts 1; 2; and 3 were collected in 2019, whereas Districts 4; 5; and few roads in District 6 were collected in 2020. Figure 4a, 4b and 4c shows the details of the collected data in 2019 and 2020.

Current Project

- 3520 miles of TSD Data collected in Idaho in 2019-2020
  - 1646.6 in 2019
  - 1873.7 in 2020
- GPR data collected statewide under separate arrangement (2016-17)
- Goal was to select 1400 miles with both GPR and TSD data
- Analyze for $SN_{eff}$, $M_r$, Remaining Life, and Reqd. Overlay Thickness

**(a)**

Map of collected data: 2019-2020




**(b)**

Roads Selected for Analysis

| Road | Direction | Begin Milepost | End Milepost | Length (miles)[1] |
|---|---|---|---|---|
| US-95 | NB | 0.0 | 537.0 | 524.2 |
| US-20 | EB | 348.7 | 400.4 | 51.8 |
| US-12 | EB | 1.8 | 73.4 | 71.6 |
| SH-55 | NB | 0.0 | 207.7 | 133.9 |
| I-90 | WB | 0.0 | 67.7 | 67.7 |
| I-90 | EB | 0.0 | 67.7 | 67.7 |
| I-84 | EB | 133.9 | 275.6 | 72.4 |
| I-84 | EB | 0.0 | 133.9 | 130.6 |
| I-15 | SB | 0.0 | 195.7 | 195.1 |
| | | | Total: | 1,315 |

[1]TSD data was not always continuously collected between the start and end milepost.

**(c)**

**Figure 4: Current Project Details (Data Collected in 2019 and 2020). Road Section for Comparison**

Figure 5 shows results of the analysis performed for US-12. The first graph (a) presents the comparison between remaining life and required overlay. The remaining life results showed higher variability whereas the required overlay results were more stable. Therefore, it was decided to use the required overlayed thickness as to measure the structural capacity of the pavement and for further comparisons. The second graph (b) shows the required overlay thickness comparison with the subgrade elastic modulus and SNeff. There was a consistent expected behaviour, where the subgrade modulus and SNeff were high, then the required overlay thickness was low and vice-versa. Graph (c) shows that there is little correlation between the required overlay and the Present Serviceability Index (PSI). The last graph (d) in Figure 5, shows the segmentation of the required overlay thickness and SNeff using the modified AASHTO-93 procedure discussed in the second webinar.

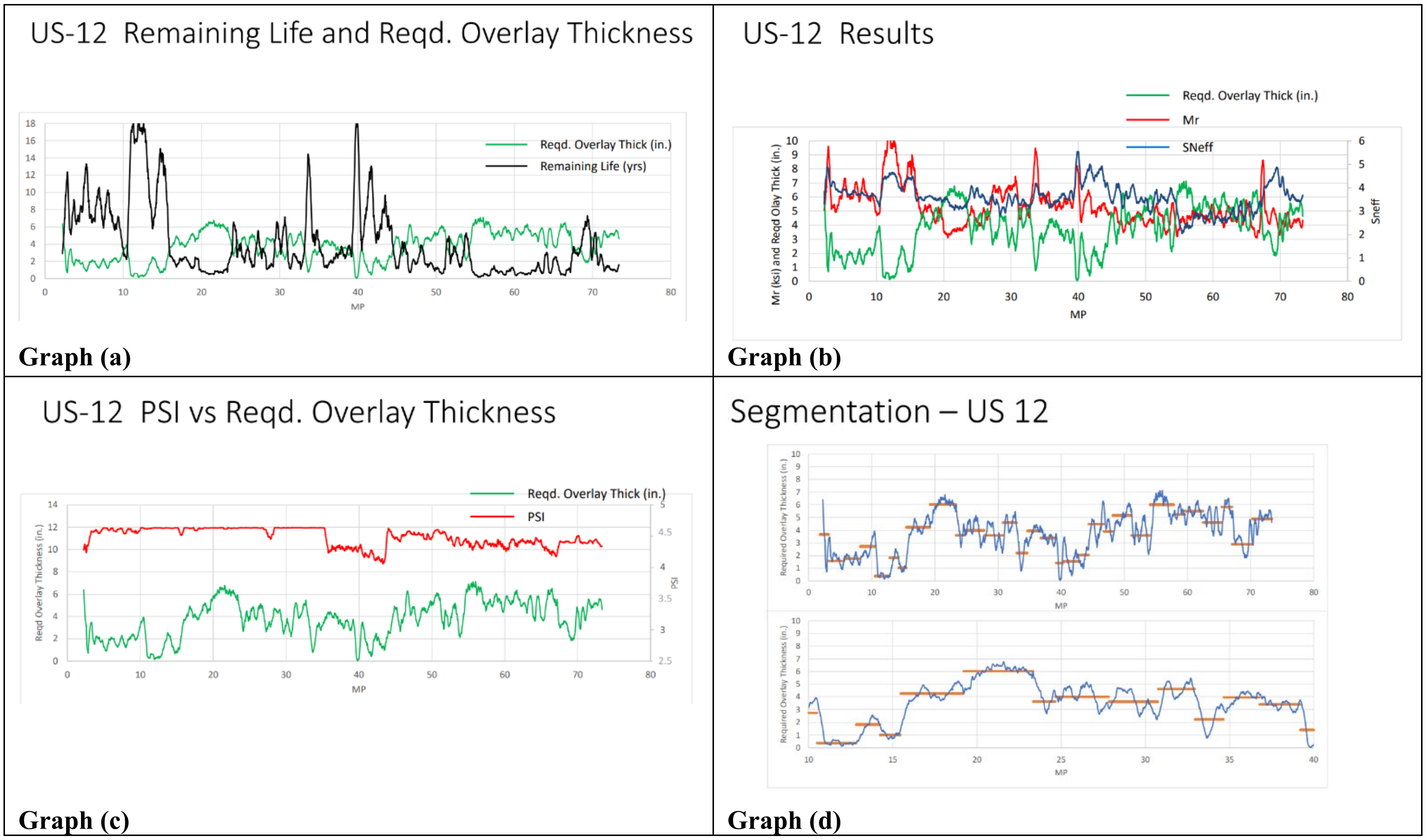



**Figure 5: US-12 TSD Results Data Comparison**

Figure 6 shows the relationship between required overlay thickness and SCI12 defined as D0 – D12, where D0 is the deflection at the center of the wheel load and D12 is the deflection 12 inches from the center of the wheel load. The correlation between SCI12 and overlay thickness is relatively low. This is because SCI12 does not take into account the in-place pavement layer thicknesses. This shows that layer thickness information is important to properly evaluate the pavement structural condition and determine an overlay thickness.

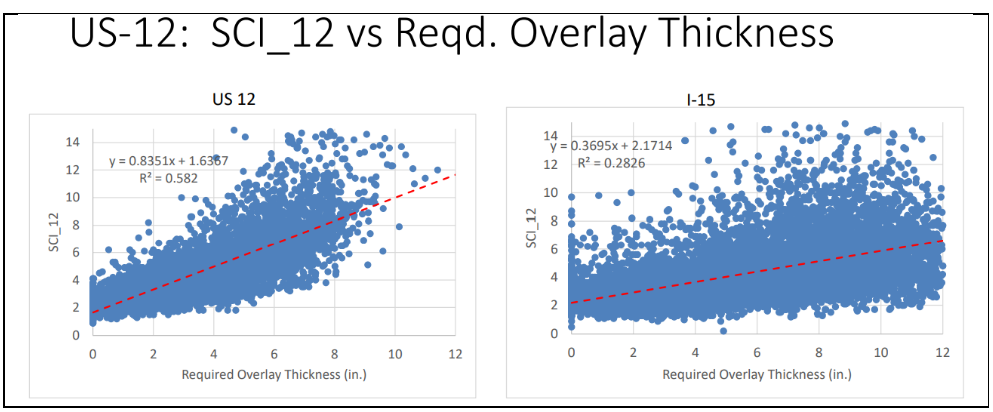



**Figure 6: US-12: SCI-12 vs Required Overlay Thickness**

After presenting the analysis results, Mr. Maser showed how the results are incorporated into the graphic tool iPlan used by IDT for displaying the results. Figure 7a and 7b below shows some thematic maps and screenshots of the graphic software. It is a versatile application with capabilities of displaying colour coded data condition attributes and the ability to zoom in and display detailed results.

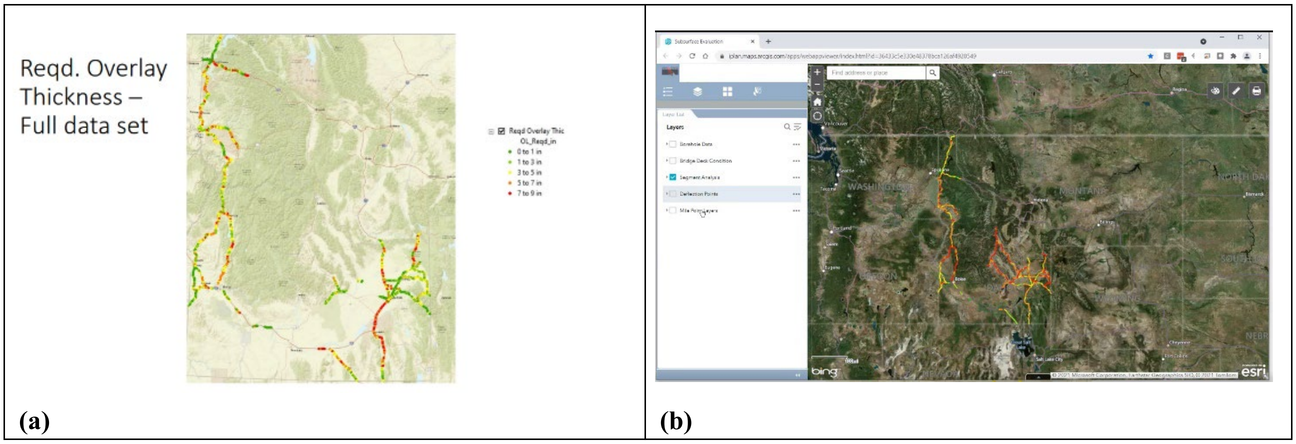



**Figure 7: iPlan Graphic Tool**

To summarize the results, a histogram of required overlay thickness for the whole tested network or for a given road was prepared. Figure 8 shows the histogram for SH-55 and for the whole tested network. The histogram shows the total number of miles requiring specific overlay thickness. This can be used to estimate the total required cost for overlay treatment.

