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Evaluating the Potential Use of Traffic Speed Deflection Device-Based Pavement Structural Data for Asphalt Pavements in VDOT's Pavement Management Processes

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Abstract:

This report describes the evaluation of a proposed approach to incorporate structural condition information obtained from a traffic speed deflection device into the Virginia Department of Transportation (VDOT) pavement management system's pavement treatment selection process for asphalt pavement sections, which are denoted within the VDOT pavement management system as BIT for bituminous. This study analyzed a subset of the more than 7,000 lane miles tested in Virginia. The subset of data includes the structural condition data on approximately 4,250 lane miles (approximately 1,690 and 2,560 lane miles on the interstate and primary networks, respectively) of the VDOT network. The proposed approach calculates the pavement effective structural number and uses this number to determine the remaining structural life (RSTL). Researchers used RSTL thresholds to determine a structural modified recommended treatment category, that is, the recommended pavement rehabilitation category based on currently used surface condition and adding in the structural condition.

Work performed by Katicha et al. (2020) showed that, for sections having the same pavement surface age, those sections in worse structural condition also had more visible surface distresses, as assessed by the load-related distress index, non-load-related distress index, and critical condition index. This shows that the structural condition influences the pavement performance and validates the need to include the structural condition in the treatment selection process. Analysis of the 2017 data collected during this study (a small subset of VDOT's entire network) shows that about 10% of the primary network had a RSTL of less than 5 years, another 10% of the primary network had a RSTL between 5 and 12 years, and the remaining 80% of the primary network had a RSTL greater than 12 years. On the interstate network, more than 82% of the network has a RSTL of 20 years or more.

The research team performed an unconstrained needs analysis and documented case studies. The unconstrained needs analysis was performed on those sections tested in 2017 that included most of VDOT's interstate network and portions of US 460, US 360, US 58, US 17, and US 29 (northbound only) on VDOT's primary network. The analysis showed the difference in needs resulting from using the currently used surface-based condition and the structural modified recommended treatment category where the structural condition was added. Detailed case studies were performed for US 29 (northbound only) from Lynchburg to Charlottesville, Interstate 64 (eastbound only) from the West Virginia border to the Interstate 81 intersection, and Interstate 95 (northbound only) from north of Richmond to Interstate 495. In addition, the research team presented proposed modifications to the Detailed Pavement Condition (Jasper) Report.

FINAL REPORT

EVALUATING THE POTENTIAL USE OF TRAFFIC SPEED DEFLECTION DEVICE-BASED PAVEMENT STRUCTURAL DATA FOR ASPHALT PAVEMENTS IN VDOT'S PAVEMENT MANAGEMENT PROCESSES

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ABSTRACT

This report describes the evaluation of a proposed approach to incorporate structural condition information obtained from a traffic speed deflection device into the Virginia Department of Transportation (VDOT) pavement management system's pavement treatment selection process for asphalt pavement sections, which are denoted within the VDOT pavement management system as BIT for bituminous. This study analyzed a subset of the more than 7,000 lane miles tested in Virginia. The subset of data includes the structural condition data on approximately 4,250 lane miles (approximately 1,690 and 2,560 lane miles on the interstate and primary networks, respectively) of the VDOT network. The proposed approach calculates the pavement effective structural number and uses this number to determine the remaining structural life (RSTL). Researchers used RSTL thresholds to determine a structural modified recommended treatment category, that is, the recommended pavement rehabilitation category based on currently used surface condition and adding in the structural condition.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) currently assesses the condition of its pavement network using an automated condition survey methodology. This process assesses the surface-observable condition of the pavement by measuring features, such as rutting, cracking, and ride quality. Pavement condition is quantified in terms of a critical condition index (CCI) with a scale of 0 to 100, which is calculated as the lesser of a load-related distress rating (LDR) and a non-load-related distress rating (NDR).

Previous research has shown that the structural condition of a pavement can have a significant influence on its service life (Bryce et al., 2013; Flora, 2009; Katicha et al., 2016). Katicha et al. (2020) investigated the effect of structural condition on the pavement performance of interstate pavements in Virginia. Figure 1 shows the LDR, NDR, and CCI as a function of time since the most recent treatment for the structurally strongest 25th percentile of interstate pavement sections and the structurally weakest 25th percentile of interstate pavement sections. For the same age of pavement surface, the structurally stronger sections had higher LDR, NDR, and CCI values than the structurally weaker sections. Figure 1 demonstrates the potential benefits to VDOT of including a structural assessment in its pavement management system (PMS) practices, as maximizing good structural capacity can be beneficial in terms of pavement performance.

