

TRANSPORTATION RESEARCH
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**State Departments of
Transportation
Experiences and
Applications with
Traffic Speed
Deflection Devices**

The National Academies of
SCIENCES • ENGINEERING • MEDICINE



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State Departments of Transportation Experiences and Applications with Traffic Speed Deflection Devices

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PUBLISHER'S NOTE

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Introduction

Traffic speed deflection devices (TSDDs) are designed to measure pavement deflections or deflection velocities in response to loads applied by trucks moving at or near prevailing traffic speeds. In January 2019, Transportation Research Board (TRB) sponsored a workshop, Workshop on the Use of Traffic Speed Deflection Device Data in Network- and Project-Level Pavement Decisions, which brought together six national and international experts on the subject who shared their thoughts, experiences, and vision for the future of TSDDs. The six presentations made at that workshop along with the ensuing discussion are documented in *Transportation Research Circular E-C254: A Workshop on the Use of Traffic Speed Deflection Device Data in Network- and Project-Level Pavement Decisions*. A few months before that January 2019 workshop, in October 2018, the Transportation Pooled Fund (TPF) -5(385) Pavement Structural Evaluation with Traffic Speed Deflection Devices was initiated with currently 25 members from state highway agencies and the Federal Highway Administration (FHWA) participating. This growing interest from highway agencies in the TSDD technology led the TRB Standing Committee on Pavement Structural Testing and Evaluation to organize a 2021 workshop on state departments of transportation (DOTs) experiences and applications with TSDDs.

This E-Circular documents the 2021 Workshop on the Use of Traffic Speed Deflection Device Data in Network- and Project-Level Pavement Decisions. Ten planned presentations organized into three topics were given at the workshop. The presentations were followed by a panel discussion and then an 11th presentation summarizing the key workshop findings.

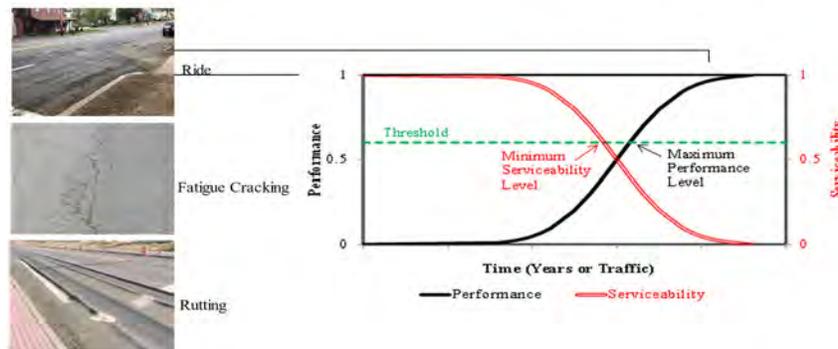
Importance of Pavement Structural Evaluation to Decision-Making Process

Going Beyond Condition Survey

SOHEIL NAZARIAN
The University of Texas at El Paso

Soheil Nazarian’s presentation stressed the importance of pavement structural evaluation to the decision-making process and provided an overview of how structural performance evaluation has evolved and where it might be going.

The goal of performance evaluation, especially at the network level, is to have a long-lasting, structurally strong, smooth, and safe road. The traditional network-level approach to managing pavements based only on functional performance evaluation (surface distresses) has limitations so including the structural performance can help address some of these limitations (Figure 1). One of the most important benefits of structural performance evaluation is that it can point to the root causes of the problem before it is manifested on the surface allowing a proactive response to address the problem. Of course, structural performance evaluation has its own challenges; the need for properly calibrated models to interpret the results being near the top of that list.



(a)

	Functional Performance	Structural Performance
	Providing users with a safe and comfortable ride	Withstanding traffic and environmental loading for a predetermined period
Advantage	<ul style="list-style-type: none"> • Many DOTs have legacy data • Criteria for triggering action exist 	<ul style="list-style-type: none"> • Estimating root cause of potential distress before it manifests • Harmonizing network and project level analysis
Disadvantage	<ul style="list-style-type: none"> • Subjective • Reactive response 	<ul style="list-style-type: none"> • Proper calibrated model are required

(b)

FIGURE 1 Structural and functional pavement evaluation: (a) performance and (b) network.

There are two aspects of performance evaluation: the network level and the project level. Network-level performance evaluation is used mainly for planning and budgeting while project-level performance evaluation is used mainly for engineering-related activities such as design and construction maintenance (Figure 2). The standard business approach has been to use functional performance evaluation at the network level and reserve structural performance evaluation to project-level-related activities. This approach to pavement evaluation has kept the management and planning decision process mostly disjointed from the design and maintenance decision process. Structural performance evaluation can provide a link between network-level and project-level practices. It will allow agencies to have a more uniform and smooth decision-making process, from budgeting and planning to design and execution.

For network-level applications, the information quality level needed from the structural performance evaluation can vary depending on how the information will be used (Figure 3). At the lowest level are qualitative measures such as the identification of anomalies and the location of relatively weaker sections. This information can be used to determine where more-detailed testing should be performed at the project level. A higher information quality level can be obtained from indices and indicators that are often well correlated with mechanistic measures that determine the overall structural capacity of the pavement. This is the current state of practice with the structural information collected by TSDDs. At this level, the structural information obtained can support the development of maintenance and rehabilitation strategies as well as cost estimates. Finally, the highest information quality level provides details that can also be used for

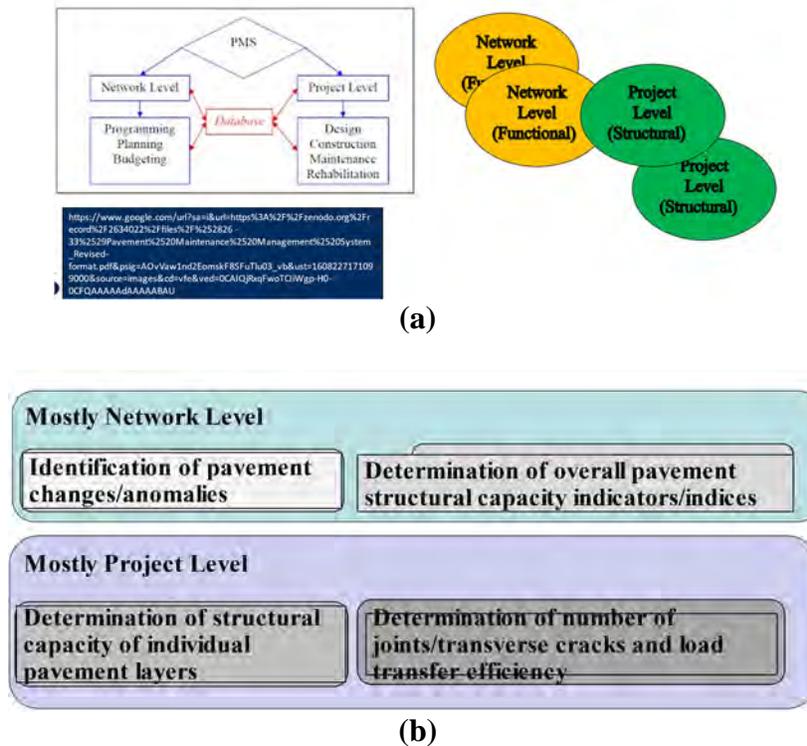


FIGURE 2 Pavement performance evaluation: (a) network level versus project level and (b) levels of structural evaluation.

1. **Identification of pavement changes/anomalies**
 - Assess variability and/or uniformity of pavements
 - Delineate homogeneous pavement sections and/or subsections
 - Identify potential problem spots/areas or anomalous locations
2. **Determination of overall pavement structural capacity indicators/indices**
 - Assess overall pavement structural capacity
 - Support development of M&R decisions and cost estimates
3. **Determination of structural capacity of individual pavement layers**
 - Assess structural capacity of individual pavement layers / overall pavement structure
 - Identify problem/weak pavement layers within project limits that must be corrected
 - Support development of detailed M&R strategies and cost estimates
4. **Determination of number of joints/transverse cracks/load transfer efficiency**
 - Estimate number of joints/working transverse cracks along length of PCC pavement
 - Assess load transverse efficiency at joints/working transverse cracks

FIGURE 3 Purpose of structural evaluation levels.

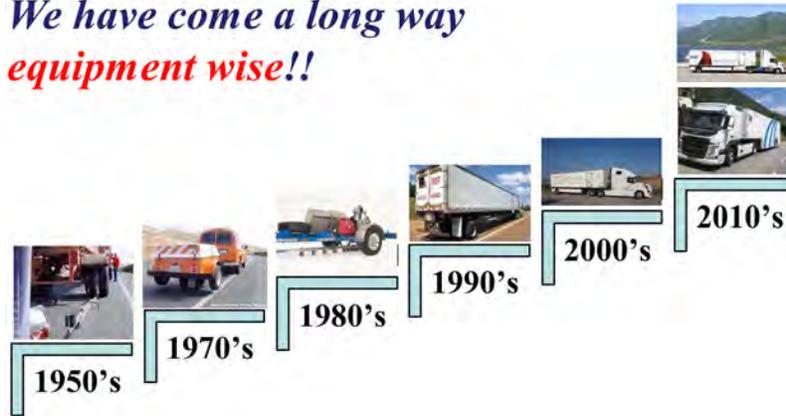
project-level applications. This can involve determining the structural capacity of individual layers for flexible pavement or determining the load transfer efficiency for rigid pavements. This is the current state of research.

The history of structural evaluation goes back to the 1950s and the Benkelman beam. We have come a long way since then with major advances occurring in the 1980s with the introduction of the falling weight deflectometer (FWD), which also coincides with the introduction of personal computers (Figure 4). The use of the FWD became widespread in the 1990s and has since been the standard device for structural evaluation. The 1990s also saw the initial development efforts for TSDDs, which build on the legacy of early slow-moving devices such as the deflectograph and the curviameter (Figure 5). These efforts started to come to fruition in the early 2000s and by the early 2010s, the Greenwood traffic speed deflectometer (TSD) was routinely being used for network-level structural data collection by highway agencies. More recently, new devices such as the Dynatest rapid pavement tester (RAPTOR) have been developed and improved versions of the TSD with more and better sensors are being built and delivered to various customers.

In terms of analysis, the 1980s saw significant theoretical developments as well as practical implementation of backcalculation procedures, which was made possible due to personal computers. These analysis techniques made significant strides in the 1990s and by the early 2000s, the backcalculation results were being effectively used in the evaluation of pavements and in the design of overlays. These results were mostly being applied at the project level, but researchers and practitioners were already considering network-level applications and, for that purpose, proposing indices that can be calculated from FWD measurements, which have really laid the foundation for the indices used with TSDD measurements. Finally, the development of machine learning and advances in computing power are providing new possibilities for interpreting the data collected by TSDDs.