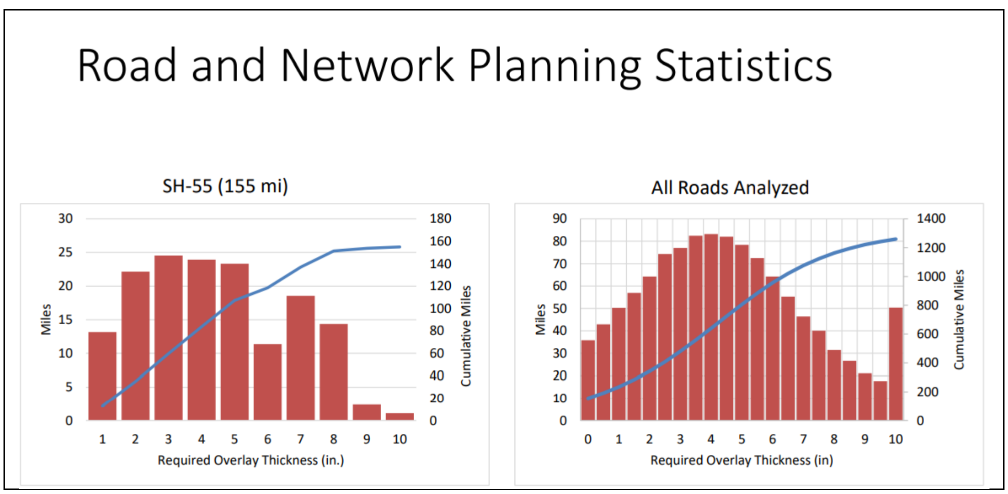
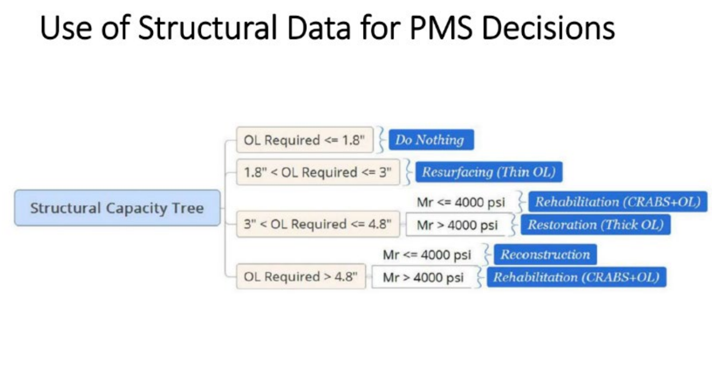
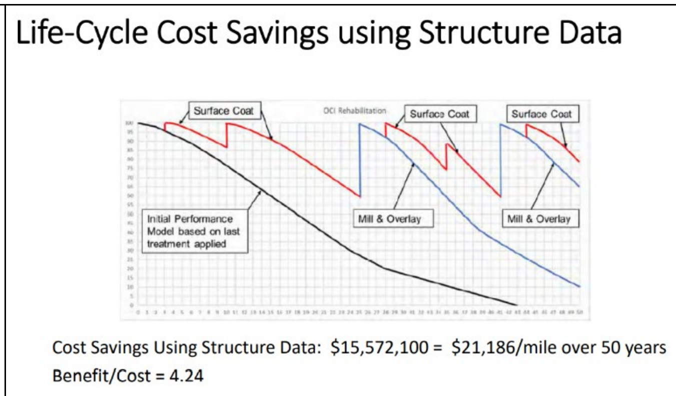



**Figure 8: Statistical Analysis (SH-55 and All Roads Sections)**

The structural analysis allows to determine the required overlay thickness; however, not all maintenance activities have to be applying an overlay. Therefore, for network level analysis, the required overlay thickness can be used to determine a treatment category. This is implemented in a decision tree as shown in Figure 9a. Another network-level analysis that can be performed is life cycle cost analysis also shown in Figure 9b, and presented in webinar four.




**Graph (a)**

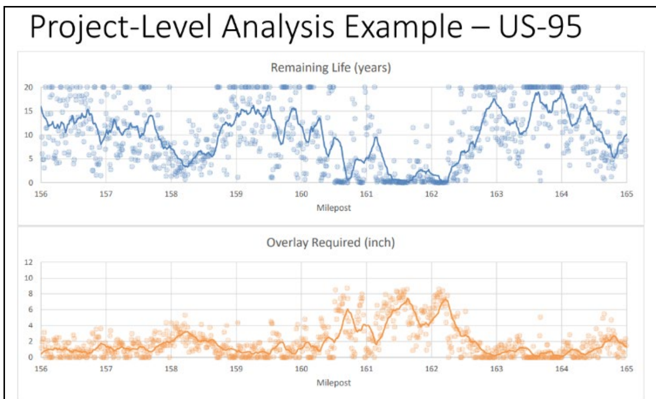



**Graph (b)**

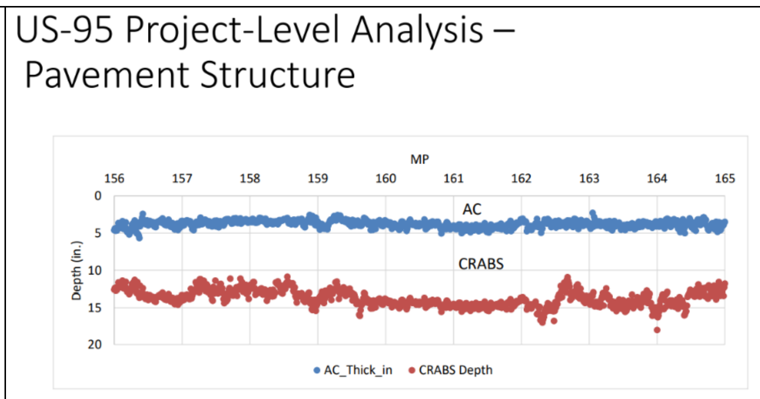
**Figure 9: TSD Data Network Level Analysis**

Mr Maser presented some treatment selection from rehabilitation and restoration alternatives. The treatment selection compares thick overlay and cemented recycle asphalt base system (CRABS) plus overlay. It is based on the subgrade resilient modulus and the required overlay, as can be seen in Figure 9 above.

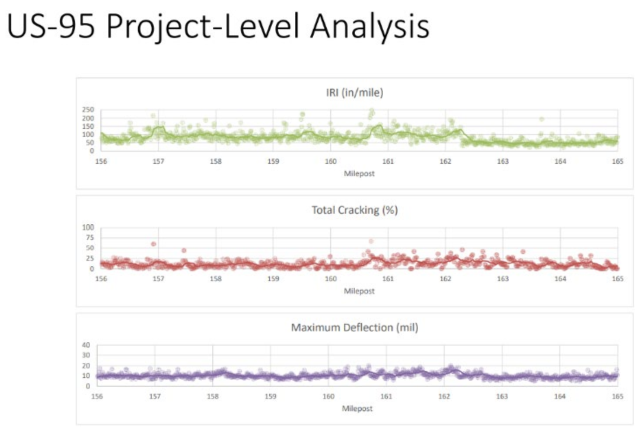
Regarding the project level analysis, Mr. Maser presented the treatment selection along U-95 (see Figure 10). It showed some comparison of the remaining life in years and the required overlay [graph (a) in Figure 10]. A weak section between 159.5 and 162.5 mileposts was highlighted. This weak section was also confirmed based on the results of the SNeff [graph (d) in Figure 10] where the SNeff dropped significantly. Additional analysis presented by Mr. Maser showed that the asphalt and CRABS structural coefficients [graph (e) in Figure 10] also dropped dramatically from the typical values also showed in graph (e). It was concluded that in the area from 160 to 162.5 mileposts, a deep mill and replace of the CRABS and asphalt layers are required.



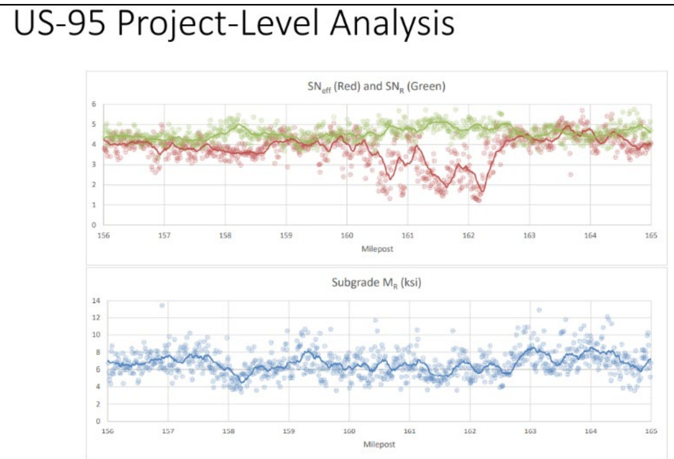

**Graph (a)**



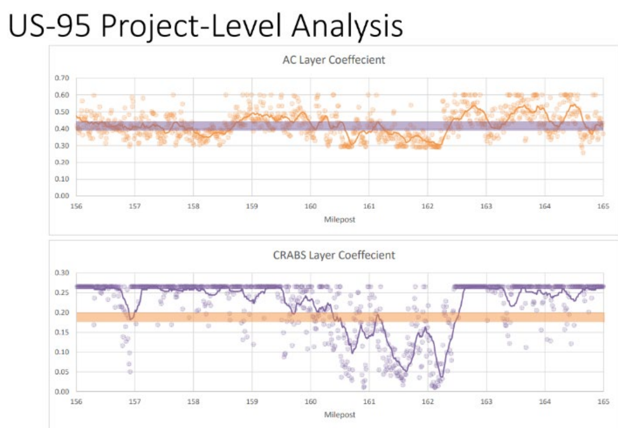

**Graph (b)**




Graph (c)



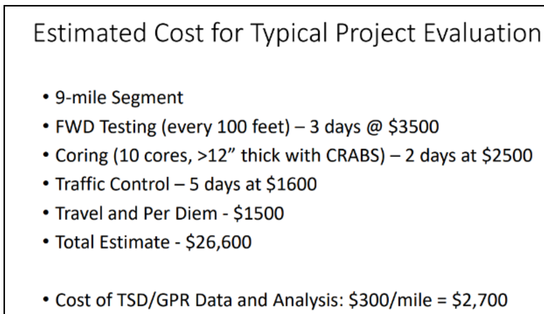

Graph (d)



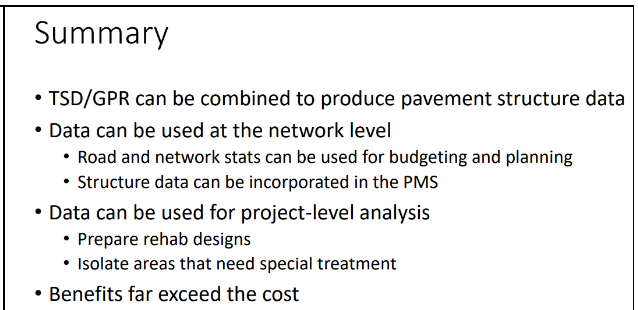

Graph (e)

**Figure 10: Project Level Treatment Selection Including TSD Data into the Decision Trees**

In summary, an estimated cost comparison of a typical project condition assessment using FWD equipment and core drills, in contrast to TSD data collection combined with GPR data was presented. A ratio of 1/10$^{th}$ cheaper was found when the assessment is conducted using the TSD and GPR systems. The conclusions and cost estimation are presented in Figure 11a and 11b.