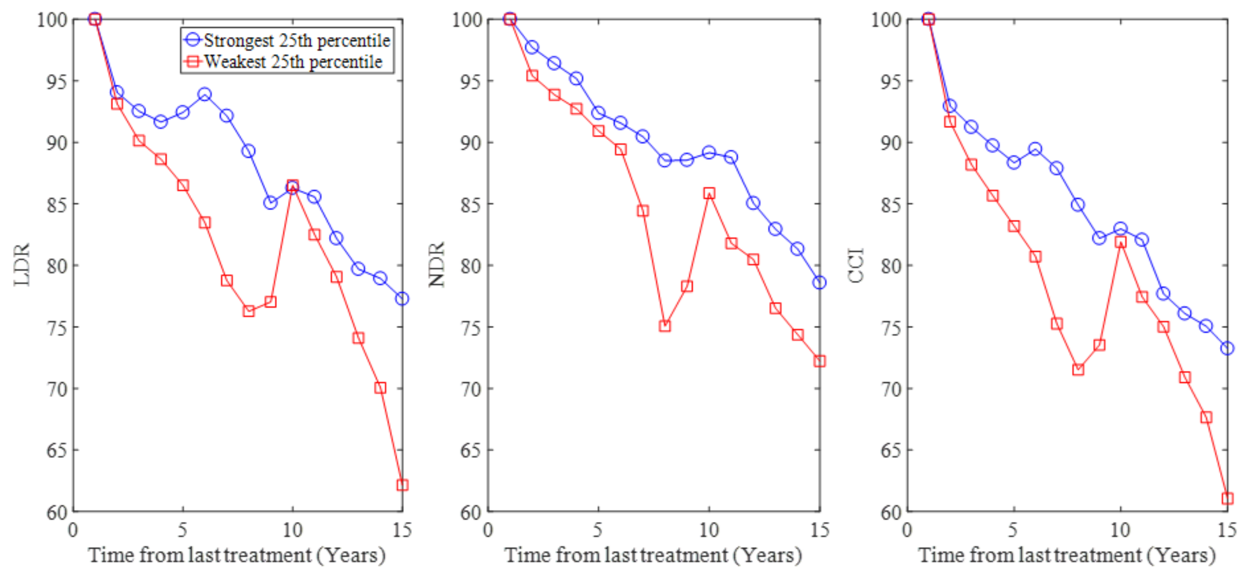


Figure 1. Average Condition for Tested Interstate Roads (LDR, NDR, and CCI) of Structurally Strongest 25th Percentile and Structurally Weakest 25th Percentile of Sections as a Function of Time from Most Recent Treatment (Katicha et al., 2020). CCI = critical condition index; LDR = load-related deterioration rating; NDR = non-load-related deterioration rating.

Between 2017 and 2023, VDOT collected structural condition data on approximately 7,770 lane miles of its pavement network using a traffic speed deflectometer (TSD), a type of Traffic Speed Deflection Device (TSDD), to conduct a network-level structural evaluation of its pavement system. Figure 2 shows the TSD.

Figure 1. Traffic Speed Deflectometer with Doppler Lasers Mounted on Measuring Beam (Provided by ARRB Systems USA, used with permission)

As Table 1 shows, the TSD collected approximately 4,250 lane miles (approximately 1,690 miles on the interstate network and approximately 2,560 lane miles on the primary network) in 2017. The structural condition data collected in 2017 also had pavement thickness data, which were collected as part of a separate effort. Structural condition data collected from 2018 to 2022 do not yet have associated pavement thickness data. Structural condition data collected in 2023 have pavement thickness data that were collected at the same time as the pavement structural data. Appendix A shows the locations of all structural data collected using the TSD.

Table 1. Routes and Distances Tested from 2017 to 2023

Year	Distance by Administrative Classification (lane miles)			Distance per Year (lane miles)
	Interstate	Primary	Secondary	
2017	1,690.9	2,558.5	—	4,249.4
2018	12.8	557.1	—	569.9
2019	252.1	—	—	252.1
2020	497.5	1,206.0	—	1,703.6
2022	188.4	246.0	16.0	450.4
2023	0.7	460.7	82.3	543.7
Subtotal by Administrative Classification	2,642.5	5,028.3	98.3	—
Total				7,769.1

— = no data.

Katicha et al. (2020) analyzed the 2017 dataset and recommended that this dataset be used within the PMS to further enhance network-level treatment selection. This report is based on that recommendation, proposing an approach to incorporate TSD-measured pavement structural condition information in VDOT's PMS to supplement the currently collected surface condition data for the planning of maintenance activities and performance reporting. VDOT's Maintenance Division publishes the annual *State of the Pavement* report, which summarizes the surface condition of the interstate, primary, and secondary VDOT roadway network (VDOT, 2022a). These condition data are at the core of the following four primary pavement management activities:

1. **Needs-Based Budgeting:** Maintenance and rehabilitation needs are determined from collected surface condition data and used to develop the biennial maintenance budget and guide districts' maintenance strategies.
2. **Planning for Preventive Maintenance and Resurfacing:** Decision trees use the surface condition data to recommend appropriate maintenance treatment categories to VDOT's districts. These treatment categories include (in order of increasing severity): Do Nothing, Preventive Maintenance, Corrective Maintenance, Restorative Maintenance, and Reconstruction.
3. **Pavement Performance Reporting:** State-level reports use the surface condition data to describe the asset conditions and asset management practices of State highway agencies.
4. **Federal Highway Performance Monitoring System Reporting:** VDOT submits the Highway Performance Monitoring System data to the Federal Highway Administration (FHWA) as the basis for the Federal apportionment of Virginia's share of Federal funds.

PURPOSE AND SCOPE

This project sought to propose and evaluate an approach for VDOT to incorporate structural condition information, obtained from TSD testing, into the VDOT PMS. The developed approach can be used to combine structural condition information with surface condition information to develop increasingly cost-effective pavement rehabilitation treatments and longer service lives. This effort focused on asphalt pavement sections, which are denoted within the VDOT PMS as BIT for bituminous. For concrete and composite pavements, structural indicators VDOT uses for falling weight deflectometer (FWD) were calculated and uploaded to PMS.

METHODS

To accomplish the work, the research team conducted the following tasks:

1. Reviewed current and potential methods for incorporating pavement structural condition into the VDOT PMS at the network level. This review included asphalt, concrete, and composite pavements.

2. Recommended an approach to include structural condition data into VDOT’s pavement rehabilitation decision making processes.

3. Identified and calculated the required structural condition parameters to be used in the recommended approach.

4. Evaluated the results of combining surface condition with structural condition for a structural-modified decision-making process.

5. Created an additional VDOT Detailed Pavement Report used to describe each section with TSD data.

The following sections discuss the most widely known TSDDs—the rolling wheel deflectometer (RWD), RAPTOR, and TSD—with a focus on the TSD as the device used to collect the structural condition data for this study. These sections present more detail about each device and additional information about this study including a map of the collected data and details of the structural calculations conducted and the overall approach of combining the structural condition with the surface condition.