So, where do we go from here? In the early 2010s, questions about the precision and accuracy of TSDDs and how TSDD measurements compare to FWD measurements started being widely investigated (Figure 6). These questions naturally lead to questions about calibration of the TSDDs and the sensitivity of the measured pavement response by TSDDs to the actual pavement conditions. Answers to these questions can help develop indices that are better related to pavement performance and therefore improve the reliability of pavement performance prediction. These questions are still being investigated and with the increased acceptance and use of TSDDs, questions are being asked about how to standardize the reported data and how to provide for inter-portability between devices. In addition, there is a need to better understand the principles by which the devices operate.

*We have come a long way
equipment wise!!*



*We have come a long way
analysis wise!!*

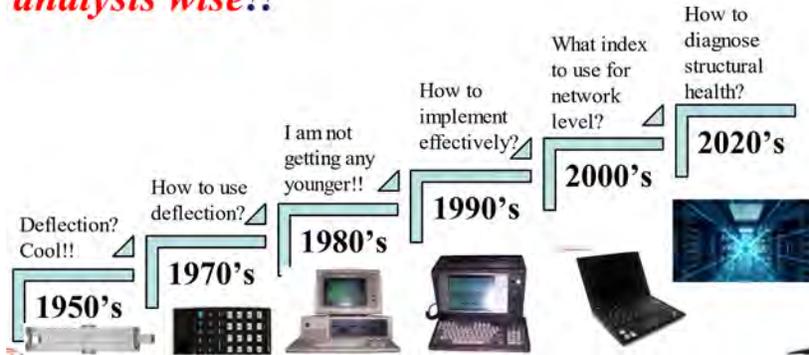


FIGURE 4 Evolution of pavement structural evaluation and the parallel evolution of computing.

Building on a Legacy!!



California Traveling Deflectograph



French Curviametre



Danish Deflectograph



Lacroix Deflectograph

FIGURE 5 Evolution of moving structural evaluation devices.

Where to go from here (2021)!!

Topic	Subject
Equipment-Related	Establishing precision of each device
	Establishing accuracy of each device
	Standardizing output for inter-operability of devices
Measurement-Related	Understanding sources of differences in deflections from TSDD and FWD
	Developing a methodology for calibration of TSDDs
Application-Related	Establishing sensitivity of measured deflections to pavement condition
	Identifying number & locations of deflection points for a specific application
	Develop realistic but practical numerical models for better understanding the performance of devices
	Utilize machine learning/artificial intelligence for pavement diagnosis

FIGURE 6 Topics and subjects of pavement structural evaluation that remain partially or completely unanswered.

Idaho Transportation Department's Travel Speed Deflectometer Experience

JIM POORBAUGHT

Idaho Transportation Department

The presentation by Jim Poorbaught highlighted how the TSD has enabled the Idaho Transportation Department (ITD) to have better insight about their pavements and how it is used to help forecast and select maintenance treatments. ITD has shown substantial return on investment from the use of the TSD and has improved engagement with stakeholders.

ITD own and operate their own nondestructive testing equipment, have a mature and robust pavement management system, and have spent a lot of effort towards performance-based treatment selection and towards being proactive in how they maintain their pavements. Still, because of the lack of information about the strength of the pavement (especially what is occurring underneath), unexpected premature failures do unexpectedly occur. This has led ITD to explore if the TSD can provide that missing information (Figure 7).

When ITD started exploring the use of the TSD, its objective was to improve and enhance the information used to support project selection. The benefits ITD initially started seeing from the use of the TSD were:

- Improved network management;
- Support for future long-range project and corridor planning;
- Improved information for project selection;
- Holistic view of the network, not just the bad sections; and
- Better project selection—right project, right treatment, right reasons.



FIGURE 7 Questions about unexpected failure led ITD to investigate if TSDs can provide an answer.

The first evaluation effort of the TSD was undertaken in 2014 with data collected on 500 mi in District 6. From that effort, ITD determined that based on visual survey alone, the right project was selected 70% of the time. It also showed that the TSD could help improve decision-making over the life of the pavement with savings (for the 500 mi) estimated at \$15 million over the life of the pavement. This represents about 3% improvement in how funds are spent and a return on investment that is over 4% (Figure 8). Since then, and through TPF-5(385), ITD has committed more money (\$880,000) and efforts to collect more TSD data and incorporate the TSD derived structural information into their asset management system (Figure 8).

ITD's rationale for using the TSD is to develop a better understanding of how the pavement substructure is performing. Using this information, it becomes possible to estimate how long the pavement will be performing adequately before the distresses (cracking) appear on the surface. For example, the use of the TSD has allowed ITD to group pavements into four categories based on the pavement and base condition. An important category is the "at risk" pavements that appear "good" but have poor subgrade strength. They cannot be identified from surface distress condition surveys and without the TSD information, remain hidden until

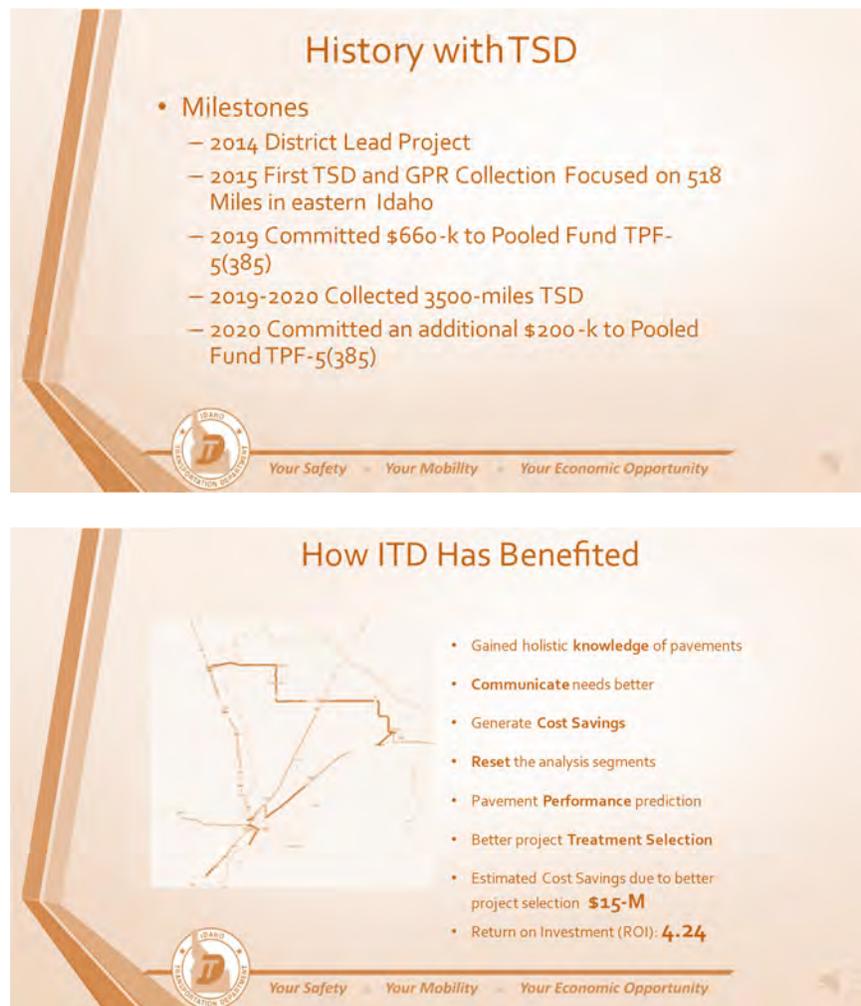


FIGURE 8 ITD history and benefit with use of TSD.

distresses appear on the surface. Similarly, pavement with a strong base but poor surface condition are good projects for light maintenance applications. This will enable ITD to make better use of their budget and maximize the long-term benefit of projects across the network.

ITD sees great potential in the TSD and are committed to keep using it. They are confident in leveraging the data the TSD produces into valuable information and have already seen a significant return on investment. This has led ITD to undertake several research projects as part of TPF-5(385) as well as with the University of Idaho. These projects focus on developing deterioration curves, metrics, and triggers to use with pavement management system (PMS) decision trees (Figure 9).

Finally, Jim offered personal thoughts on what the future may look like in terms of pavement evaluation:

I believe that in the near future, Structural performance measures and metrics will become incorporated into the National Transportation Performance Metrics. For those that may scoff at that assertion, they need to consider the driving goals of the federal mandated Transportation Asset Management Plans. The overarching objective is to ensure that transportation agencies are being effective and good stewards with the taxpayer dollars with which we are entrusted. Viewed through this lens, we can conclude, “that which cannot be seen is more important than that which is.” In other words, it does not matter how beautiful a structure is because it is only as good as the foundation upon which it is constructed... I admit that there is a long journey ahead across uncharted territory. We should not focus upon the challenges and risks so that it prevents us from advancing, but be resolute in overcoming these so we may reap the benefits this technology promises.



FIGURE 9 Planned research activities with TSD.

South Carolina Department of Transportation's Experience and Application

DAHAE KIM

South Carolina Department of Transportation

Daehae Kim presented South Carolina's experience with the TSD and gave an overview of initial findings from a South Carolina DOT-sponsored research project on how to effectively use TSD data.

South Carolina DOT joined TPF-5(385) and over a period of 4 days in 2019, collected about 1,000 mi of data on primary roads. Although states participating in the pooled fund have the option to collect the data 1 day a year for 3 years, South Carolina DOT intentionally decided to collect all the data in consecutive 4 days to minimize the effect of temperature and year-to-year variations. Only a limited number of pavement design engineers have access to the data and to make better use of the data, South Carolina DOT initiated a research project with the following two objectives:

1. Classify pavements into structurally good, fair, and poor conditions, and
2. Use TSD data in South Carolina DOT's rehabilitation candidate project-selection procedure.

As part of the project, a survey was sent to state DOTs asking if they collect structural condition data and how it is incorporated into their PMS. Twenty-five agencies responded and a summary of the responses is given below.

1. 80% of the respondents collect pavement structural data.
2. 60% of respondents use FWD and 20% respondents are using TSD.
3. Only 13% of the respondents have incorporated structural condition data into their PMS for network-level and project-level decision-making.