(a)




(b)

**Figure 11: Project condition Assessment Comparison and Project Summary**

## Comparison of TSDD and FWD Interstate 64 Westbound. James City and York Counties, VA

**Amy Simpson, Ph.D., P.E.**

Wood

Dr. Simpson presented a comparison of TSD and FWD deflection data collected along Interstate 64 between James City and York Counties in Virginia. The comparison was conducted using the structural parameters of SCI, BCI, SNeff and subgrade elastic modulus using the AASHTO-93 approach. In general, the TSD and FWD data did not compared well. However, in some sections of the road, Dr. Simpson found slight similarities between the TSD and FWD in the case of SCI and BCI. Regarding the SNeff and subgrade modulus calculated using the AASHTO-93 approach, the results did not match, and it was recommended another analysis approach should be used for TSD data. Some discussions, questions, and recommendations were raised at the end of the presentation.

The investigated road section is part of the Virginia state road network. Dr. Simpson analysed the asphalt section of the road. Figure 1a shows the objective of the study, and the location of the analyzed road section is shown in Figure 1b.

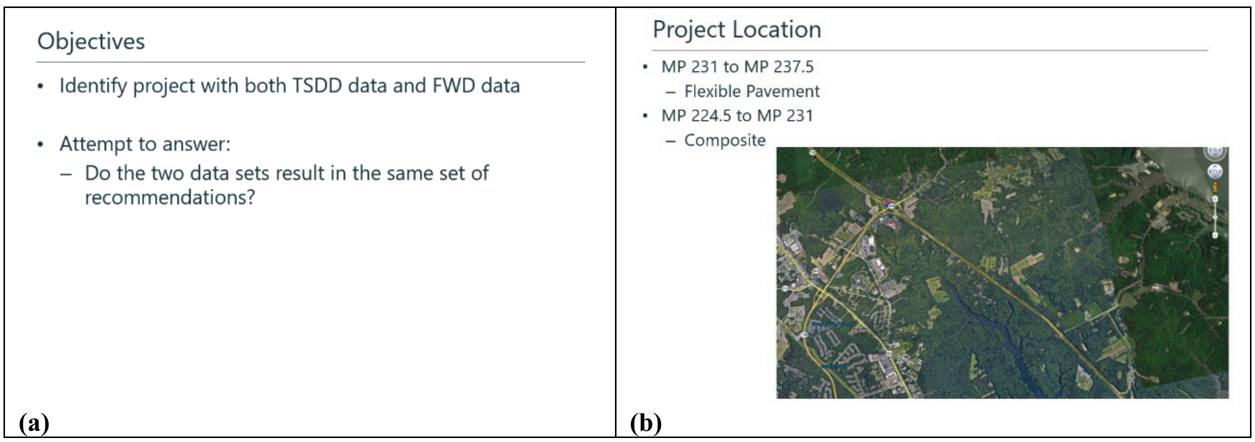



**Figure 1: Project objectives and Road Sections Location**

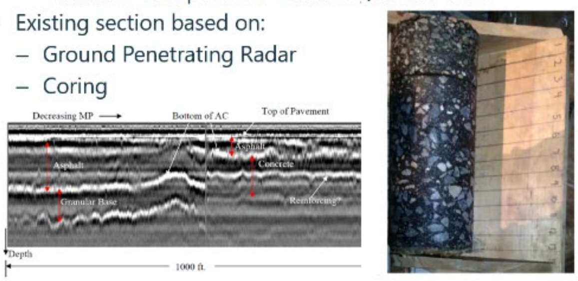
The road section has shown some localised distressed areas as it is shown in Figure 2.


**Figure 2: Photos of the Localised Distressed Areas along the Road Section**

Along with the TSD and FWD structural information, layer thicknesses information, based on collected GPR data, pavement surface condition data, and traffic information are also available for that section (see Figure 3a and 3b).

**Pavement Section**

- Flexible pavement section
  - 11 inches of asphalt on 6 inches granular base
- Existing section based on:
  - Ground Penetrating Radar
  - Coring




**(a)**

**Traffic Data**

| | |
|---|---|
| 2015 AADT | 32,500 |
| Single Unit Trucks | 1.0% |
| Tractor Trailer Trucks | 7.0% |
| Traffic Growth Rate | 1.4% |
| ESAL Estimate (12-year) | 12,043,000 |
| ESAL Estimate (30-year) | 18,072,000 |

**(b)**

**Figure 3: Pavement Cross Section Details and Traffic Data Information**

Figure 4 shows a summary of the PMS recommended pavement rehabilitation based on the surface condition and traffic information.

**Recommendations**

- Overlay
  - 2-inch mill and 4.6-inch overlay
- Reconstruction
  - 2.0 inches SMA-12.5 (PG76-22)
  - 3.0 inches of IM-19.0D
  - 6.5 inches of BM-25.0D
  - 2.0 inches open-graded drainage layer
  - 6.0 inches of cement treated aggregate base

**Figure 4: Recommended Pavement Rehabilitation Structure**

Dr. Simpson highlighted that the TSD and FWD data were collected within 1.5 years difference, with the most recent data collected by the TSD in August 2017 and the FWD data collected in May 2016.

Dr. Simpson found that the SCI-12 did not match very well between the two data sets. However, after the milepost 13, the correlation is slightly better. There was not an explanation of why the correlation improved after milepost 13. However, Dr. Simpson mentioned that the TSD data was not corrected by temperature, and the difference in collection dates and time of the year, may affect the results. Figure 5a and 5b below summarises the results. As can be seen both (SCI and BCI) showed very low $R^2$.

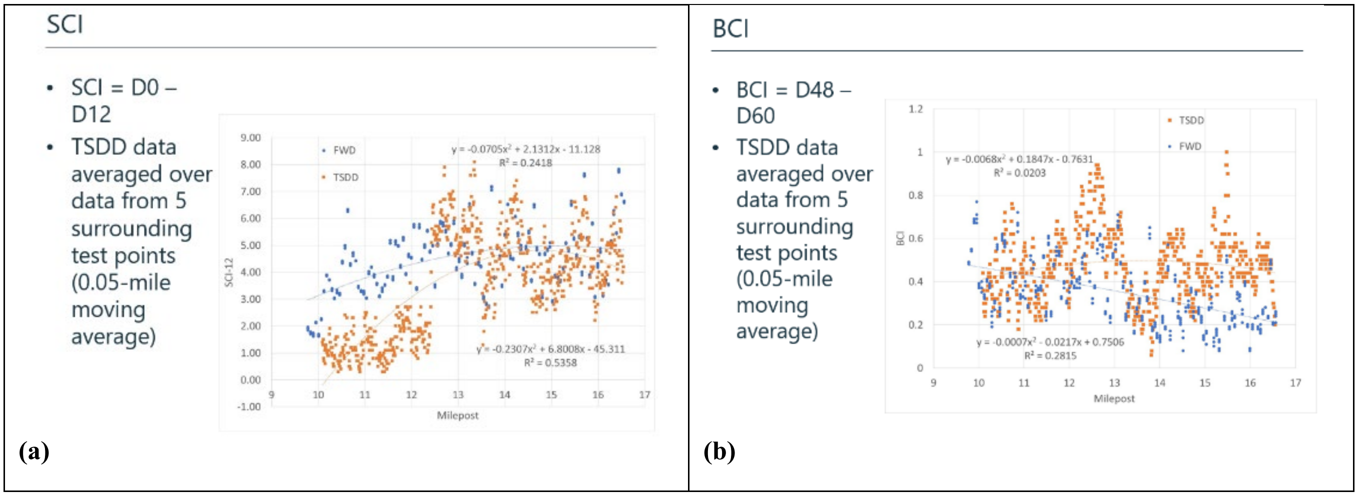



**Figure 5: SCI-12 Data Comparison between TSD and FWD Data Sets**

Dr. Simpson performed additional analysis using the AASHTO-93 guide for the backanalysis of the subgrade elastic modulus and SNeff. Figure 6 below shows the AASHTO-93 Guide equations.

Analysis – 1993 AASHTO Guide

- Design $M_R$
  - $M_R = C\frac{0.24\,P}{d_r r}$
- Effective SN
  - $SN_{eff} = 0.0045D\sqrt[3]{E_p}$

**Figure 6: AASHTO-93 Guide Equations**

Figure 7 shows the result of the comparison of SNeff and the subgrade elastic modulus. Dr. Simpson highlighted that both parameters have a very poor comparison with very low correlation factor reflected on low $R^2$ and the trend on the graphs.