Traffic Speed Deflection Devices

TSDDs evolved from the need for network-level structural evaluation. In the United States, FHWA funded the development of the Rolling Wheel Deflectometer (RWD). The only working prototype of RWD was launched in 2003 and was used for numerous demonstration projects throughout the United States (Flintsch et al., 2013; Jitin et al., 2006; Rada and Nazarian, 2011; Rada et al., 2016; Steele et al., 2015; Wilke, 2014). The device used laser distance measurements to determine the pavement deflection response to loading. After a comprehensive evaluation by Rada et al. (2016), the RWD underwent a major redesign to produce an updated device that relied on imaging technology to determine the pavement response to the wheel load, which was field tested in 2019. Steele et al. (2020) reported on this field testing. In 2020, the RWD was decommissioned.

With the RWD decommissioned, two TSDD designs are currently operating in the world—the TSD (Figure 2) and the Rapid Pavement Tester (RAPTOR; Figure 3). The RAPTOR was developed jointly by Dynatest and the Technical University of Denmark as a device that uses an array of line lasers to scan a strip of pavement (Andersen et al., 2017; Deep et al., 2020). The use of line lasers reduces the effect of texture by averaging the scans. However, this method leads to the measurements being obtained at an offset from the wheel load (Figure 3). The sensing system consists of an array of 12 4-kHz line lasers mounted on a beam that is inside the right wheel path. Gyroscopes and accelerometers are mounted on the support beam to measure changes in horizontal and vertical alignments. The trailer unit that encases the RAPTOR is custom built to accommodate the instrumentation, the independent wheels with their corresponding suspension system, and additional weights that can adjust the load to 11.2 kips (50 kN) on each rear wheel (Andersen et al., 2017; Athanasiadis and Zoulis, 2019; Skar et al., 2020). RAPTOR is currently not available in the United States, and only two RAPTOR devices have been built so far.

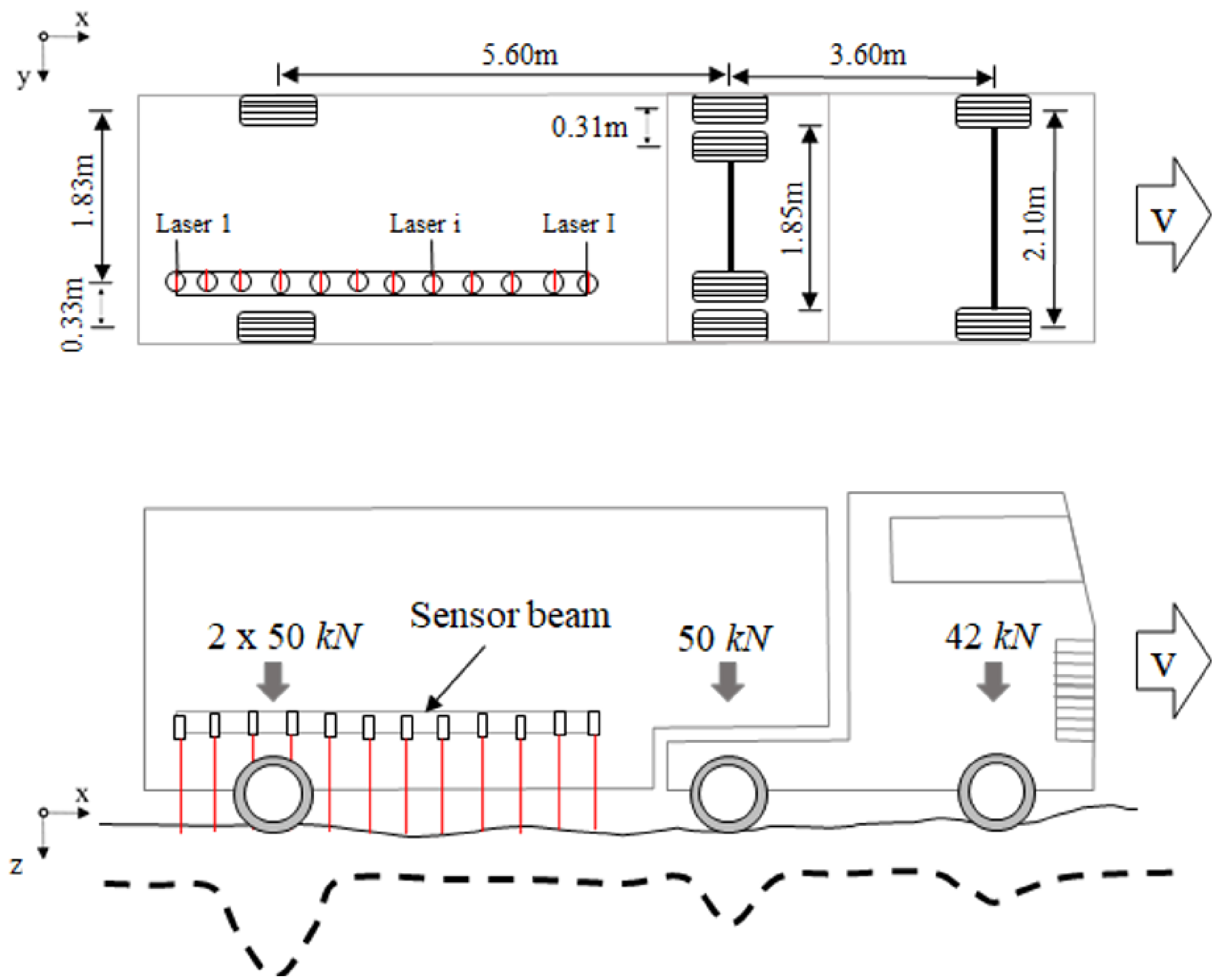


Figure 3. Schematics of Rapid Pavement Tester (Shrestha, 2022; used with permission)