Based on a review of the literature (Figure 10), South Carolina DOT selected structural condition index 12 (SCI) (D_0 or deflection under the center of the load minus D_{12} or deflection 12 in. away from center of the load) to classify the pavement into good, fair, and poor conditions and selected the thresholds based on the Transportation Asset Management Plan (TAMP). In the TAMP, 28% of the pavements are classified as good. That value of 28% was used to determine the SCI 12 threshold for good (that is the threshold for which 28% of the SCI values are lower). This corresponded to an SCI 12 of 1.6 (Figure 11). A similar approach was followed to define a threshold for structurally poor pavements. With these thresholds defined, a visual approach to combine TSD data with the pavement quality index (PQI) to select treatments was developed (Figure 12). The plot of SCI 12 (y -axis) versus PQI (x -axis) is divided into nine regions. Region 1 has high distress (low PQI) and high SCI 12 and can be a good candidate for reconstruction or full-depth reclamation. Region 7 has high distress but low SCI 12. This could be a good candidate for a light treatment. Region 3 has low distress but high SCI 12. The surface is still in good condition, but the structural condition suggests a weak pavement. This case is a good candidate for further project-level investigation. Although the final decision on how to use the

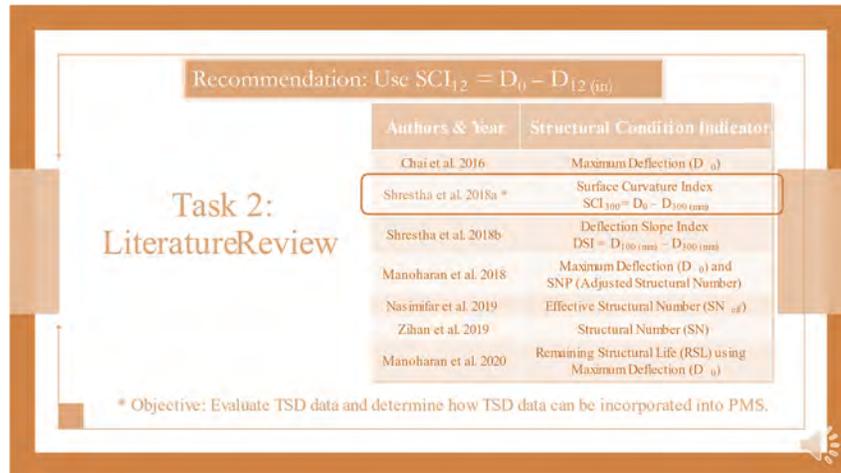


FIGURE 10 Reviewed literature as part of TSD research project.

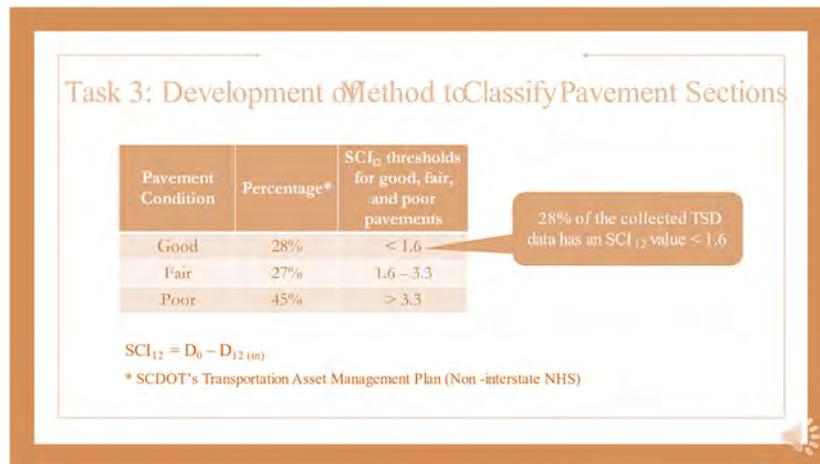


FIGURE 11 Thresholds for pavements in good, fair, and poor structural condition.

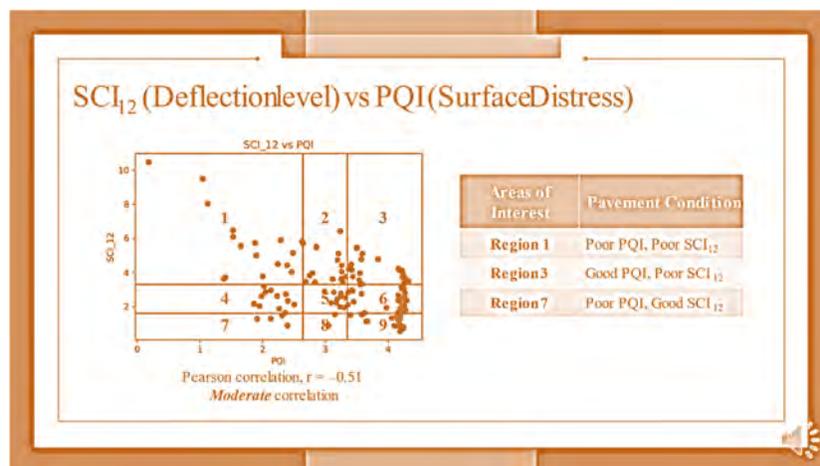


FIGURE 12 Treatment selection approach based TSD SCI_{12} and PQI.

Task 5: "Secondary Filter"

- SCDOT Engineering Directive 63
 - Candidate projects are selected based on various criteria, including PQI, IRI, ADT, ADTT, etc.
 - Top 20% of candidate projects are given to district engineers, who uses another set of criteria to complete ranking.
- SCDOT wants to provide structural condition information at second stage, referred to as "secondary filter."
- Proposed method: add another criterion to account for TSD score, which is a weighted average of the segments with poor SCI₁₂.

Example: percentage of pavement with poor SCI₁₂ = 30%. Length of pavement with poor SCI₁₂ = 2 miles, and total segment length = 10 miles.

$$\text{TSD Score} = \frac{2}{10} \times 30 = 6$$

FIGURE 13 Example of TSD score as a secondary filter criterion for project selection.

data from the TSD has not yet been made, South Carolina DOT envisions the use of TSD information as a "secondary filter" (Figure 13) with the "primary filter" being the surface condition and traffic. An example of how the structural information can be taken into account is shown in Figure 13.

As for future work, South Carolina DOT plans to implement an Excel-based tool to calculate the TSD score, evaluate the cost-effectiveness of TSD data collection, and determine whether TSD data is valuable and merits changes in current pavement management practices (Figure 14).

Future Work

- Implement Excel-based tool to calculate TSD score using actual candidate lists provided to district engineers.
- To be determined: Assess cost-effectiveness of collecting TSD data every 5 years for network-level decision making.
- To be determined: if TSD data are deemed worthy, propose revision to Engineering Directive 63.

FIGURE 14 Planned future implementation of TSD data.

New Mexico Department of Transportation's Early Experiences and Applications with Traffic Speed Deflection Devices

JEFFREY MANN

New Mexico Department of Transportation

Jeff Mann from the New Mexico DOT presented the experiences of the New Mexico DOT with the TSD and their future plans. New Mexico DOT is a member of TPF-5(385) and plans to collect about 4,200 mi of TSD data, mostly on National Highway System and Interstate roads, through the pooled-fund study. They received their first two sets of data in February and June 2020.

With the help of the ARRB Systems virtual training, New Mexico DOT have so far provided training for six districts on how to use the TSD data for project scoping or at least how to view and navigate the data in the viewer provided by the TSD vendor. The feedback from the trained districts has so far been very positive with most districts wanting to see more data collected and more information and guidance on how to best use the data (Figure 15).

Over the last 6 months since receiving the data, New Mexico DOT has already used the TSD data in the following three applications (Figure 16):

1. Project scoping. New Mexico DOT creates project scoping reports as preliminary assessment for project-related data. The reports are pavement condition assessment reports, which are based on pavement surface condition data (data in the pavement management, indices, distresses, etc.) Where available, structural condition data from the TSD, such as the maximum deflection, is now also provided in these reports.

2. Field exploration coring practices. Historically, for field exploration, New Mexico DOT takes four cores per mile (or one core every quarter of a mile). New Mexico DOT has used the TSD data to better refine and define field exploration locations. Concurrent plots of surface distresses and TSD data show that the locations where the surface distresses are the most

•Early Experience

- Data Dump in Feb, June 2020
- Upon Completion of TPF-5(385), ~4,200 Miles
- Interstate, Mostly NHS
- 2-4 Year STIP Projects
- Trained Districts in Use/Navigate TSDD and Hawkeye
 - ARRB Group provided virtual training early summer 2020
 - Well Received by Districts, excited to see additional data and use-cases
 - Districts have access to TSDD db

FIGURE 15 New Mexico DOT's experiences with the TSD.

NMDOT Applications

- Project Scoping Report
 - Intended to Provide Preliminary Project Related Data
 - Pavement Condition Assessment Report (PCAR)
 - Pavement Management Related Data
 - Including Distress, Decision Tree Analyses
 - TSDD
- Field Exploration
 - Typical Frequency 4/Mile
 - with TSDD Data, NMDOT able to refine (define) field exploration locations to address variability or unknown conditions

FIGURE 16 New Mexico DOT applications with TSD collected data.

prevalent does not necessarily coincide with the locations where the pavement is structurally weakest, where coring should be performed.

3. Allocation of pavement preservation funding. The TSD data is being used as a screening tool to help better allocate pavement preservation funds. Locations that need treatment but where the pavement is relatively strong are good candidates for preservation treatments.

An example of project scoping application is given in [Figure 17](#). A section structural condition such as D_0 and surface distresses can be viewed in the same plot. These plots show areas of high deflection corresponding to structural weak locations. Having both surface distress information and structural condition information help identify the causes of observed distresses or identify problem locations that do not show the presence of surface distresses.

A consultant is helping New Mexico DOT in performing an engineering and deflection analysis. This work is still in the early stages, but the results of the analysis will be provided to the design- build group for assessment ([Figure 18](#)). Finally, New Mexico DOT used TSD D_0 measured deflections (threshold of 20 mils) to screen sections that are good candidates for preservation treatments.

New Mexico DOT's next steps include more data collection and integration into the PMS ([Figure 19](#)).

NMDOT Applications

- Typical Graphs Provided During Scoping and Project Development Process
 - Observe areas of high(er) deflection along with pavement distress. Additionally, surface distress may not necessarily reflect subsurface conditions.

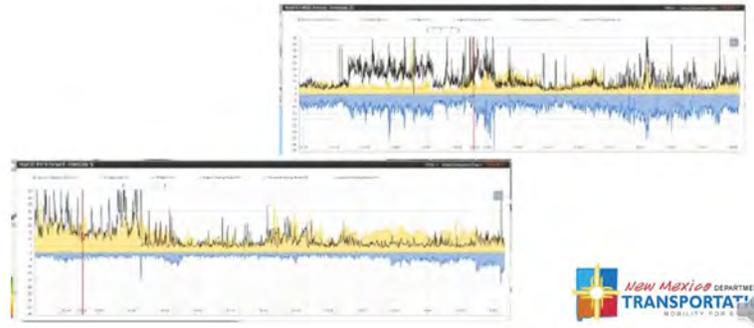


FIGURE 17 Example project scoping application.

NMDOT Applications

- Design Build Applications
 - 2020 NCE Performed Engineering and Deflection Analyses
 - Results to be provided to Design Build Team
- Pavement Preservation Recommendations, \$20 Million Preservation Funding
 - Routes were screened based on total deflection of \geq -20 mils
 - Asphalt Good + Strong Criteria

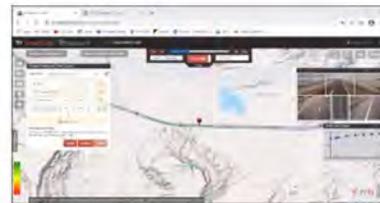


FIGURE 18 Example design-build application and pavement preservation application.