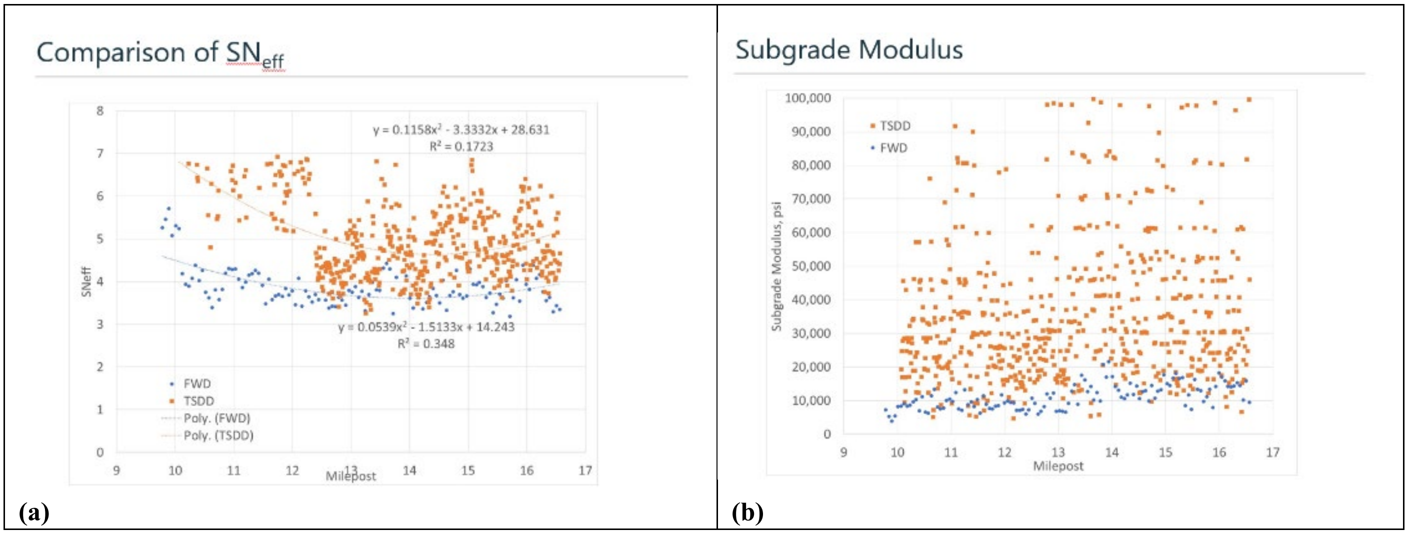



**Figure 7: SNeff and Backcalculated Subgrade Resilient Modulus Comparison Results**

Dr. Simpson concluded that another analysis approach with regards to the TSD deflection data is required. Figure 8 shows Dr. Simpson's conclusions and recommendations.

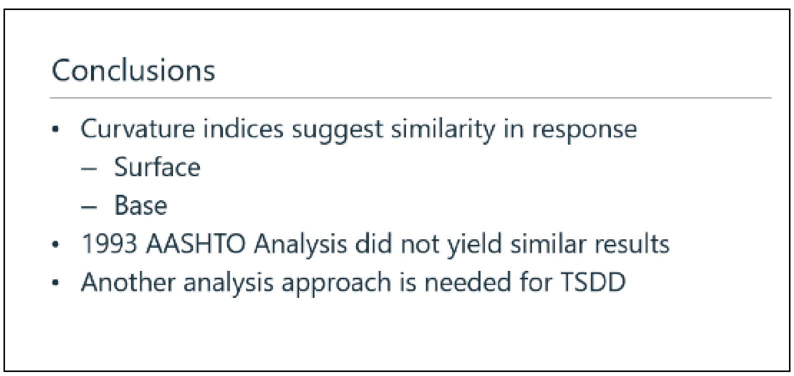



**Figure 8: Presenter's Conclusions and Recommendations**

## New Mexico TSD. Data Analysis Results

**Linda Pierce, Ph.D., PE and Nick Weitzel, PE**

NCE

Dr. Pierce presented the results of the TSD data analysis performed on a road section in New Mexico. The analysis is based on the AASHTO-93 rehabilitation method of flexible pavements which is based on determining the subgrade modulus and pavement effective structural number (SNeff) from measured deflections. Having obtained these two quantities, the required overlay thickness is then obtained based on projected traffic and the current pavement serviceability index (PSI) calculated from measured pavement distresses. The analysis used layer thickness information from Ground Penetrating Radar (GPR) measurements, which in some cases can have difficulties delineating the base layer. Therefore, the impact of including or excluding the base layer from the analysis was also investigated (see Figure 1).

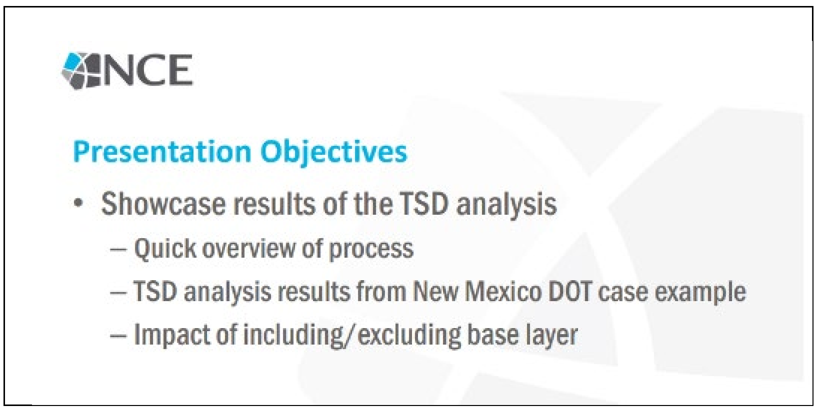



**Figure 1: Study and Presentation Objectives**

Figure 2 shows the flowchart of the approach followed to determine the pavement remaining service life, the required structural number (SNreq) and the overlay thickness. In the AASHTO-93 rehabilitation approach of flexible pavements, the SNeff is determined from the equivalent pavement modulus. The equivalent pavement modulus can be determined from layer moduli backcalculation or using a simplified approach described in the AASHTO-93 guide. Dr. Pierce used primarily the method based on backcalculation of layer moduli unless the root mean square error (RMSE) of the fitted deflection was higher than 5% in which case the simplified method was used.

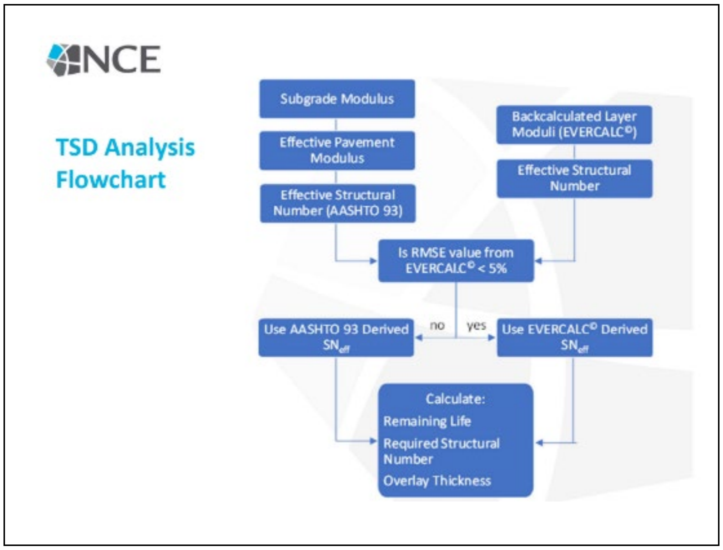



**Figure 2: The TSD Analysis flowchart**

The Figure 3 below, shows the location of the road section under study. It is a low volume road located in the Southern side of New Mexico state.

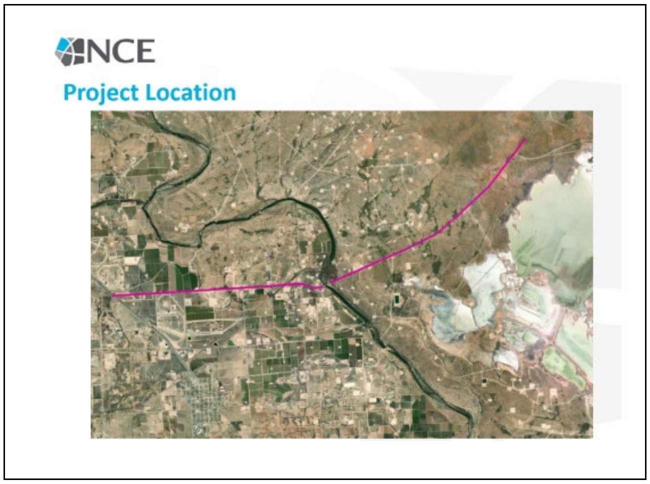



**Figure 3: Section Under Study Location**

Figure 4a shows the calculated subgrade modulus and pavement SNeff (Figure 4b). A moving average is also calculated to better visualize the spatial variation of the subgrade modulus and the SNeff. In general, lower values of both calculated parameters are observed before milepost 4.

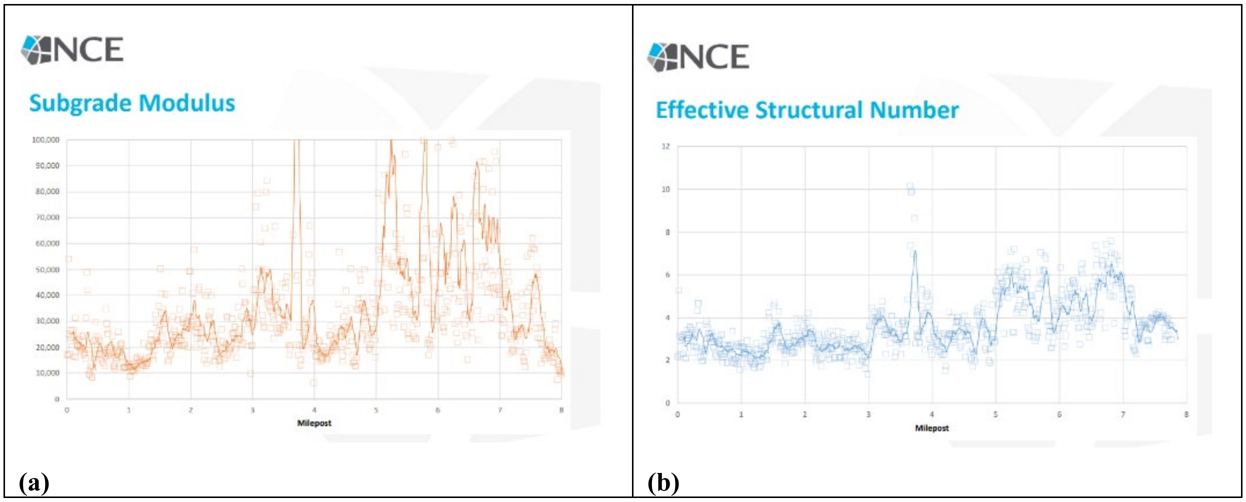



**Figure 4: Subgrade Elastic modulus and SNeff Results**

Figure 5a, 5b and 5c shows the calculated required overlay thickness. As can be seen, a thicker overlay is required at the beginning of the tested section and the thickness generally decreases toward the end of the road section. The right of way images show that some localized fatigue cracking is affecting the road at the start of section.