The TSD (Figure 2) is currently the only device available in the United States. It is an articulated truck with a rear-axle load that can be varied from 13.4 kips to 29.2 kips (60 kN to 130 kN) by using sealed lead loads. The TSD used to collect the data for this study, TSD9, is the 9th device built. The TSD has Doppler lasers mounted on a servo-hydraulic beam to measure the deflection velocity of a loaded pavement. To prevent thermal distortion, the steel measurement beam is housed in a climate-controlled trailer that maintains a temperature of 68°F (20°C). Six Doppler lasers are positioned to estimate the pavement deflection velocity at nominal distances of 4, 8, 12, 24, and 60 inches (100, 200, 300, 600, 900, and 1,500 mm) in front of the loading axle. A seventh sensor is positioned 11.5 feet (3,500 mm) in front of the rear axle, largely outside the deflection bowl, to act as a reference laser. The data were collected at a sampling rate of 1 kHz.

Currently, 20 TSDs have been produced and the current TSD operating in the United States is TSD21, which ARRB Systems operates. This most recent version includes three additional lasers for measuring deflection velocities at nominal distances of 8, 12, and 18 inches (200, 300, and 450 mm) behind the wheel and three-dimensional ground penetrating radar (for measuring pavement thickness). Data for the most recent TSD are recorded at a survey speed of up to 60 mph (100 km/h) at a sampling rate of 250 kHz.

The TSD differs from other TSDDs in that it uses Doppler lasers to measure the pavement deflection velocity, rather than distance-measuring lasers that measure deflections (velocities are the time derivative of deflection). The Doppler lasers rely on the Doppler effect (Figure). Objects moving relative to the lasers alter the laser signal frequency in a way that is proportional to relative velocity. This effect allows the relative velocity to be determined in terms of the change in frequency.

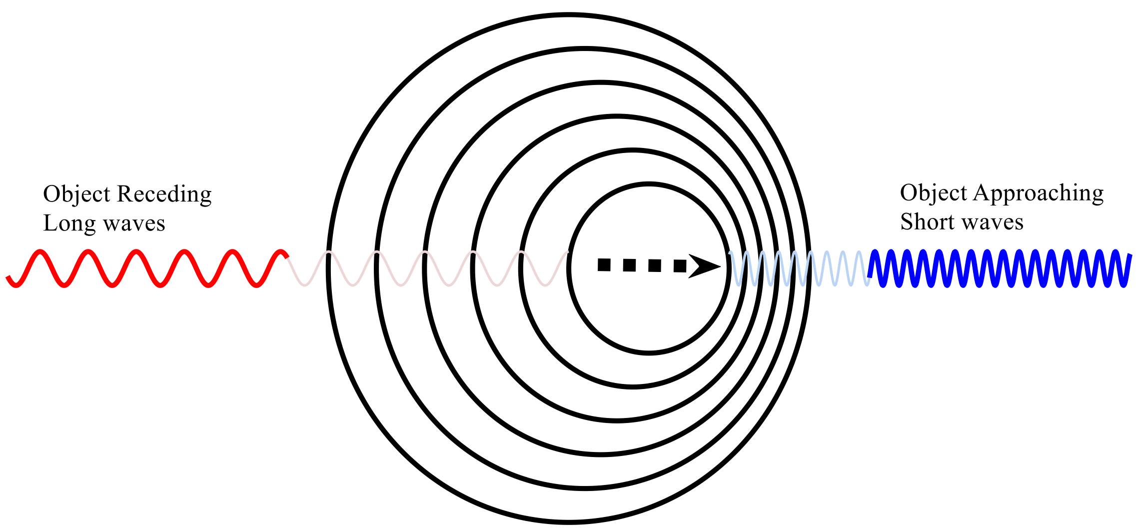


Figure 4. Illustration of the Doppler Effect (figure created by the authors based on Hildebrand and Rasmussen (2002) from Wright (2002))

The TSD Doppler lasers are mounted at a small angle to the vertical to measure the vertical pavement deflection velocity together with components of the horizontal vehicle speed and the vertical and horizontal vehicle suspension velocities. The pavement deflection velocity is divided by the instantaneous vehicle speed to obtain the deflection slope as follows.

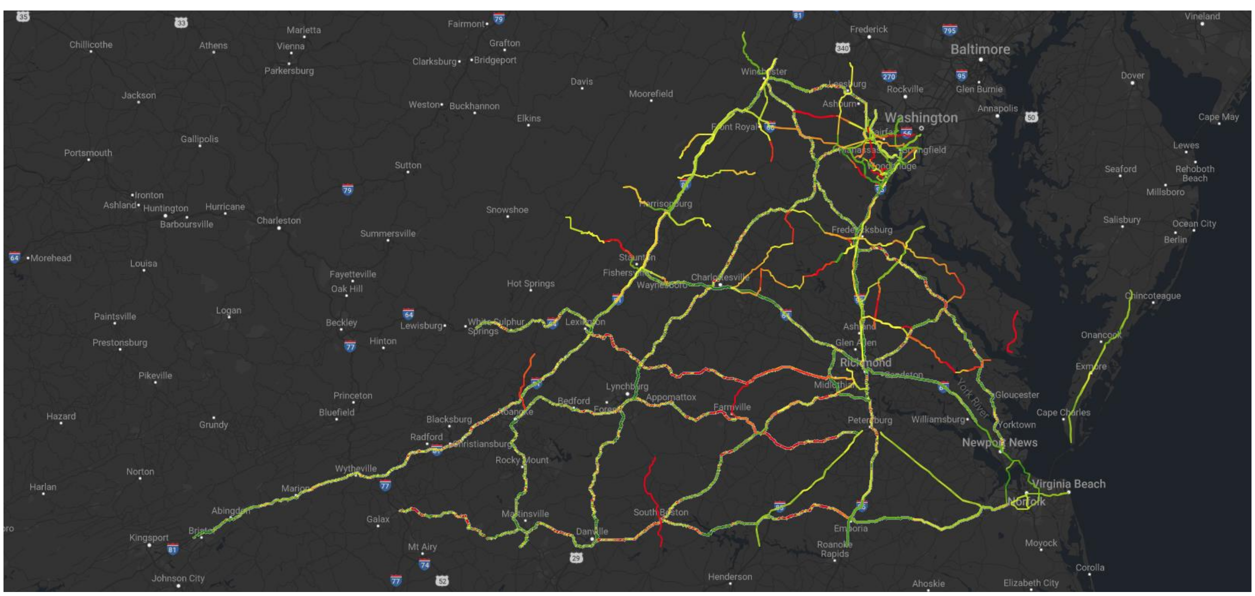
$$S = \frac{V_v}{V_h} \qquad \text{(Eq. 1)}$$