NMDOT Next Steps

- Continue to Learn
- More Comprehensive Data Collection
- Future Data Integration in to PMS db
 - Decision Trees
 - Maximum Deflection
 - Treatment Recommendation
 - Using Pavement Preservation Funding as Initial Consideration

FIGURE 19 Planned next steps in New Mexico DOT's implementation of TSD data.

Georgia Department of Transportation's Traffic Speed Deflection Device Data *Experience So Far*

IAN RISH

Georgia Department of Transportation

The presentation given by Ian Rish summarized the Georgia DOT TSDD data and the experience accumulated so far.

Georgia DOT collected TSD data on I-59, which includes a section that is scheduled for maintenance based on typical PMS targets and other programming constraints Georgia DOT uses for all its Interstate maintenance projects. Once an Interstate project is scheduled for maintenance, Georgia DOT performs a pavement evaluation, which includes destructive testing. Because of the planned detailed evaluation of the pavement, Georgia DOT took the opportunity to also collect TSD data on I-59 to compare the TSD data to the data from their pavement evaluation and see if the information obtained from the TSD data would agree with the information obtained from their pavement evaluation. Figure 20 shows location and major details of the project.

The TSD data analyzed under this effort included the deflections under the load (D_0), SCIs, SCI 8 (Equation 1) and SCI 12 (Equation 2), and SCI subgrade (Equation 3). Figure 21 shows the visual assessment for D_0 , SCI 12 (SCI 8 showed similar results) and SCI subgrade.

$$SCI\ 8 = D_0 - D_8 \tag{1}$$

$$SCI\ 12 = D_0 - D_{12} \tag{2}$$

$$SCI\ subgrade = D_{36} - D_{60} \tag{3}$$

I-59 Maintenance Project

- Regularly schedule Maintenance project for I-59 in GA based on typical procedures
- Pavement evaluation completed for the project which includes destructive testing
- Planned our TSDD data collection in this area due to project for research and pavement evaluation purposes
- Collected each lane each direction

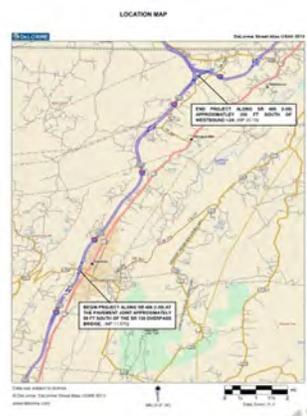
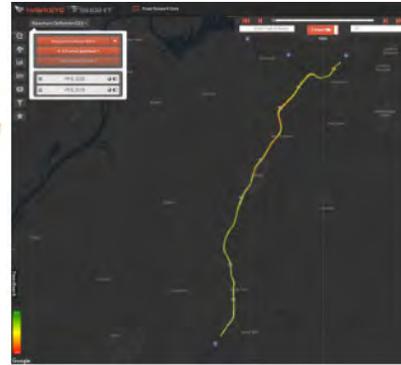


FIGURE 20 Project location and major details.

I-59 D0

- D0 looks mildly worse in project location area but not that bad
- Normal filters used are based on D0 so nothing out of the ordinary would be noticed about this area.



(a)

I-59 SCI 12

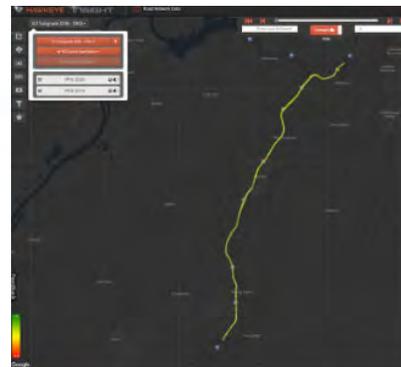
- SCI 12 also shows areas of concern that match SCI 8
- Could the subgrade show us anything more?



(b)

I-59 SCI Subgrade

- SCI for the subgrade D36 – D60 shows nothing different from the rest of I-59 so the subgrade is potentially not the issue
- Further investigation is needed



(c)

FIGURE 21 Visual assessment for (a) D₀, (b) SCI 12, and (c) SCI subgrade.

As background information, the pavement corridor was originally constructed in 1966 and consisted of 6 in. of stabilized subbase, 10 in. of stabilized base course, 3 in. of hot-mix asphalt (HMA) as a base, and 1½ in. of topping. Project history, summarized in [Figure 22](#), includes a surface treatment with leveling performed in 1975 (3 in. of B-modified HMA placed and covered with surface treatment and an overlay with 60 lb./y² of HMA), a ¾-in. mill and overlay (135 lb./y² of HMA) performed in 1986, and resurfacing performed in 1997 (no records on this). An open-graded friction course is placed on the surface. Rish pointed out that

I-59 Project History

- Project location last resurfaced per historic records in 1997 and no construction plans area available
- 1986 Milled $\frac{3}{8}$ inch and overlaid with 135 lb/sy of HMA
- 1975 no milling, surface treatment with leveling if needed, 3" of B-modified HMA placed and covered with surface treatment plus 60 lb/sy of HMA
- 1966 original construction of 6" stabilized sub-base, 10" stabilized base course, 3" HMA, and 1.5" HMA
- B-modified mixes are prone to stripping due to reduction in AC content from the Oil Crisis.

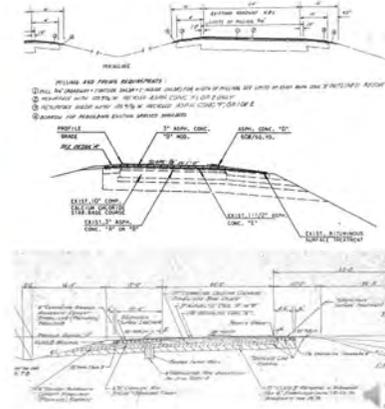


FIGURE 22 I-59 project history.

B-modified mixes were developed during the oil crisis in the 1970s to have a reduced asphalt content and are prone to stripping.

Figure 21 shows D₀ and SCI subgrade on the tested section of I-59 (which includes the section scheduled for maintenance) do not highlight a location where the pavement is structurally weaker. However, SCI 12 shows that there is a section, that corresponds to the area with red colors in the figure, which is structurally weaker than the rest of I-59. This area also corresponds to the section that is scheduled for maintenance.

As part of the Georgia DOT pavement evaluation, ground penetrating radar (GPR) scans and cores at various locations were taken (Figure 23). The GPR data showed that the layer thicknesses are consistent across the pavement. Hamburg wheel testing was performed on material taken from the coring and the two layers directly beneath the open-graded friction course failed “miserably” (the failure criteria Georgia DOT uses are 12.5 mm for the total rut with 20,000 passes and no stripping inflection point). During the test, the mixes came apart and sand was flushed out of the mix. “Older” mixes used natural sand, which are prohibited within the current Georgia DOT instructions because of stripping prone potential.

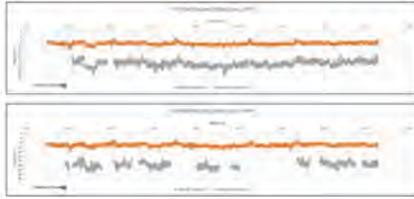
The data analysis based on the TSD and the Hamburg test allowed the Georgia DOT engineering team to provide the final recommendation of full reconstruction for this project, which will move the project from the maintenance office to preconstruction. Furthermore, the data on this project confirmed that the existing HMA is different from the rest of the network.

Rish pointed out the need of further understanding how the SCIs are calculated from the TSDD data and thus identifying other potential problem areas in the network, overcoming the limitations associated with windshield distress surveys. Other issues that may require further investigation are the TSD itself and the associated software, especially in those cases where the sensor is not functioning properly, causing errors to the best-fit model output, and causing missing data. Last, Rish indicated that a strategy for collecting data should also be developed, especially in relation to temperature differentials during data collection campaigns, which may affect the parameter values and subsequently their interpretation in support of the pavement condition assessment. Alternatively, temperature corrections for the different types of parameters should be developed and eventually implemented towards a more objective pavement assessment.

Table 2. Core Data

Core	Route	Direction	Lane	Mile Post	AC Core Length (inches)	Base Material	Core Condition
1	I-490	NB	2	12.00	10.13	G40	Good
2	I-490	NB	1	13.50	10.89	G40	Good
3	I-490	NB	2	13.50	8.25	G40	Substandard at #1
4	I-490	NB	1	13.50	8.25	G40	Substandard at #1 & #2
5	I-490	NB	2	15.00	10.25	G40	Good
6	I-490	NB	1	14.50	8.83	G40	Good
7	I-490	NB	2	15.00	10.75	G40	Good
8	I-490	NB	2	15.00	10.1	G40	Top Down, #1
9	I-490	NB	1	15.50	8.36	G40	Good
10	I-490	NB	2	16.00	10.13	G40	Good
11	I-490	NB	1	16.50	10.00	G40	Good
12	I-490	NB	2	17.50	8.75	G40	Good
13	I-490	NB	1	17.50	8.1	G40	Top Down, #1
14	I-490	NB	1	17.50	8.86	G40	Good
15	I-490	NB	2	18.00	10.38	G40	Good
16	I-490	NB	1	18.50	8.92	G40	Good
17	I-490	NB	1	18.50	8.73	G40	Good
18	I-490	NB	2	19.00	8.8	G40	Top Down, #1
19	I-490	NB	1	19.50	8.76	G40	Good
20	I-490	NB	1	19.50	11.75	G40	Top Down, #1
21	I-490	NB	1	19.50	8.73	G40	Good
22	I-490	NB	1	19.50	8.73	G40	Good
23	I-490	NB	2	19.50	10.25	G40	Good
24	I-490	NB	1	19.50	8.82	G40	Good
25	I-490	NB	1	19.50	8.26	G40	Top Down, #1
26	I-490	NB	2	19.50	8.82	G40	Good
27	I-490	NB	1	19.50	8.26	G40	Substandard at #1
28	I-490	NB	2	19.50	8.78	G40	Good
29	I-490	NB	1	19.50	8.75	G40	Substandard at #1
30	I-490	NB	1	19.50	8.80	G40	Top Down, #1
31	I-490	NB	2	19.50	8.73	G40	Good
32	I-490	NB	1	19.50	8.38	G40	Good
33	I-490	NB	2	19.50	10.38	G40	Good
34	I-490	NB	1	19.50	8.25	G40	Substandard at #1
35	I-490	NB	2	19.50	8.25	G40	Good
36	I-490	NB	1	19.50	8.96	G40	Good
37	I-490	NB	2	19.50	8.73	G40	Substandard at #1
38	I-490	NB	1	19.50	10.25	G40	Good
39	I-490	NB	1	19.50	8.25	G40	Substandard at #1
40	I-490	NB	2	19.50	8.76	G40	Good
41	I-490	NB	2	19.50	8.73	G40	Good

*Selected for the Hamburg Testing



HWTD T-324 Testing

* Complete failure for all samples tested



Table 3. Summary of I-69 Cores Tested on HWTD by Milepost

Milepost	Direction	Lane	Location	Number of passes to failure	
				Layer 1	Layer 2
12	SB	1	LWP	3060	7935
13.5	SB	2	RWP	3110	N/A
16	SB	1	LWP	3979	N/A
17.5	SB	2	CEN	4480	9547
18.5	SB	2	LWP	2326	10534
19	SB	1	CEN	5400	N/A
12.5	NB	1	LWP	4276	N/A
14	NB	2	RWP	3562	18411
14.5	NB	1	RWP	2996	9993
16	NB	2	CEN	2711	N/A
16.5	NB	1	CEN	2690	8747
18	NB	2	LWP	3336	17271
18.5	NB	1	LWP	2729	N/A
Passing				0	0
Failing				13	7
Total				0%	7
Percent Passing				0%	0%

LWP = Left Wheel Path
RWP = Right Wheel Path
CEN = Center

FIGURE 23 Other collected pavement data.