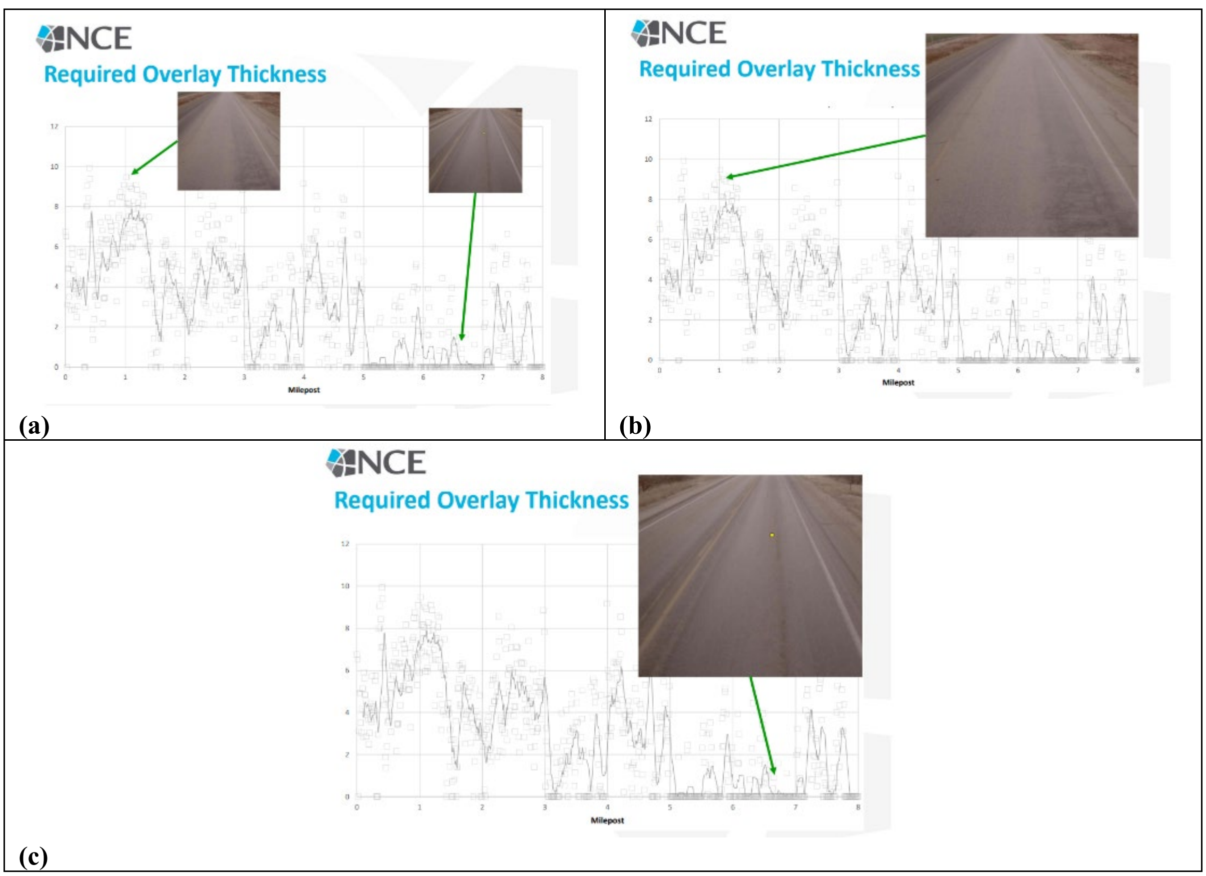



**Figure 5: Required Overlay Thickness Results**

Dr. Pierce mentioned that there were some evidences where the existence of the granular base could not be confirmed from the GPR, so additional analysis of the required overlay thickness and remaining life was performed modelling the pavement structure with and without granular base. Figure 6a, 6b and 6c shows the results of this analysis.

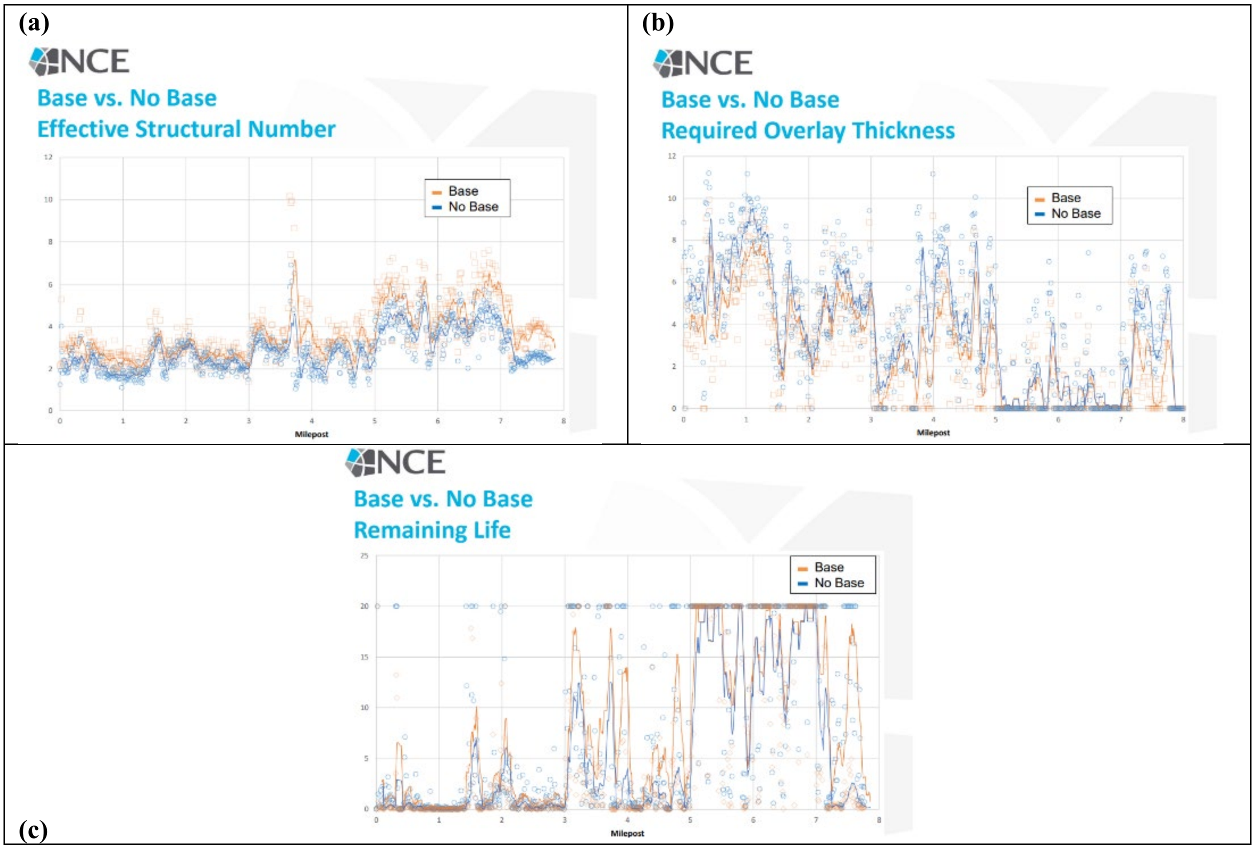



**Figure 6: Required Overlay Thickness, Remaining Life and SNeff, With and Without Granular Base Results**

As can be seen in Figure 6 above, when the base layer is included in the analysis, the required overlay thickness is reduced and the remaining life and SNeff increase, compared to when the base layer is not included. This is expected, due to the additional strength the base layer provides.

Figure 7 shows a colour coded thematic maps of the required overlay thickness with and without considering the base layer.

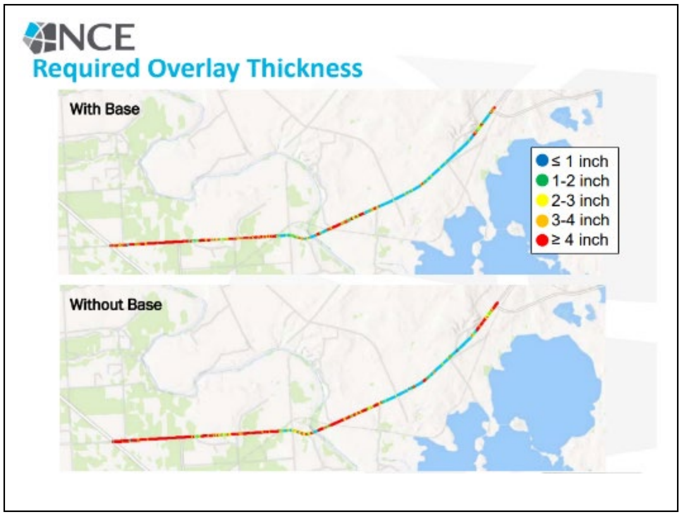



**Figure 7: Colour Coded Georeferenced Thematic Maps**

Figure 8 shows the remaining service life and the required overlay thickness as a function of SCI300 and D0. This plot was used to determine trigger values for SCI300 or D0. These triggers were only valid for the specific road being considered in this study.

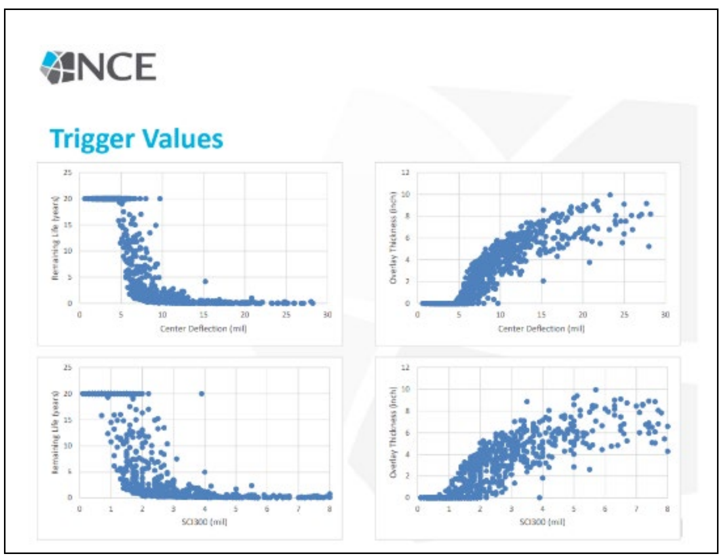



**Figure 8: Trigger Values for PMS Tools**

For the centre deflection D0, Dr. Pierce found that a trigger value around 10 mils seems to be appropriate to differentiate between sections with good remaining service life, and sections with low remaining service life. For overlay thickness, the trigger value of D0 seems to be around 7 to 7.5 mils. In the case of the SCI300, the trigger value for both remaining service life and overlay thickness seems to be around 3 mils.

Finally, Dr. Pierce highlighted that the TSD data is georeferenced, and can be combined with any set of results to show interactive maps with colour coded layers for better representation and understanding the results. The Figure 9 shows the highlighted comments from Dr. Pierson at the presentation.