Where:
S = deflection slope.
V_v = vertical pavement deflection velocity.
V_h = vehicle horizontal velocity.

Typically, the deflection velocity is measured in inches/s (mm/s), and the vehicle speed is measured in feet per second (m/s). Therefore, the deflection slope measurements are output in units of inches per feet (mm/m) and generally reported at a 33- to 53-feet (10- to 16-m) interval, although a 3.3-ft (1-m) interval is also possible. Further details about the TSD and its use can be found in Katicha et al. (2022).

Collected Traffic Speed Deflectometer Data

Figure a illustrates the entire network tested by the TSD in Virginia, which consists of approximately 7,770 lane miles. Only the portion of the network that was tested in 2017, shown in Figure b, was analyzed for this study. This portion of the tested network was chosen for its layer thickness information, which is needed to perform the pavement structural analysis. This portion includes three interstate routes with a total distance of approximately 1,691 lane miles and 11 primary routes with a total distance of approximately 2,560 lane miles. Table 1 lists the tested roads.



(a)

(b)

Figure 5. Routes Assessed with Traffic Speed Deflectometer: (a) Total Network (b) Network Portion Used in this Study

Data Analysis

The following sections describe how researchers analyzed the collected TSD data for asphalt pavements and considered a different approach for concrete and composite pavements.

BIT Pavements

The recommended data analysis approach was based on the structural number (SN) concept used in the *AASHTO Guide for the Design of Pavement Structures* (AASHTO, 1993). Although the approach was developed for FWD testing, it is also appropriate for network-level analysis using TSD data and is the approach most other agencies recommend (Huang et al., 2022; Maser et al., 2017. The approach requires collecting deflection data to measure the maximum deflection (D_0), normalizing D_0 to a reference temperature of 20°C (68°F), calculating the subgrade resilient modulus, and calculating the effective structural number (SN_{eff}). The calculated SN_{eff}, along with traffic equivalent single axle load (ESAL) information, is then used to determine the remaining structural life (RSTL). RSTL can then be applied to determine the appropriate treatment category based on structural condition, which is combined with the treatment category obtained from the surface's observed condition to determine a modified treatment category.

The main advantage of the RSTL index is that it accounts for most of the factors that determine whether a specific pavement should be considered strong or weak, which is because pavement strength is a relative measure rather than an absolute measure The strength of a pavement section should be viewed in context with other parameters, such as facility type and truck traffic volume. Another advantage of RSTL is that it is an index that does not require engineering knowledge of pavements. RSTL can be easily understood and interpreted by elected officials and decisionmakers, who play a role in deciding on the levels of funding available for pavement maintenance and rehabilitation. The following section shows the process for calculating RSTL.

Temperature Normalization of D_0

To normalize D_0 with respect to temperature, the BELLS3 equation (Lukanen at al. 2000) was used to calculate the asphalt mid-depth temperature. This process requires the pavement temperature during testing, the time of testing, and the previous day's temperature. Equation 2 shows the BELLS3 equation to calculate the temperature at depth *d*.

$$T_d = 0.95 + 0.892 \times IR + \{\log(d) - 1.25\}\{-0.448 \times IR + 0.621 \times T_p + 1.83 \times \sin(hr_{18} - 15.5) + 0.042 \times IR \times \sin(hr_{18} - 13.5)\} \quad \text{(Eq. 2)}$$

Where:
T_d = pavement temperature at depth *d* (ºC).
IR = pavement surface temperature (ºC).
log = base-10 logarithm.
d = depth where temperature will be predicted (mm).
T_p = average air temperature the day before testing (ºC).
sin = Sine function on an 18-hour clock system, with 2π radians equal to one 18-hour cycle.
hr_{18} = time of the day in a 24-hour clock system but is calculated using an 18-hour asphalt concrete temperature rise and fall time cycle.

National Oceanic and Atmospheric Administration land-based weather station data were used to obtain the average temperature on the day before testing. The temperature correction factor is obtained from the values of T_d (calculated using the BELLS3 equation) and the asphalt pavement thickness using Figure .