Kansas Department of Transportation’s Experiences and Applications with Traffic Speed Deflection Devices

RICK MILLER

Kansas Department of Transportation

The presentation by Rick Miller of the Kansas DOT covered the Kansas DOT’s TSDDs experience and current and future initiatives. In 2018, Kansas DOT directly funded its first TSD endeavor on I-70 in the western half of the state, then opted into TPF-5(385) and acquired additional data in the eastern third of the state. Those efforts were previously presented at the January 2019 TRB Annual Meeting and at the Road Profiler Users Group meeting in the fall of 2019. In addition to the 800 mi of data collected earlier, there were additional pooled-fund collection efforts earlier this year. **Figure 24** shows the past and current data collection efforts.

The presentation slide in **Figure 25** provides a summary of past data collection efforts and collection project details. The I-70 effort confirmed pavement problems for areas already identified within the network. Nevertheless, the data analysis results provided additional information regarding pavement issues such as sinkholes and layer delamination. Data visualization allowed the comparison of FWD and TSDD data, eventually identifying different pavement problems. The 2018 TSDD data collections efforts in eastern Kansas were designed to monitor and evaluate the pavement system condition along those more geometrically challenging routes. TSDD data were already collected for the Interstate network; therefore, lower-class routes needed performance and deflection data. The findings confirmed that the TSDD performs well on those routes and they revealed that the pavements in these routes were not so structurally heterogeneous, as previously assumed. Additionally, the Kansas DOT team started evaluating potential correlations between surface distress and deflection data.



FIGURE 24 Past and current Kansas DOT data collection efforts.



FIGURE 25 Past Kansas DOT data collection efforts.

Kansas DOT has collected additional data collection projects along the network in 2020 that will be delivered soon and will continue its involvement in TP-5(385) (Figure 26). The overall intent is to utilize the deflection data for proper scope and schedule decisions for maintenance activities and, additionally, identify if there is a need for additional pavement condition data for specific locations. The TSD collects network-level structural data. Historically, structural data is used by designers and network-level data is used by planners. One of the challenges Kansas DOT faces is planners, designers, and district staff involved to better use the TSD data.

Kansas DOT recognizes that the TSD has a lot of potential for the pavement network assessment and in maintenance planning however there are still many questions that need to be answered to take full advantage of TSD collected data (Figure 27). Some of the most important questions from Kansas DOT’s perspective are 1) how do we implement and use TSD data for PMS and project-level applications and 2) how much of the network should be covered, at what frequency, and how do we pay for it?



FIGURE 26 Where is Kansas DOT going?



FIGURE 27 Important questions that should be addressed.

Texas Department of Transportation's Experiences and Applications

JENNY LI

Texas Department of Transportation

The presentation by Jenny Li provided an overview of the Texas DOT's TSDD experience and applications. Historically, pavement asset management was based on the *Condition of Texas Pavements Pavement Management Information System (PMIS) Annual Report* often called "Bad and Good" report. Every year, this report was used by the Texas DOT administration to question districts on their respective pavement condition and maintenance actions. For example, the districts were questioned why their pavement repairs did not last more than 2 years; the Report identified sections in bad condition 4 years prior, which were repaired after one year (3 years prior) and their condition was assessed as 'bad' after only 2 years from the repair. Due to the funding restrictions, districts had to perform multiple stopgap maintenance just to keep pavements functional. In other cases, maintenance actions were not adequately selected due to the lack of pavement structural information and data or because such information was not part of the maintenance plan decision-making process. The Bad and Good report sent a clear message to the districts pointing that functional and structural data are needed when preparing the full year pavement management plan, thus preventing early pavement failure.

In 2018, Texas DOT became aware of TPF-5(385) and joined it in 2019. Through the pooled fund, 3 days' worth of TSDD data were collected every year. A total of 1,690 mi of TSDD data were collected mainly in the districts of Austin, San Antonio, Paris, and Odessa. Figure 28 provides an overview of the routes and areas for the collected data. These routes cover Interstate highways, U.S. roads, state highways and farm-to-market roads. District engineers are familiar in utilizing TSDDs because the devices can be used at highway speed in the primary, thus expediting the survey. Furthermore, TSDDs allow rapid identification of pavement weaker spots and potentially initiate further investigations. The FWD was already utilized and the data well understood concerning pavement structural analysis. Because of this, there is the clear need to correlate TSDDs to the well-known FWD. The Pavement Management Asset Office conducted several internal studies by collecting GPR and FWD data in addition to TSDD. The results indicate that TSDD and FWD data follow similar general trends; however, in some road segments, TSDD data show more variability than FWD data.

The Pavement Management Asset Office focused on adding the TSDD data to the PMS and providing access to those data to district engineers for maintenance planning. Figure 29 summarizes the multiple steps followed to process TSDD data and add those data to the PMS. In some cases, layer thickness information was not available, and a regression approach was utilized for the missing data. Temperature corrections were also applied to TSDD data prior insertion in the PMS. Concerning the SCI (Figure 30), the University of Texas at Austin worked on calculating the SCI for FWD data, whereas the recently published FHWA Turner Fairbank Highway Research Center's report¹ was used to calculate SCI based on TSDD data.



FIGURE 28 TSDD routes in Texas by district.

From Data Delivery to PMIS

- Required steps as follows
 - Data Extraction from TSDD files
 - Data Cleaning if necessary (correct roadbed designation, remove non decreasing deflections, etc.)
 - Mapping to the Texas Reference System
 - Convert GPS coordinates in TSDD file to correct roadbed and DFOs that PA can interpret
 - Layer Thickness – Estimated or User Input
 - Temperature Adjustment
 - Computed Indexes
 - Mapping Structural Data with Surface Condition Data for the road segment
- In general, steps are similar for FWD and TSDD
 - TSDD data vendor will fit the data to Texas referencing system

FIGURE 29 Step process to integrate TSDD data into PMS.

Structural Condition Index

- The SCI is the ratio of the “Effective/Required” AASHTO Structural Number. SN_{Eff} is determined from both the FWD/TSDD measurements and the total pavement thickness. SN_{Req} is based on the estimated 20 year ESALs for the route, and subgrade modulus.

$$\text{Structural Condition Index, } SCI = \frac{SN_{Eff}}{SN_{Req}}$$

- SN_{Eff} from recalibrated Rhode’s equation
- SN_{Req} based on
 - Estimated 20-year Equivalent Single Axle Loads (ESALs) for the pavement
 - Computed subgrade modulus (M_u) using AASHTO 1993 Equation

FIGURE 30 Structural condition index formulation.

These newly calculated parameters were thus inserted into the Texas DOT PMS, providing district engineers with a full overview of the parameters depicting pavement condition, including cracking, rutting, and international roughness index.

The Texas DOT adopted a decentralized strategy with 25 districts autonomously managing their assigned network and optimizing proper maintenance plans. Figure 31 shows an example of the PMS interface with the different types of data by section and district and visualized maps. Maps combine functional and structural data, used for planning future projects. The period of January to May is district pavement management plan season. The Pavement Management Asset Office plan is to continue work with each district to improve tools and information access. Based on the preliminary application experience, additional initiatives are planned (Figure 32) and include, among others, recalibrating the structure number for TSDD measurements for sealcoat surfaces, redefine modulus estimation using TSDD sensors closer to the load, defining new threshold values for indices derived from TSDD data, and investigating the application of TSDD on rigid and composite pavements, which are about 4% of the Texas pavement network.

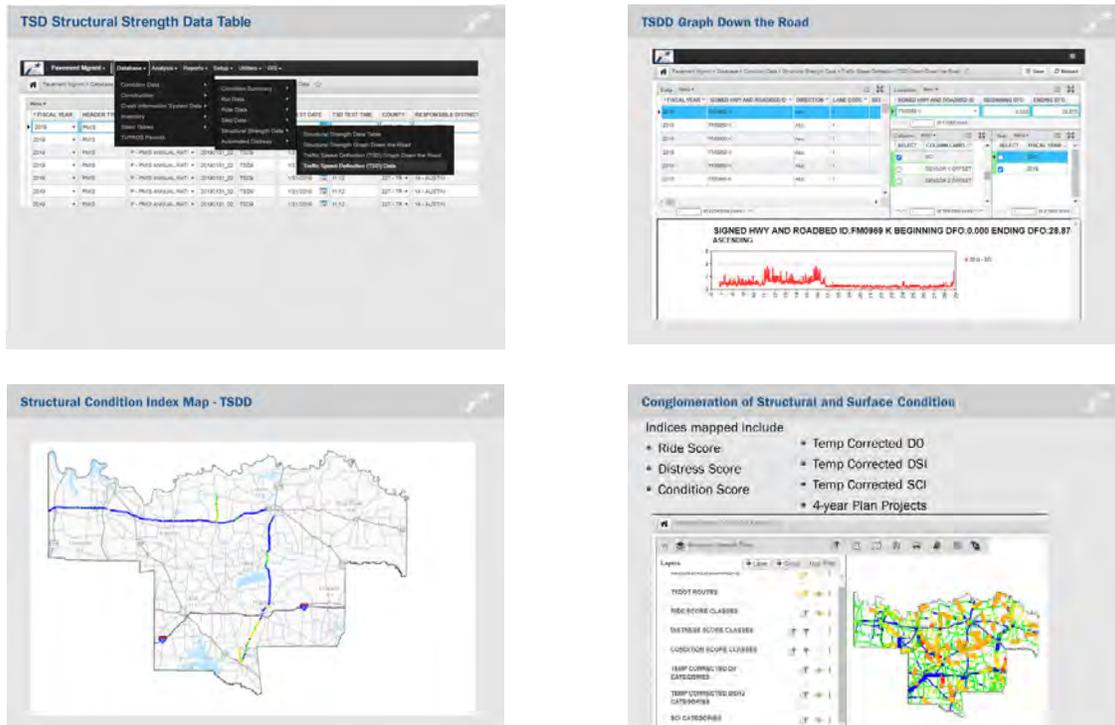


FIGURE 31 Texas DOT PMS user interface examples.