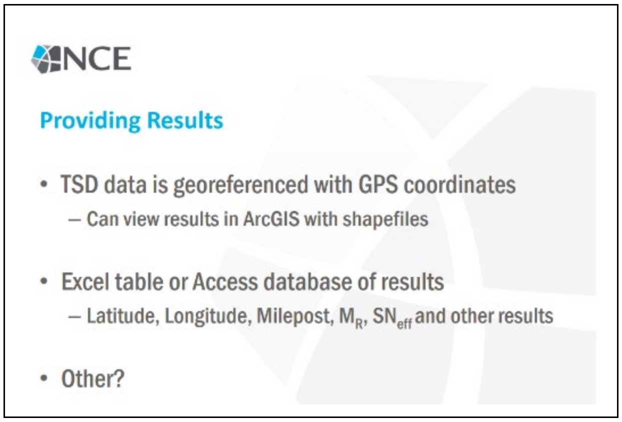



**Figure 9: Presentation's Highlights**

# Implementation of Traffic Speed Deflectometer Data into the Pavement Management System

**Amir Arshadi, PhD., PE; Mirkat Oshone, Ph.D., PE and Gerhard du Toit, PE**

AECOM

The presentation was introduced by Gerhard du Toit and then delivered by Dr. Arshadi. The objective was to combine the TSD data with the surface distresses for a better understanding of the behaviour of the pavement to improve the treatment selection at the PMS level. Figure 1 shows the project statement and objectives of the study.

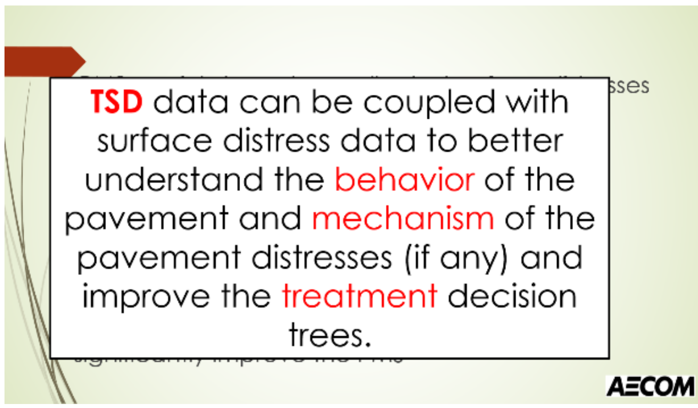



**Figure 1 Project Statement and Objectives**

Dr. Arshadi presented the concept of curvature zones of the deflection bowl and how they relate to the condition of the different layers in the pavement structure. Figure 2 shows the different curvature zones along a three layers pavement. As can be seen, is the load is more concentrated at the bottom of the asphalt layer compared to the top of the subgrade. In addition, Figure 2 lists the representative structural parameters that can be used to describe each curvature zone. These structural parameters were later used for data analysis and representation.

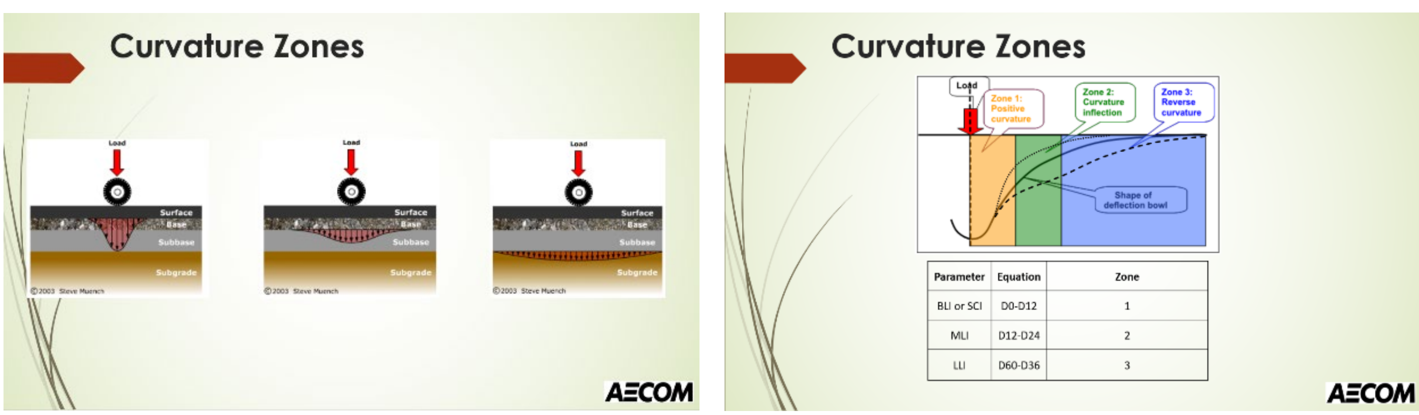


**Figure 2 Curvature Zones**

Figure 3 shows details of the traffic speed deflectometer and its principles for computing the deflection data. The deflection slope as the ratio of the horizontal speed and vertical speed is presented.

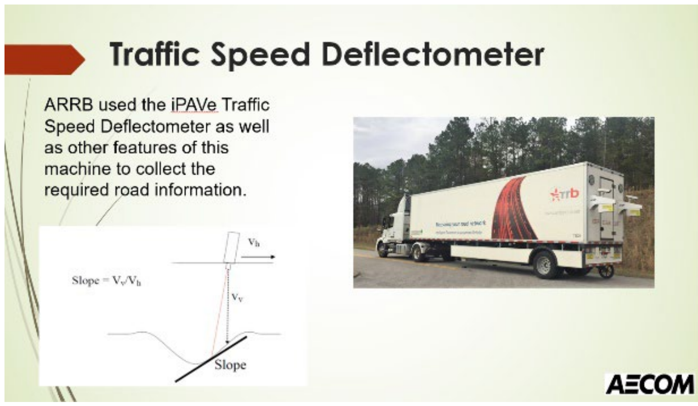



**Figure 3 Traffic Speed Deflectometer (TSD) Details and Principles**

The road under study comprised of two sections (Part I and Part II) of SH-11 in North Carolina. The traffic data (Figure 4), the surface condition data in terms of block cracking, longitudinal cracking, and transverse cracking (Figure 5) were used along with the TSD deflection data to perform the analysis. As can be seen in Figure 5 above, the road section is affected by low severity fatigue cracking in localized areas; low to moderate severity block cracking, and low to moderate severity longitudinal and transversal cracking. Furthermore, the information about the pavement structure and layer thicknesses and the backcalculated subgrade moduli and CBR values is presented in Figure 6. .

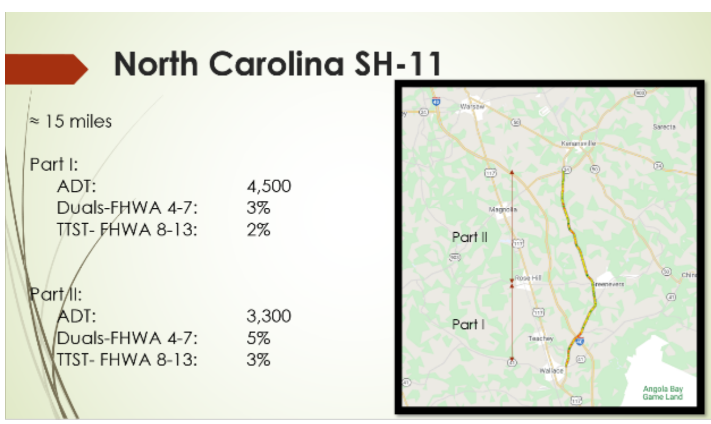
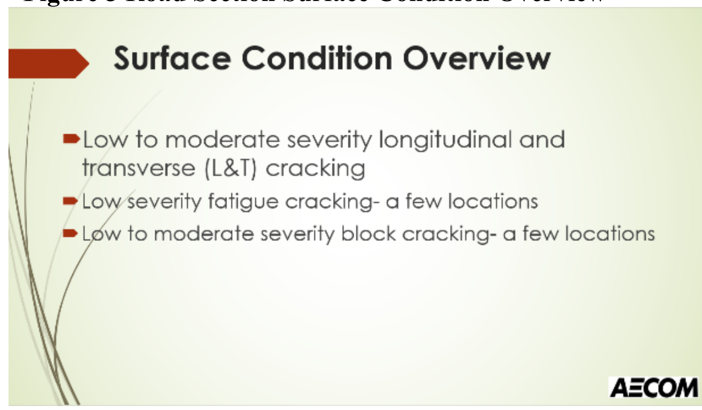
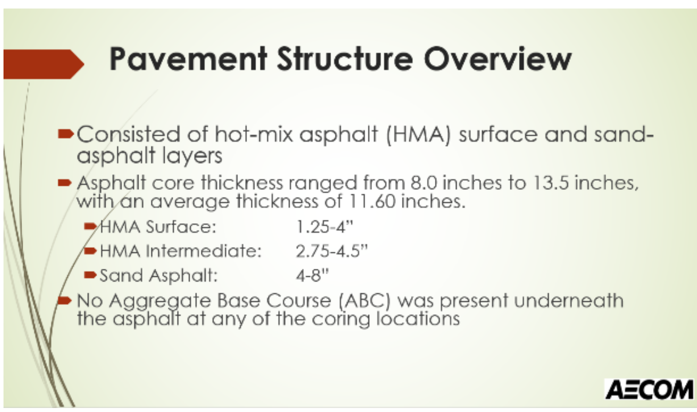
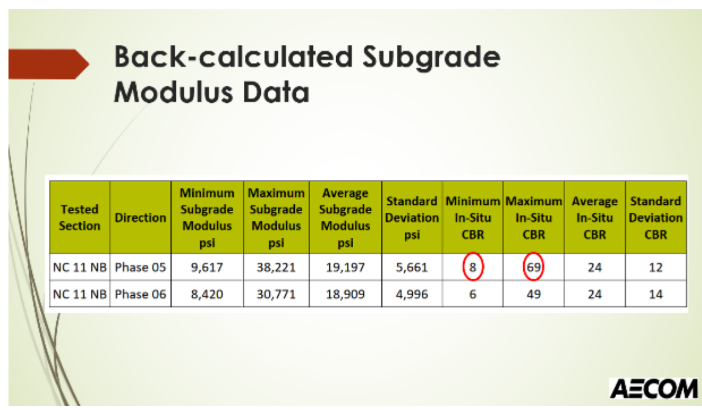



**Figure 4 North Carolina SH-11 Traffic and Section Location Details**


Figure 5 Road Section Surface Condition Overview




| Tested Section | Direction | Minimum Subgrade Modulus psi | Maximum Subgrade Modulus psi | Average Subgrade Modulus psi | Standard Deviation psi | Minimum In-Situ CBR | Maximum In-Situ CBR | Average In-Situ CBR | Standard Deviation CBR |
|---|---|---|---|---|---|---|---|---|---|
| NC 11 NB | Phase 05 | 9,617 | 38,221 | 19,197 | 5,661 | 8 | 69 | 24 | 12 |
| NC 11 NB | Phase 06 | 8,420 | 30,771 | 18,909 | 4,996 | 6 | 49 | 24 | 14 |

**Figure 6 Road Section Pavement Structure and Subgrade Elastic Modulus**

For the analysis of the TSD data, Dr. Arshadi presented three methods of analysis:

1. Analysis of deflection data based on histograms
2. CUMSUM analysis of deflection data and distress data
3. Analysis based on the effective structural number (SNeff) and the required structural number (SNreq)

Histograms of the measured deflections and the calculated structural indices (Figure 7) suggesting that at the basic level of data analysis, the deflection data can be combined with additional data such as traffic data and climate data to come up with structural condition thresholds.