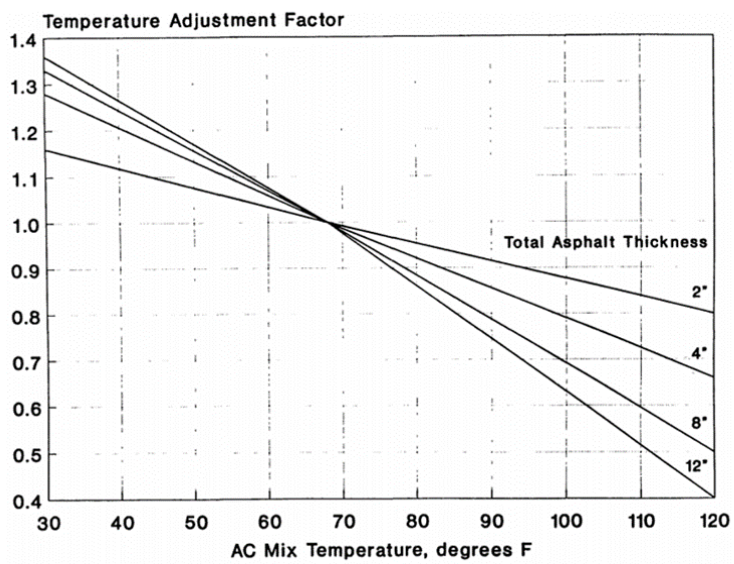


Figure 6. Temperature Adjustment Factor from AASHTO (1993), Used with Permission

Calculation of Subgrade Resilient Modulus

The subgrade resilient modulus was calculated using the Boussinesq equation shown in Equation 3.

$$M_r = \frac{P(1-\mu^2)}{r\times\pi\times d_r} \approx \frac{0.24P}{r\pi\times d_r} \quad \text{(Eq. 3)}$$

Where:
P = applied load (pounds).
μ = Poisson's ratio (usually assumed to be 0.5).
r = distance from center of load (inches).
dr = measured deflection at distance r (inches).

The value of r that should be used in the equation is related to the minimum value, such that the measured deflection d_r comes solely from the subgrade. This criterion is based on stress distribution in the pavement under the FWD testing shown in Figure 7, where the minimum distance is labeled a_e and depends on the total pavement thickness, the equivalent pavement modulus, and the subgrade resilient modulus. In the AASHTO (1993) design guide, Equation 4 gives the condition on relationship between r and a_e (where $\mathrm{r} \geq 0.7\mathrm{a_e}$).

$$a_e = \sqrt{a^2 + \left(H_p \sqrt[3]{\frac{E_p}{M_r}}\right)^2} \quad \text{(Eq. 4)}$$

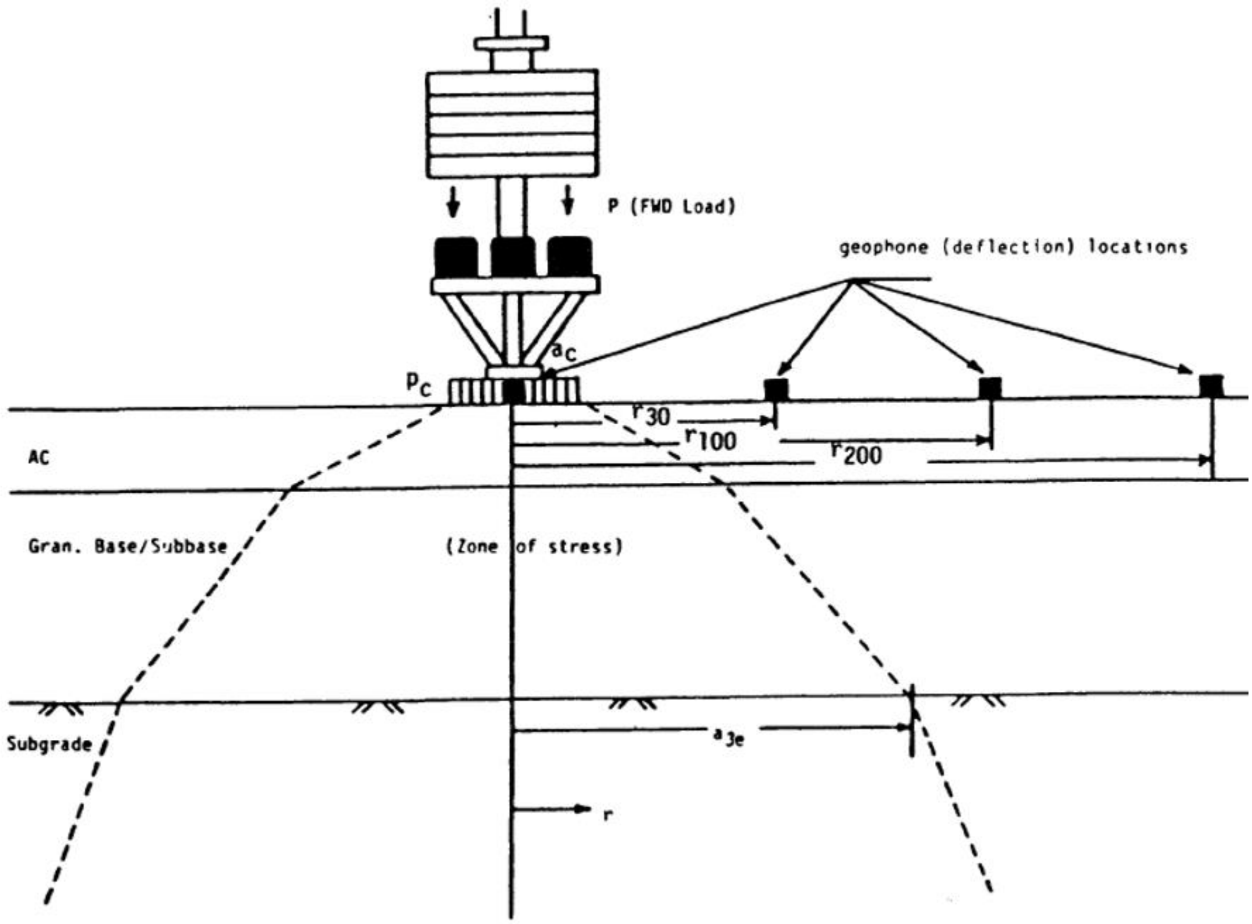


Figure 7. Stress Zone Within a Pavement Structure Under Falling Weight Deflectometer Load from AASHTO (1993), Used with Permission

Calculation of SN_{eff}

The pavement SN_{eff} is calculated using the temperature-normalized D_0, the total pavement thickness, the subgrade resilient modulus, the applied load, and the circular radius of the loading area. First, the pavement equivalent modulus is calculated using Equation 5.

$$D_0 = 1.5 \times p \times a \left\{ \frac{1}{M_r \sqrt{1+\left(\frac{H_p}{a}\sqrt[3]{\frac{E_p}{M_r}}\right)^2}} + \frac{1-\frac{1}{\sqrt{1+\left(\frac{H_p}{a}\right)^2}}}{E_p} \right\} \qquad \text{(Eq. 5)}$$

Where:
p = contact pressure (psi).
a = circular load radius (inches).
E_p = equivalent pavement modulus (psi).
H_p = total pavement layer thickness (inches).
D_0 = deflection at the center of the loading area (inches).