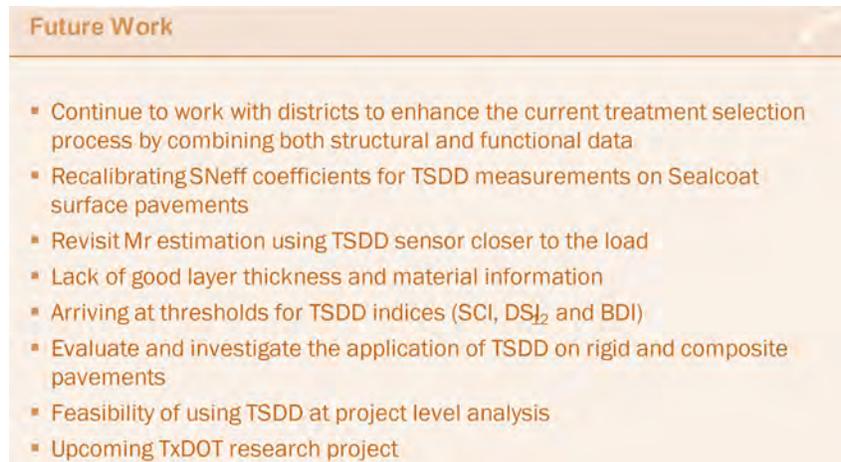


FIGURE 32 Texas DOT future initiatives.

NOTE

1. Rada, G. R., S. Nazarian, B. A. Visintine, R. V. Siddharthan, and S. Thyagarajan. *Pavement Structural Evaluation at the Network Level*. No. FHWA-HRT-15-074. Federal Highway Administration, U.S. Department of Transportation, 2016.

Virginia's Traffic Speed Deflectometer Data Experience

GIRUM MERINE
Virginia DOT

Girum Merine's presentation covered the Virginia DOT's experience with TSDD data collection.

Virginia DOT started the collection of TSD data under a research project in 2017 that involved over 4,000 mi of testing on Interstate and primary routes. Through their participation in the TPF-5(385), many additional miles of data have been collected. In 2020 about 1,550 mi were tested on Interstate and primary routes. Merine presented the map highlighting the roadways that have been tested in the state network. Figure 33 shows the slides summarizing the extent of data collection by Virginia DOT under various efforts.

TSDD data can be accessed by all Virginia DOT staff. Those accessing and/or using the data most are the members of the Pavement Design Group at Virginia DOT Central Office, Virginia Transportation Research Council staff, and district pavement managers as summarized in Figure 34.

Virginia DOT has also engaged in multiple research efforts for identifying meaningful use of the data collected as summarized in Figure 35. One of those studies that compared TSDD and FWD data showed that structural condition information can be obtained from the TSDD similar to that obtained from the FWD. A research report was prepared by Katicha et al. (2020) to integrate TSD-based structural condition data into state PMS.

□ Virginia TSD Data

- 2017
 - ✓ 4000+ miles of testing on interstate & primary routes.
- 2018 – 21
 - ✓ Pooled Fund Study with other agencies.
- 2020
 - ✓ Approximately 1550 miles of testing on interstate & primary routes.



FIGURE 33 TSDD data collection in Virginia DOT pavements.

□ TSD Data Access

- District Pavement Managers, Central Office Maintenance & Pavement Design Engineers, and VTRC staffs have access to the data.
- Anyone in VDOT can access the data.

□ TSD Data Usage

- Currently mainly used by CO Pavement Design group, VTRC staff, and by a number of district pavement managers.

FIGURE 34 Access and use of Virginia DOT's TSDD data.

Investigation Conducted to Date

▪ Studies to facilitate the use of TSD

- ✓ Recently VTRC completed a research project titled "Network Level Pavement Structural Testing with TSD" and the report was published.
 - The study compares TSDD and FWD.
 - The finding of the study indicated that information obtained from TSD can be used to provide structural information similar to FWD testing.
- ✓ Report in 2020 (Katicha et al.) that talked about how to incorporate TSD results into agency PMS

FIGURE 35 Summary of Virginia DOT's research and findings for use of TSDD data.

Virginia DOT also presented its perspective on the use of TSDD data for network-, and project-level applications as shown in [Figure 36](#) and [Figure 37](#), respectively. At the network level, the data can serve as a screening tool and can provide indicators to distinguish between sections that are strong and weak, sections that need deep treatment and preservation, and help identify areas needing detailed evaluation. Additionally, at the project level the TSDD data can be used to assess the structural condition of segments within a project such as areas of weak subgrade, or to evaluate the condition of subsurface layers including joint condition of concrete pavement overlaid with a flexible pavement layer.

Network Level Application

- Can be used as Network Level Screening Tool
- To Identify strong vs. weak section
- Deep treatment vs. Preservation
- To identify areas that need more detailed evaluation

FIGURE 36 Virginia DOT's perspective on use of TSD data for network-level application.

Project Level Application

- Assessment of Structural condition – Weak/strong subgrade areas.
- Identify weak joint areas for Composite Pavements (Asphalt over Concrete).

FIGURE 37 Virginia DOT's perspective on use of TSD data for project-level application.

Virginia DOT anticipates expanding its use of TSDD data over the next 5 years as summarized in **Figure 38**. The plans include the incorporation of TSD into the PMS decision matrix, the development of criteria based on structural indices to rate pavement condition and expanding the TSD data collection program. This has already started and as part of an implementation project. As part of that project, a panel consisting of pavement management engineers from the Virginia DOT central office and engineers from three districts will decide based on recommendations from the project research team on the appropriate index and criteria for classifying the pavement sections into structurally good/bad.



FIGURE 38 Virginia DOT's plan for use of TSDD data over the next 5 years.

Traffic Speed Deflection Devices for Network- and Project-Level Pavement Structural Evaluation

NADARAJAH SIVANESWARAN
Federal Highway Administration

Nadarajah Sivaneswaran of the Office of Research Development and Technology at the Turner Fairbank Highway Research Center, FHWA discussed FHWA's research and development (R&D), and implementation efforts on the use of TSDDs for network and project-level structural evaluation of pavements. A historical perspective of R&D in this area was presented covering the broad areas addressed and the advancements to date. References were provided for the research efforts described. Implementation efforts were discussed with details on data collection efforts and anticipated use of data on specific roadway networks.

Figure 39 provides an outline of the various research efforts that have systematically advanced the TSDD to its current level of sophistication and application in pavement evaluation. As shown in Figure 39, the first approach was to evaluate the robustness of the measurement system and to determine the accuracy and precision of TSDD measurements of pavement responses. This initial evaluation was conducted on instrumented sections at the MnROAD test facility.¹

Ensuing series of research efforts focused on evaluating the effectiveness of TSDD in pavement applications through theoretical simulations and field data analyses. These studies involved either the adoption of existing methodologies or development of new methodologies for analysis of TSDD data. The completed efforts with research documentation (see Figure 45 for relevant references listed) include:

- Approaches to calculate surface deflections from measured responses such as slope.
- Development of deflection indices that can be used in structural evaluation. Almost 70 different indices have been developed and correlated to pavement primary responses or critical mechanistic responses such as tensile strain at the bottom of asphalt concrete (AC) layer or compressive strain at the surface of the subgrade.
- Because of backcalculation of FWD data is a common DOT practice, the potential of TSDD data for backcalculation was evaluated and found to show promising results. The approaches used backcalculation using slope of moving load and the traditional static methods.
- Temperature correction procedures to normalize deflections to a reference temperature so that measurements at different times of the day or at different ages or from different sections can be compared. Analytical modeling was used to simulate the temperature correction procedure developed for SCI from FWD deflection data, and it was adjusted for use with TSDD data. This procedure was verified using field data collected on the same pavement at different temperatures using both FWD and TSDD.
- Procedures to develop effective Structural Number from TSDD data based on a modification of the procedure used with FWD data.

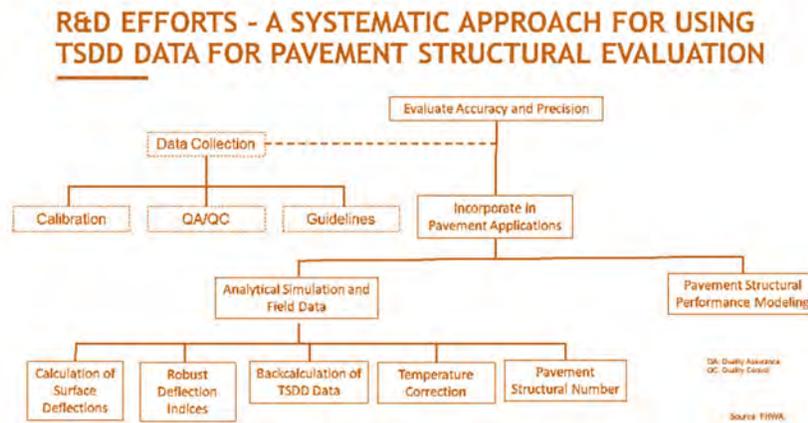


FIGURE 39 Summary of research advancing use of TSDD for structural evaluation.

The studies described above address the structural evaluation of the condition of the pavement at the time of data collection. Other applications that are still under development are:

- Integration with pavement management. Effective network-level management will require structural performance models to project future rate of decline in structural capacity akin to the forecasting models of visual distresses or IRI for planning rehabilitation activities in PMS.
- Guidelines for Data Collection. Procedures for calibration of the device, standard methods to perform quality checks on data, and guidelines for data collection such as frequency of data collection or optimal operational conditions, etc. are still under development. The currently ongoing National Cooperative Highway Research Program (NCHRP) Project 10-105, Verification of Traffic Speed Deflection Devices' (TSDDs) Measurements, and pooled-fund study are partly addressing these needs.

Analysis procedures that have been established have been integrated into an MS Excel tool (Figure 40) called Tool for Data Extraction and Processing for Structural Data (TDEPS) and is available from the pooled-fund data website <https://www.pooledfund.org/Details/Study/637>.²

FHWA has led or participated in implementation efforts listed in Figure 41. The first is FHWA-led TPF-5(282), Demonstration of Network-Level Pavement Structural Evaluation with Traffic Speed Deflectometer, conducted between 2013–2017. The final report is on the TFF site, <https://www.pooledfund.org/Details/Study/518>. The second is an ongoing, Virginia DOT-led study, TPF-5(385), Pavement Structural Evaluation with Traffic Speed Deflection Devices, with 26 state DOTs participating and other DOTs continue to show interest as well. The FHWA's Eastern Federal Lands Highway Division (EFLHD), which manages the National Park Service's (NPS) roadway networks, has also collected TSDD data on several of its NPS networks and has ongoing efforts to assess other pavement structural information for use in making maintenance and rehabilitation decisions.