A more statistically sound analysis would be to divide the road analysed into uniform sections using the CUMSUM approach shown in Figure 8. The CUMSUM method applied to the structural data, the cracking data, and the roughness data is shown in Figure 9. The analysis based on the structural information data resulted in identifying four homogenous sections that matched the changes in asphalt layer thickness between 10 inches, 11 inches and 12 inches. while the analysis based on cracking and roughness identified only two homogenous sections.

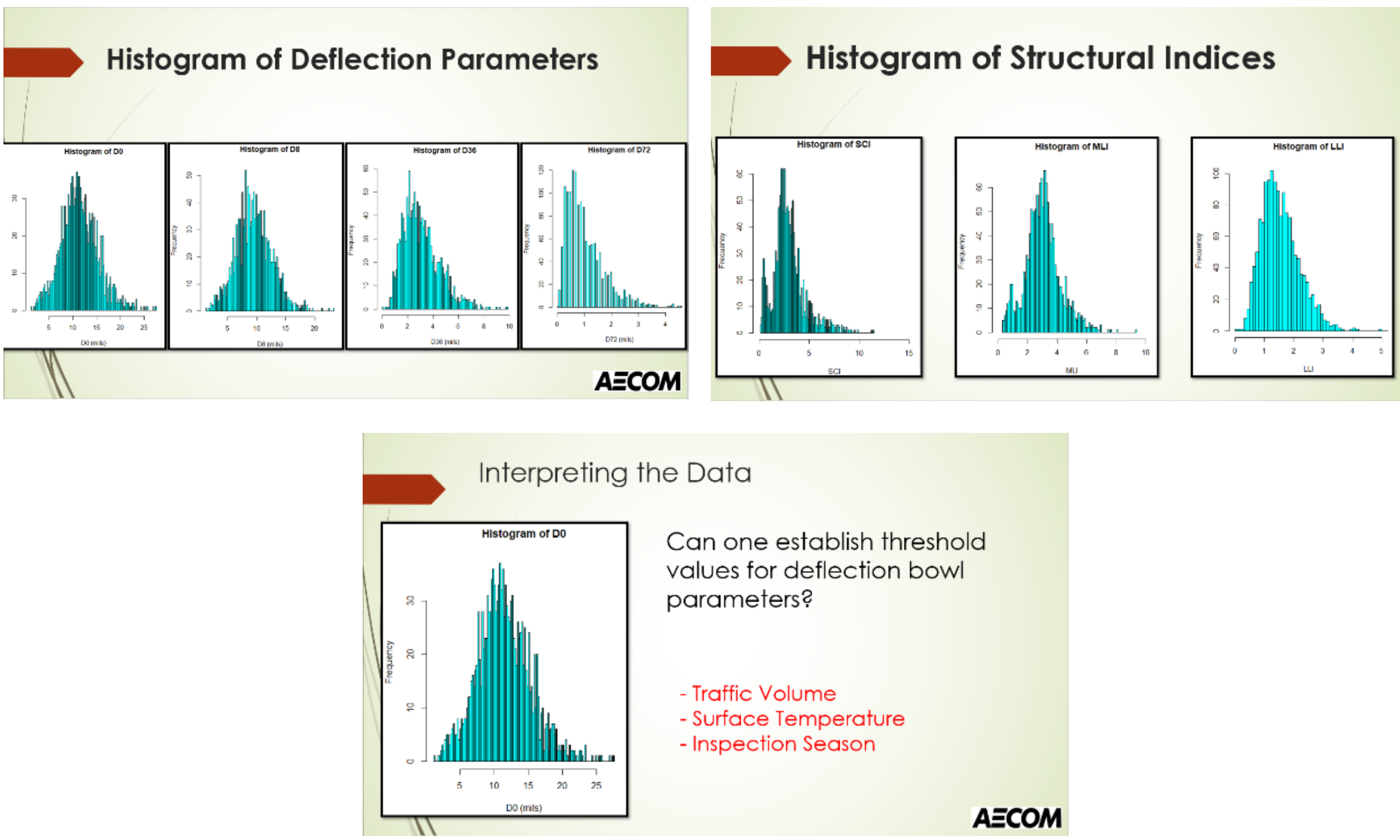



**Figure 7 TSD Data. Histograms and Data Analysis**

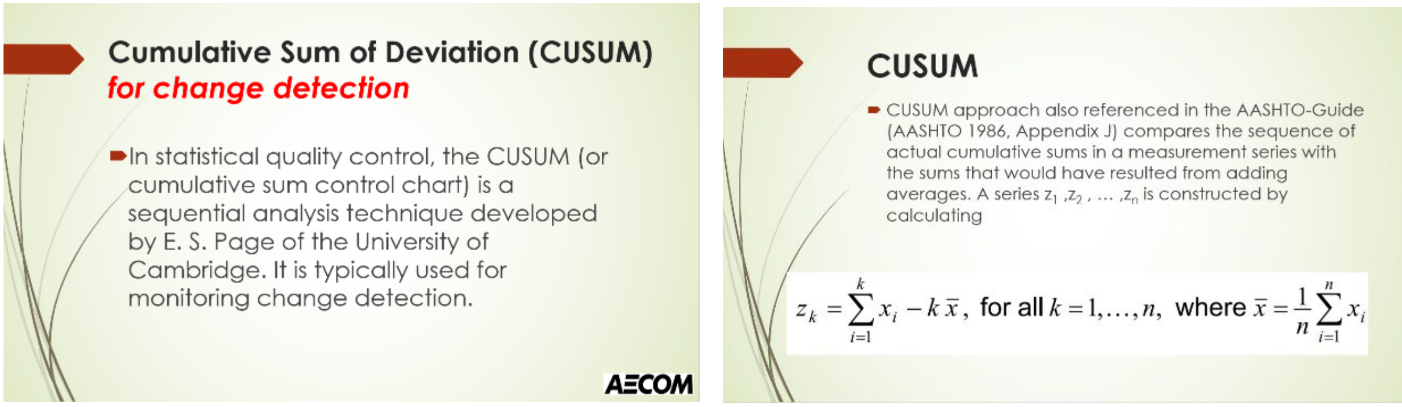



**Figure 8 AASHTO-93 CUSUM Analysis Methodology**

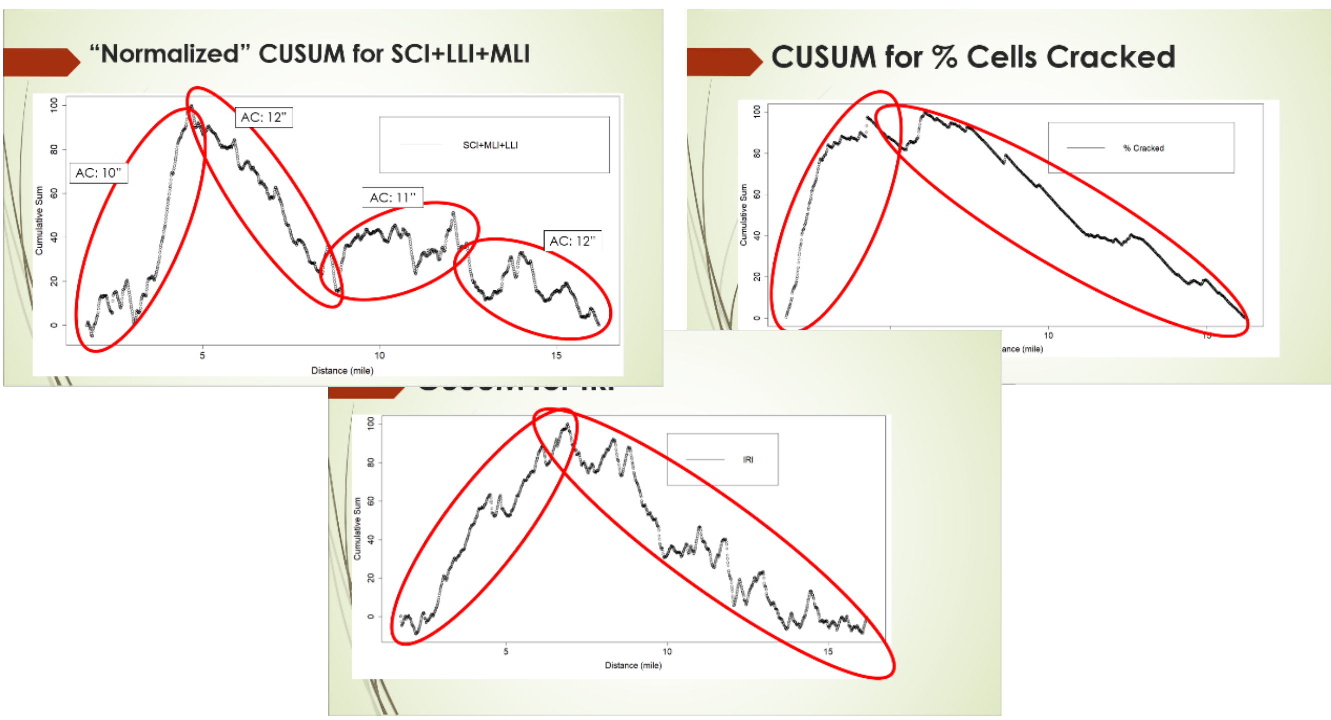



**Figure 9 CUSUM Analysis**

Finally, Dr. Arshidi also presented a TSD data analysis using the structural ratio defined as the ratio of SNeff over SNreq (Figure 10). The SNeff was calculated based on the modified Rohde's equation and the SNreq was estimated using the AASHTO-93 equation for a 20 years design traffic. The IRI and cracking as a function of the structural ratio are presented in Figure 11 showing that an inverse exponential relationship describes the dependence of these surface observed distresses on the structural ratio.