The value of E_p is determined in an iterative procedure. The SN_{eff} is then calculated from E_p using Equation 6 as follows.

$$SN_{eff} = 0.0045 H_p \sqrt[3]{E_p} \quad \text{(Eq. 6)}$$

Calculating Remaining Structural Life

The RSTL calculation is based on the AASHTO design equation shown in Equation 7.

$$\log(ESALs) = z_R S_0 + 9.36\log(SN+1) + \frac{\log\left(\frac{p_0 - p_t}{2.7}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\log(M_r) - 8.27 \quad \text{(Eq. 7)}$$

Where:
$ESALs$ = number of equivalent 18-kip single axle loads during the design period.
z_R = standard normal z-value (based on required design reliability, which is often based on functional classification of road).
S_0 = standard deviation (usually 0.45).
p_0, p_t = initial and terminal serviceability (Table 3).
M_r = subgrade modulus (psi).
SN = structural number.

When Equation 7 is used for the rehabilitation of asphalt pavements based on FWD testing, the subgrade resilient modulus (Equation 3) is multiplied by a field-to-laboratory correction factor. VDOT uses 0.33 (VDOT, 2022b). The standard deviation in the design equation that VDOT uses is 0.49, and the reliability and serviceability inputs to the design equation are given in Tables 2 and 3.

Table 2. VDOT Reliability Values for Pavement Design (VDOT, 2022b)

Highway Classification	Urban, %	Rural, %
Interstate	95	95
Divided Primary Route	90	90
Undivided Primary Route	90	85
High Volume Secondary Route	90	85
Farm to Market Secondary Route	85	75

Table 3. VDOT Serviceability Value for Pavement Design (VDOT, 2022b)

Highway Classification	Initial	Terminal
Interstate	4.2	3.0
Divided Primary Route	4.2	2.9
Undivided Primary Route	4.2	2.8
High Volume Secondary Route	4.2	2.8
Farm to Market Secondary Route	4.0	2.5

By replacing SN from Equation 7 with SN_{eff}, as calculated from the TSD measurements, a revised equation to determine ESALs that can be carried, given the current structural capacity, truck traffic and traffic growth information, is shown in Equation 8.

$$\log(ESALs) = z_R S_0 + 9.36\log(SN_{eff} + 1) + \frac{\log\left(\frac{p_0 - p_t}{2.7}\right)}{0.4 + \frac{1094}{(SN_{eff}+1)^{5.19}}} + 2.32\log(M_r) - 8.27 \quad \text{(Eq. 8)}$$

Then, solving for the time RSTL in years, using Equation 9.

$$ESALs = 365 \times ESAL_0 (1 + GF)^{RSTL-1} \quad \text{(Eq. 9)}$$

Where:
GF = yearly truck traffic growth factor.

Using traffic data to calculate the number of ESALs per year that are expected, the number of years of RSTL can be calculated.

Calculation of Expected Equivalent Single Axle Loads

The research team calculated the expected traffic loading (in terms of ESALs) using traffic count and vehicle distribution information obtained from VDOT and a lane distribution factor of 90% for two-lane roads, 70% for three-lane roads, and 60% for four-lane and greater roads. Table 4 shows the ESAL equivalency factor used for VDOT's vehicle categories.
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Table 4. ESAL Equivalency Factors for Asphalt Pavements based on Smith and Diefenderfer (2009) and VDOT (2022b)

VDOT Category	**2- and 4-Tire Vehicles**	**Buses**	**Single-Unit Trucks with 2 Axles**	**Single-Unit Trucks with 3 or more Axles**	**Combination Trucks with 1 Trailer**	**Combination Trucks with 2 or more Trailers**
FHWA Category	**1-3**	**4**	**5**	**6-7**	**8-9-10**	**11-12-13**
ESAL Factor Interstate	0.0002	0.44	0.28	0.46	1.04	1.33
ESAL Factor Primary	0.0002	0.35	0.36	0.7	0.98	1.10

ESAL = equivalent single axle load.

Concrete (JPC, JRC, or CRC) and Composite (BOJ or BOC) Pavements

For concrete and composite pavements, researchers did not find an approach to calculate RSTL in the literature. The research team investigated whether a RSTL approach for concrete and composite pavements could be developed based on the AASHTO (1993) approach for rehabilitation of concrete and composite pavements. However, the researchers concluded that a similar approach would be too complicated to implement because knowledge of the load transfer factor of the existing slab, the joints and crack adjustment factor, the slab durability adjustment factor, and the fatigue damage adjustment factor would be required. Therefore, use of the same procedure currently implemented within VDOT's PMS for interstate roads is recommended. For this purpose, the AREA and K-value equations shown in Equation 10 and Equation 11 are recommended.

$$AREA = \frac{6(D_0 + 2D_{12} + 2D_{24} + D_{36})}{D_0} \quad \text{(Eq. 10)}$$

$$K = \frac{PD_0^*}{D_0 l^2} \quad \text{(Eq. 11)}$$

Where:

$$l = \left[\frac{\ln\left(\frac{k_1 - AREA}{k_2}\right)}{-k_3}\right]^{\frac{1}{k_4}}$$