The screenshot shows a software interface with a menu bar at the top (File, Edit, View, etc.) and a toolbar with various icons. Below the toolbar is a data grid with several columns and rows. The columns include headers like 'ID', 'Name', 'Description', 'Status', 'Date', and 'Value'. The rows contain numerical and text data. At the bottom right of the interface, there is a small text box that reads 'Source: FHWA' and a larger text box with a URL: 'Kuhh B. and Sorensonen H. "Treatment Structural Evaluation with Traffic Speed Deflection Devices (TSDDs)" Transportation Pooled Fund Program, last accessed 2023-12-05. <https://www.pooledfund.org/Details/Study/517>'.

FIGURE 40 TDEPS tool for processing TSDD data.

- Transportation Pooled Fund (TPF)-5(282) "Demonstration of Network Level Pavement Structural Evaluation with Traffic Speed Deflectometer," FHWA-led, 2013-2017:
 - Nine State departments of transportation (DOTs) and Federal Highway Administration (FHWA) participated.
 - The final summary report and State DOT-specific reports are available at <https://www.pooledfund.org/Details/Study/518>.
- TPF-5(385) "Pavement Structural Evaluation with Traffic Speed Deflection Devices (TSDDs)," VA DOT-led, 2018:
 - Twenty-six State DOTs and FHWA participating.
 - The study is ongoing.
- FHWA's Eastern Federal Lands Highway Division (EFLHD)/National Park Service (NPS) efforts.

FIGURE 41 Implementation efforts with FHWA participation.

The EFLHD supports the management of NPS routes. The NPS routes carry minimal truck traffic, and as a result, the pavement network experiences deterioration primarily from environmental factors and site-specific interactions with traffic loads and material behavior. Details of the efforts are listed in [Figure 42](#).

- George Washington Memorial Parkway, Virginia. Data was collected using the iPave and GPR on a total of 32 mi of roadway consisting of AC pavement (ACP). A future major rehabilitation project is being planned that may use a design–build contract, which could provide the contractor the TSDD data collected.
- National Mall, Washington, D.C. TSDD data was collected at 1-m intervals on the NAMA routes consisting of composite pavement sections [i.e., AC over Portland cement concrete (PCC)]. The objective is to assess the condition of the PCC pavement underneath the AC layer, including load transfer of the joints. Data will be used in the scoping of multiple rehabilitation projects.
- Blue Ridge Parkway (BLRI), Virginia and North Carolina. TSDD has been collected and GPR data collection is underway on 469 mi of ACP. This is a pilot effort to develop a database with structural indices for use in the agency's PMS.
- Vicksburg National Military Park (VICK), Mississippi. TSDD data has been collected on 20-mi of this network consisting of jointed reinforced concrete pavement and ACP. The roads are on loess soil that can result in nonuniform subgrade support conditions and can

EFLHD/NPS EFFORTS

- **George Washington Memorial Parkway (GWMP), Virginia:**
 - Between I-495 and Key Bridge (about 8 miles)—two lanes each direction.
 - Pavement type: Asphalt Concrete Pavement (ACP).
 - Ground Penetrating Radar (GPR) data to be collected and major rehabilitation (rehab) project planned.
 - **National Mall (NAMA) Routes, Washington, D.C.:**
 - Pavement types: ACP and composite (majority).
 - Major objective: assess underlying Portland Cement Concrete (PCC) joint condition for rehab planning.
 - TSDD data processed at 1 m intervals.
 - To be used for scoping of multiple future projects.
 - **Blue Ridge Parkway (BLRI), Virginia and North Carolina:**
 - Pavement type: ACP.
 - Total of 469 miles—two lanes, two-way, data collected in both directions.
 - Pilot study to develop a database with structural indices ((Effective Structural Number) SNeff, (Surface Curvature Index) SCI²², etc.) to potentially incorporate into Pavement Management Systems (PMS) (network -level) with decision trees. A program for GPR data collection is underway to support the TSD structural analysis.
- 
- **Vicksburg National Military Park (VICK), Mississippi:**
 - Pavement Types: Jointed Reinforced Concrete Pavement (JRCP) and ACP.
 - Description: Total of 20 miles—one lane, one-way, multiple routes.
 - VICK roads are on loess formation that is highly susceptible to erosions and pavement has experienced recurring damages and failures due to the unstable subgrades and formation of sinkholes. This is to help with developing targeted repairs.
 - **Natchez Trace Parkway (NATR), Tennessee, Alabama, and Mississippi:**
 - Pavement Types: ACP.
 - Total of 444 miles—two lanes, two-way, data collected in both directions.
 - Part of pilot study—also, data used to supplement existing functional data-based PMS at project level to determine appropriate treatments.

FIGURE 42 Slides showing TSDD data collected by EFLHD on NPS routes and plans for future use in pavement management and rehabilitation projects.

form sinkholes. These data are intended for use in assessing condition of the subsurface for future rehabilitation design or targeted repairs.

- Natchez Trace Parkway (NATR), Tennessee, Alabama, and Mississippi. TSDD data was collected on 444 mi of ACP roadway along with GPR data for use in agency PMS.

TSDD data collected by the EFLHD are available for public download from FHWA INFOMATERIALS, which is an online portal developed by FHWA to share research data. Data collected under the pooled-fund studies by state DOTs willing to share their data will be added to this portal shown in [Figure 43](#). Data visualization capabilities are offered by the portal, a sample of which is shown in [Figure 44](#).

A disclaimer and a list of references of the R&D efforts are shown in [Figure 45](#).



FIGURE 43 Screenshot of the FHWA INFOMATERIALS portal.

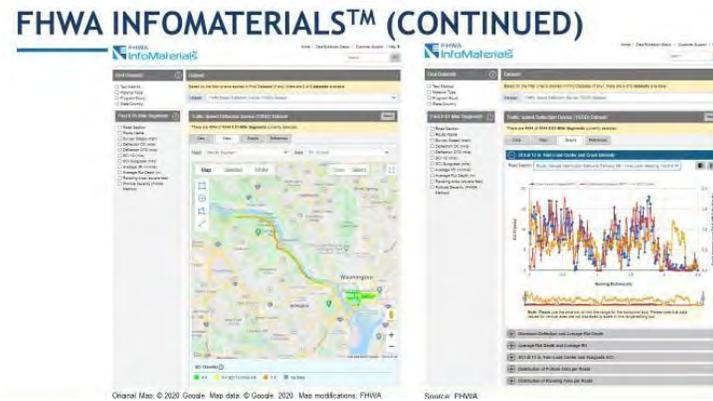


FIGURE 44 Data visualization of TSDD data overlaid on a map.

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FIGURE 45 Disclaimer and references.

AASHTO Perspective on Traffic Speed Deflection Device Applications

JOHN DONAHUE

Missouri Department of Transportation

John Donahue of the Missouri DOT discussed the American Association of State Highway and Transportation Officials (AASHTO) perspective on TSDD applications in pavement evaluation. He described the need for AASHTO standardization and the different elements of standardization specific for TSDDs.

As states evaluate new technologies and transition to mainstream adoption, they require standard procedures for wider implementation and for the development of specifications. AASHTO serves as the organization represented by all states to help legitimize and standardize a test procedure, such as the collection of performance data using the TSDD. The standardization harmonizes data across states, which is necessary for FHWA data requests. Standardization also establishes the frequency for performing calibration, validation, and verification for the device as discussed in the slide shown in [Figure 46](#).

As shown in [Figure 47](#), the three topics of primary interest in the standardization of pavement performance data collection procedures are

- Calibration,
 - Validation, and
 - Verification.
-
- Mainstream adaptation
 - Legitimizes testing procedures
 - Harmonizes test results across State lines (FHWA data requests)
 - Sets calibration/validation/verification frequencies for equipment management

FIGURE 46 Reasons for AASHTO standardization.

Topics of Standards

- Calibration
- Validation
- Verification

Calibration

- Difficult because of different data collection technologies
- Uncertain future TSDD technology
- Unlikely investment for majority of DOTs
- May have to forgo AASHTO standard development for calibration

Validation

- Reference measurements used to determine precision and bias of TSDD
- Likely to rely on pavement test sites instrumented with geophones or accelerometers
- Possible portable validation option to eliminate reliance on distant fixed site

Verification

- Likely scenario of correlating TSDD deflections with another dynamic load response device (FWD)
- Need to better understand maximum deflections between devices based on loading applications and pavement structure
- Correlation may depend more on basin curvature characteristics than maximum deflections
- FWDs could transition from PMS structural inventory tool to primarily verification device

FIGURE 47 Elements of AASHTO standardization for TSDD.

Figure 47 details AASHTO's current perspective on these three elements of standardization for the TSDD, and which are summarized below:

- **Calibration.** Standardized calibration of a TSDD device may not be undertaken by AASHTO because of the challenges involved. The underlying technology for deflection measurement is different in each of the devices, and future devices may use newer methods making necessary the calibration process specific to each device. In addition, because it is unlikely DOTs will invest in a device, the onus of calibration may fall on the device operators. They will have to adopt a manufacturer specified calibration procedure.
- **Validation.** Standardized validation will require reference measurement on field to determine precision and bias for the TSDD, similar to annual certifications on other field measurement devices. TSDD validation may have to rely on instrumented test sites that provide the target/control measurement for validation. Reducing the cost and logistics involved in this process may require the development of portable validation options.
- **Verification.** This may occur more frequently than validation and may involve the correlation to a measurement from a known device such as the FWD. To standardize the verification procedures, correlations between devices need to be established for different pavement material–pavement structure configurations. Depending on the degree of TSDD adoption, FWDs may eventually be used only for verification.

As shown in [Figure 48](#), other existing or ongoing activities that are expected to support the assimilation or implementation of TSDDs include:

- **Pavement Assessment Road Map.** This is a spreadsheet document developed several years ago listing indices necessary to assess surface and structural condition of pavements and the associated standards. Leading metrics are those providing structural assessment, and secondary metrics are those providing surface characteristics. TSDD is deemed as a primary provider of the leading metric.
- **Current AASHTO FWD Standards.** Existing standards for FWD can serve as templates for the development of TSDD standards despite the two devices using different technologies for deflection measurement. Figure 48 lists the governing FWD standards.
- **Pooled-Fund Studies.** TPF-5(385) has by far been the most significant study, consisting of more than 26 participating state DOTs and the FHWA. This study has provided pilot demonstration of 300 mi or data collection for each state, developed guidelines, and provided preliminary procedures to integrate TSDD-based structural data into an agency's PMS.
- **NCHRP Project 10-105.** Completion of NCHRP Project 10-105 can set into motion the adoption of TSDD, which includes the development of draft AASHTO standards for TSDD validation and verification. The study involves both preliminary testing for the draft standards and secondary testing to refine the standards. Expected timeframe is shown in Figure 48.