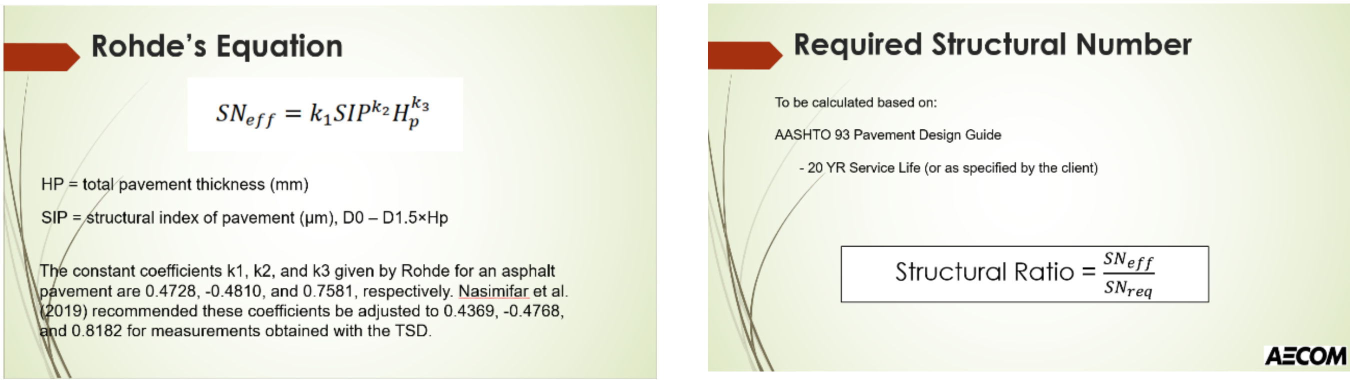



**Figure 10 Modified Rohde's Equation**

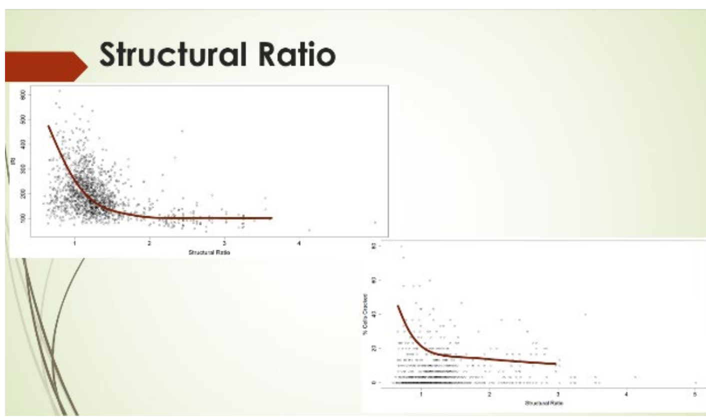



**Figure 11 Structural Ratio vs IRI and % Cell Cracked**

Figure 12 shows the calculated structural ratio along the analysed road along with the four identified homogenous sections from Figure 9. Figure 12 shows that most of the values of structural ratio less than one are found in the first homogenous section along the road which is the sections that has a 10 inches asphalt layer. This suggests that this first section along the road might be a good candidate for a structural treatment. In contrast, for the remaining three homogenous sections, the majority of the structural ratio values are larger than one suggesting a functional treatment is the most likely appropriate treatment for these sections. It should be highlighted the yellow section, which has most of the structural ratio values less than one in these three sections, consists of a section of the road where the asphalt concrete thickness is 11 inches , whereas the two sections in green have an asphalt concrete thickness of 12 inches. Similar analysis of structural treatment vs. functional treatment was conducted using the % Cell Cracked, and the results are shown in Figure 13 below.

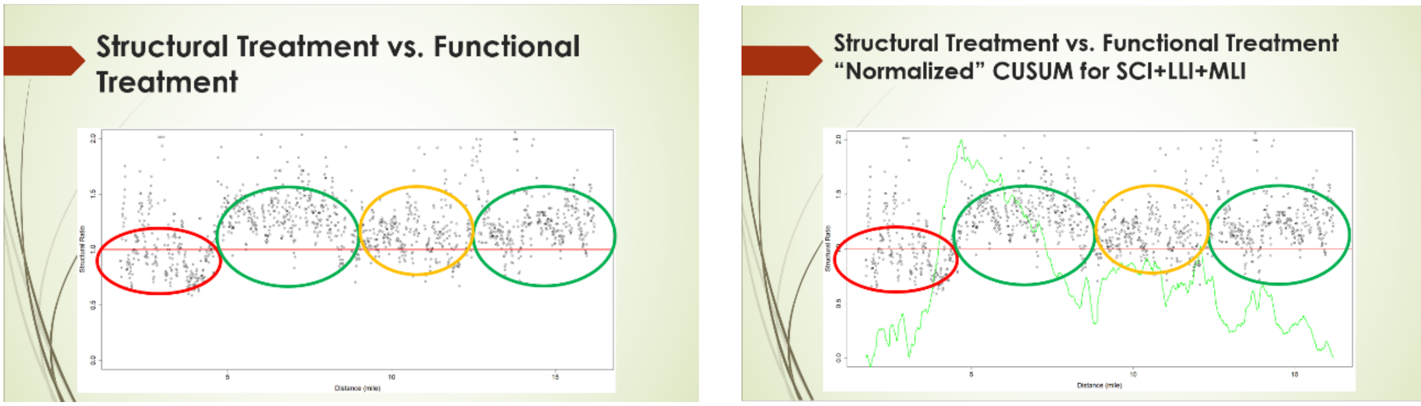



**Figure 12 Structural Treatment vs. Functional Treatment Based on the Structural Ratio (CUSUM Analysis using the Sum of SCI+LLI+MLI)**

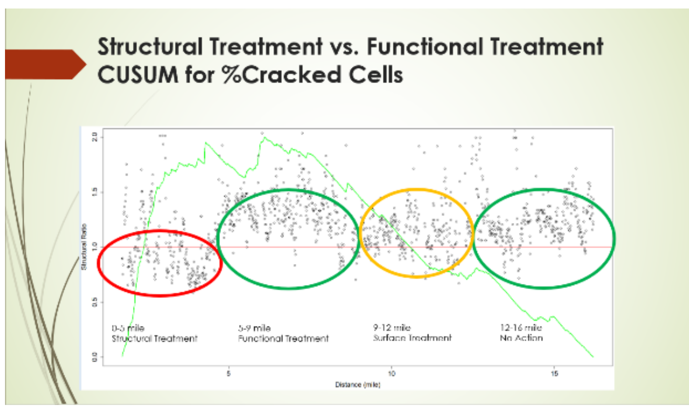



**Figure 13 Structural Treatment vs. Functional Treatment Based on the Structural Ratio and % Cell Cracked**

Dr. Arshadi presented a discussion of recommended threshold values for sections in good, fair and poor condition based on the D0 frequency histogram. Figure 14 shows the approach. As can be seen D0 values around 10 mils and 15 mils look adequate for this particular study.

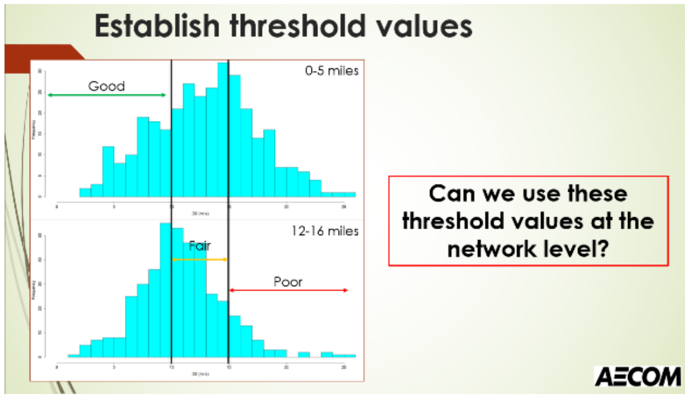



**Figure 14 Proposed Intervention Level Threshold**

In summary, Dr. Arshidi concluded that there are different ways to analyse TSD data, and it can be implemented into a PMS decision tool. He concluded that the combination of TSD data and surface distresses is a good approach to understand pavement behaviour. Finally, it was concluded that TSD data can be used at project level analysis to optimize treatment selection procedures. Recommendations for future work, included the establishment of threshold for intervention levels, include the seasonal effects and extend the finding of this study to other pavement surfaces, e.g., concrete and composite pavements.

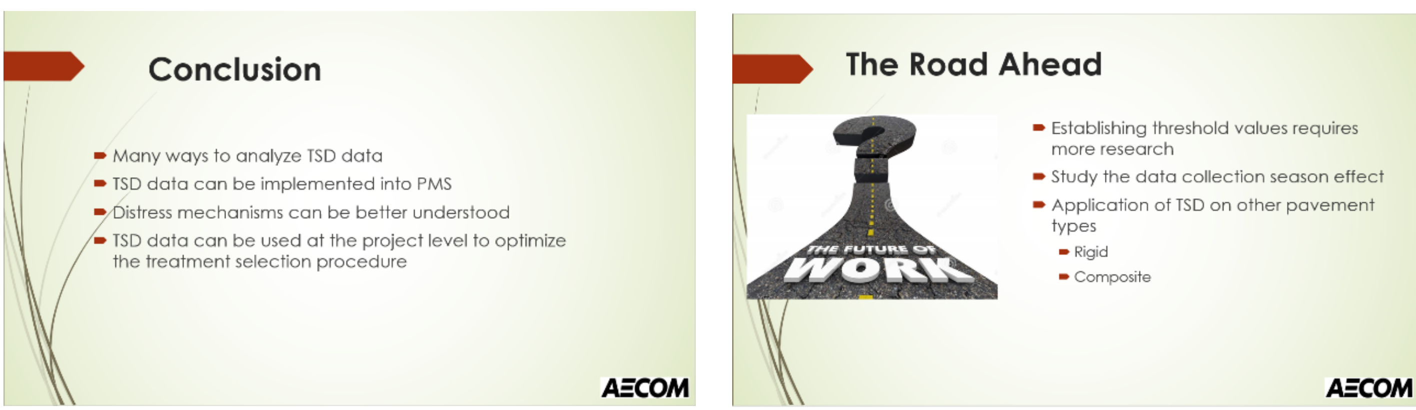



**Figure 14 Conclusions and Future Works**