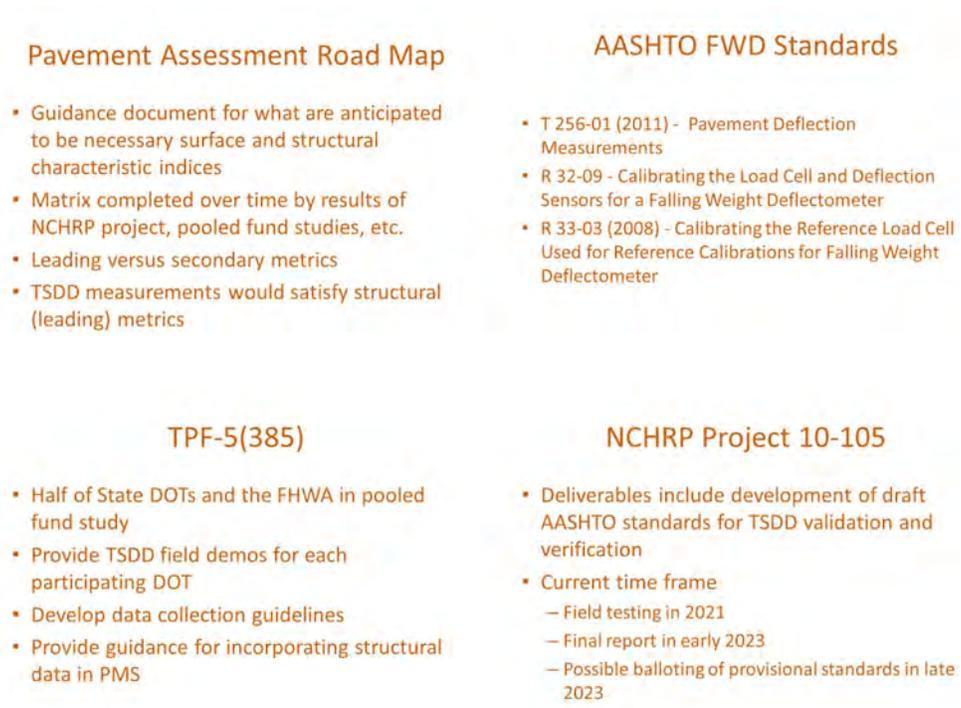


FIGURE 48 Elements of TSDD assimilation support.

Panel Discussion

GONZALO RADA
Wood, Moderator

After the presentation, Gonzalo Rada moderated a panel discussion. Some of the key points of that discussion are presented below:

1. Need for case studies. Many state DOTs have collected TSDD data and performed some level of analysis with the data. What is still lacking are case studies or application reports that document the process of collecting the data, performing the analysis, combining the TSDD data with the surface condition data, implementing the results of the analysis in the decision-making process, and documenting the final field applied decision. It seems from the presentations made by state agencies that these case studies are feasible (e.g., the work presented by Idaho). Furthermore, Eastern Federal Lands are currently planning to perform such a case study where they plan on collecting GPR data to combine with TSD data and use the information from the structural evaluation (e.g., SN_{eff}) with the surface condition data to come up with recommendations on the type of treatment work needed at the pavement sections. This discussion on the need for case studies led to the question of the type of information we want to obtain from TSDDs. Do we want to just delineate structurally good–fair–poor sections or do we want to get into more details regarding calculation of SN_{eff} or back calculation?

2. What type of information do we want TSDDs to provide? There was a relatively wide range of opinions regarding this question. There was the viewpoint that TSDDs can be used to delineate areas that might need different treatments or fine tune the locations to target for detailed investigation (e.g., where to do coring). This information is already valuable without the need to go all the way with a project-level structural analysis to determine layer moduli and calculated overlay thicknesses. This led to the question of what criteria should be used to delineate sections. The engineers that are going to look at the data and try to use it to make the decision between a simple maintenance and a more-involved rehabilitation need some guidance on how to interpret the data. In that respect, engineers that are making the final project-level decision on the appropriate treatment need “project-level–like” information from TSDDs. This led to the point of view that if we want TSDDs to replace FWDs then some way to come up with similar information as provided by the FWDs is needed (i.e., overlay thicknesses). In that respect, we need to be able to back calculate the layer moduli. Similar viewpoints from international transportation agencies were expressed at the November 2020 DaRTS meeting. Some agencies were quite happy with delineating sections while other agencies were looking into backcalculation of layer moduli. Agencies that were interested in delineating sections stressed the importance of repeatability while those interested in backcalculation of layer moduli equally stressed the importance of repeatability and reproducibility.

3. How does TSDDs data relate to FWD data? The question of how the two technologies relate to each other was raised because most highway agencies are familiar with the FWD and are able to interpret the results of FWD testing. While the TSDDs and FWD mostly show the same trends in the structural condition along a road, there are cases (as observed by the Texas DOT where the two devices tell a different story). Naturally, because of the long history of

FWD use, state highway agencies have a higher level of confidence with the FWD data than with TSDD data. Therefore, there is a pressing need to better understand the inner workings of TSDDs and how they are affected by testing speed, road roughness, and other parameters. Rick Miller also commented on the fact that areas where TSDDs (specifically the TSD) and FWD did not agree were observed in data collected in Kansas. It was later discovered that these areas had slippage between the pavement layers. Because TSDDs are moving devices and apply a rolling load, they could be more sensitive to slippage than the FWD, which applies a vertical impact load. In that respect we should not expect the two devices to agree all the time; it is up to the engineers and researchers to continue providing new and better methods to interpret the data collected by TSDDs but the information we can extract now, even if we cannot fully interpret it mechanistically, is still valuable.

4. Need for guidelines and standardization for data collection. Concurrent with the need for improved data interpretation methods for TSDDs, there is also a need for guidelines and standardization for data collection. Highway agencies have for the most part clear guidance on how to collect surface condition data and similar guidance for structural data will be very helpful. This is where AASHTO can play a role in providing standards.

5. Implication of structural data collection on surface condition data collection and interpretation. The discussion veered towards the interplay between structural condition data and surface condition data. While surface condition data is generally classified into load-related distresses and non-load-related distresses, the observed load-related distresses do not provide the information obtained from TSDDs; the pavement can be weak but have a new surface in which case no load-related distresses will be observed on the surface. Similarly, the structural condition is a driving force in the development of surface distresses; however, there are many other factors that affect the development of surface distresses and we cannot accurately predict surface distresses just from the structural condition data. As observed in Idaho, the surface condition data is good enough to get the right treatment roughly 70% of the time. Adding the structural information data will allow us to get the remaining 30% of the cases right.

6. What about rigid and composite pavements? Most of the work with TSDDs has been performed on flexible pavements. However, there are some promising early results about the possibility of locating weak joints in a jointed-concrete pavement (either exposed or under an asphalt layer). FHWA has collected data on the National Mall, which is a composite pavement with jointed concrete under the asphalt layer. One-meter data has been provided and shows the potential to identify weak joints. There has also been some research in the United Kingdom by the Transport Research Laboratory, which also showed promise. Finally, the new generation TSD device, which is planned to start operating in the second quarter of 2021, uses Doppler lasers with a 250-kHz frequency rather than the 1-kHz frequency of the previous generations. In principle, this much higher frequency should allow better evaluation of the joints (by allowing analysis at smaller resolutions or the same resolution but with higher accuracy). There are also some ideas (still in the very early conceptual stages) of using the data from the TSDDs on bridges.

Key Workshop Findings and Path Forward

GERARDO FLINTSCH
Virginia Tech

Gerardo Flintsch summarized the key points of the presentations and the panel discussion. First, there seems to be a consensus that adding network-level structural evaluation can enhance pavement management decisions (Figure 49). This was to a certain extent known but now we are starting to see more hard evidence such as good return on investment numbers. At the basic level, TSDDs can screen pavement sections that are good preservation candidates (strong versus weak sections). For pavement management applications, DOTs envision using the TSDD information as a “second filter” to complement the decision trees that are based on the surface condition. This additional information helps select the right project for the right application. TSDDs have also been used to develop better pavement deterioration curves that take into consideration structural condition. Methods that have been used to evaluate the structural condition from TSDD data are mostly based on the ones that have been developed for the FWD and there are still some questions regarding which indices are “best.”

There is also an interest in TSDD project-level applications, which seem feasible (Figure 50). A simple project-level application is refining the field exploration (coring) locations. More sophisticated use is to not just identify the weak areas but also identify the causes of the problem (subgrade, base, HMA, etc.). This could require more-detailed analysis such as backcalculation of layer moduli. Of course, more work needs to be done to gain more confidence in the use of TSDDs for project-level applications. Perhaps most importantly, a better general understanding of TSDDs is still needed. For example, how do they work? What is actually measured? How is the response affected by the pavement condition (e.g., delamination)? In addition, how are the measurements affected by pavement (surface) characteristics.

- ✓ Consensus that adding structural evaluation can enhance pavement management decisions
 - IDOT: ROI > 4
- ✓ Network level applications have proven useful
 - Based on the ones used with FWD
 - “Second filter” to complement traditional decision trees
 - Help select the right project
 - Development of better performance curves
 - Screen for good preservation candidates (strong vs weak sections)
 - Using different indices to indicate strength of pavement and subgrade
 - what are the best indices to use?

FIGURE 49 Key takeaways for network-level applications.

- ✓ Project level applications also seem feasible
 - Refine field exploration (coring) location
 - Identify particularly weak areas and help identify the cause of the problem (subgrade, base, HMA, etc.)
 - Some important questions may need to be answered to gain confidence (may be addressed, at least partially, by TPF -5(385))
 - Criteria for weak or strong?
 - How do we get an overlay thickness?
 - How do we link it with the MEPDG?
 - Better understanding of the devices

FIGURE 50 Key takeaways for project-level applications.

Finally, based on the questions asked and the panel discussion, some of the most urgent needs (Figure 51) are:

1. TSDD calibration, validation, and verification procedures;
2. Guidelines for data collection and quality management and assurance;
3. Investigation of TSDDs on concrete or composite pavements;
4. Defining performance measures; and
5. Need for more case studies that document the process from data analysis to decision-making.

Some of these needs are currently being investigated and will be partially answered. For example, NCHRP Project 10-105 is investigating methods to verify and maybe validate measurements; TPF-5(385) is developing draft documents for data collection procedures and guidance on pavement management applications. In addition, some case studies are being performed by the agencies that are members of TPF-5(385) either through the pooled fund or through other means. Regarding the evaluation of rigid and composite pavements, the new TSD device that is planned to be operational in the United States in the second quarter of 2021 has shown promise in the ability to evaluate concrete and composite pavements. Finally, having witnessed the advances in machine learning and artificial intelligence that have occurred over the last decade we cannot but wonder how these will affect how pavement diagnosis will be done in the future.

- ✓ Need consensus calibration (certification?), validation and verification procedures (being addressed in NCHRP 10 -105)
- ✓ Need data collection and quality assurance guidelines (and standards?) (being addresses in TPF -5(385))
 - Different requirements for project and network level?
 - E.g., spatial and temporal frequency, etc.
- ✓ Can we the use the TSD on concrete and composite pavements?
- ✓ Can we define performance measures based on structural condition for strategic-level asset and performance management?
- ✓ Need case studies from agencies – from data to decision making

FIGURE 51 List of most pressing questions regarding TSDDs.

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