$k_1 = 36.$
$k_2 = 1812.597.$
$k_3 = 2.559.$
$1/k_4 = 4.387.$
$D_0^* = 0.12450 \times e^{-0.14707 \times e^{-0.075765 \times l}}.$

Relating RSTL with Structural Treatment Category for BIT Pavements

VDOT's current decision making process uses the results from automated surveys to assess the surface-based condition of the pavement network. From this assessment, a decision-tree process is used to determine a general treatment category that includes Do Nothing (DN), Preventive Maintenance (PM), Corrective Maintenance (CM), Restorative Maintenance (RM), and Reconstruction (RC). Within each treatment category, a range of pavement rehabilitation activities may exist. For example, a PM treatment category could include treatments, such as slurry seals, chip seals, microsurfacing, or other similar treatments, depending on the route type.

A CM treatment is most often a 2-inch-thick asphalt overlay or 2-inch-thick mill and inlay. A RM treatment is most often a 4-inch-thick asphalt overlay or a 4-inch-thick mill and inlay. A RC treatment is generally any rehabilitation process that is greater than 4 inches thick. To implement the structural data from the TSD into this process, the researchers suggested including a structural treatment category recommendation based on the calculated RSTL. A relationship between RSTL and the structural treatment category is shown in Table 5. The ranges of RSTL for each treatment category were based on a consensus from the researchers and the Technical Review Panel.

Table 5. Structural Treatment Category from Calculated Remaining Structural Service Life

Remaining Structural Service Life (years)	Structural Treatment Category
> 20	DN
≤ 20 to > 12	PM
≤ 12 to > 8	CM
≤ 8 to > 3	RM
≤ 3	RC

CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance.

VDOT Pavement Management System Integration

To better describe how the RSTL process can be integrated into VDOTs PMS, a series of terms are introduced here. In 2006, VDOT began collecting digital images to quantity pavement distresses in an annual survey of its interstate, primary, and secondary roadway networks (VDOT, 2010). This practice is termed herein as VDOT's *original decision-making process*. Between 2004 and 2007, FWD testing to collect structural data on portions of its interstate network (Diefenderfer, 2008). Subsequently, VDOT added structural parameters calculated from these data to the PMS, along with age and traffic level, in a method referred to in this report as VDOT's *enhanced decision-making process*. Including RSTL into VDOT's PMS practices is referred to in this report as VDOT's *structural modified decision-making process*. The structural modified process includes substituting RSTL in place of FWD-based structural parameters and age and traffic level. Age and traffic level are already included in the calculation of RSTL. Where data do not exist to calculate RSTL, VDOT should revert to its original decision-making process.

RSTL can be included in VDOT's decision-making processes using the following steps. First, the treatment category is recommended, based on the surface condition. Following this recommendation, the calculated RSTL is used to develop the structural condition recommended treatment category. Finally, a structural modified recommended treatment category can be selected as shown in Table 6. This category is based on a combination of the surface condition and structural condition data and the consensus of the researchers and the Technical Review Panel. Additional details on how the structural modified treatment category recommendations were developed are presented in the following sections.

Table 6. Structural Modified Recommended Treatment Category Based on Surface and Structural Condition

		Surface Condition Recommended Treatment Category				
		DN	**PM**	**CM**	**RM**	**RC**
Structural Condition Recommended Treatment Category	**DN**	DN	PM	CM	CM	CM
	PM	DN	PM	CM	CM	CM
	CM	DN	DN	CM	CM	RM
	RM	DN	DN	RM	RM	RC
	RC	DN	DN	RC	RC	RC

CM = Corrective Maintenance; DN = Do Nothing; PM = Preventive Maintenance; RC = Reconstruction. RM = Restorative Maintenance.

Do Nothing Surface Condition Recommended Treatment Category

The DN surface condition recommended treatment category means that the pavement surface is in good condition. If the structural condition recommended treatment category is DN, PM, or CM, this rating means that the structural condition of the pavement ranges from good to fair. Since the surface condition is good, the recommendation is that no treatment needs to be applied to the pavement, and thus, the structural modified recommended treatment category is DN. If the structural condition recommended treatment category is RM or RC, this rating means that the structural condition of the pavement is poor or very poor, and a treatment that improves the structural condition should be applied. However, since the surface is in good condition, the structural improvement should be delayed to a time when the surface condition deteriorates to a level that it needs to be replaced. Thus, a structural modified recommended treatment category of DN is also recommended.

Preventive Maintenance Surface Condition Recommended Treatment Category

The PM surface condition recommended treatment category means that some intervention to preserve the life of the pavement is beneficial. If the structural condition recommended treatment category is DN or PM, the structural condition of the pavement is good, and thus, a PM treatment is the structural modified recommended treatment category. If the structural condition recommended treatment category is CM, RM, or RC, then PM will not be an effective treatment, and DN is the structural modified recommended treatment category. Delaying any treatment until the surface condition further deteriorates is preferred; after this deterioration, the appropriate treatment of CM, RM, or RC should be applied.

Corrective Maintenance Surface Condition Recommended Treatment Category

The CM surface condition recommended treatment category indicates that some treatment is required for the pavement surface, and this treatment should be more severe than a PM treatment. If the structural condition recommended treatment category is DN, PM, or CM, this rating means the structural condition of the pavement is at least fair. Therefore, structural improvement is not needed, and a structural modified recommended treatment category of CM is appropriate. If the structural condition recommended treatment category is RM or RC, this rating means the pavement is structurally weak, and the surface condition recommended treatment category of CM is not adequate. Therefore, the structural modified recommended treatment category should be RM or RC.

Restorative Maintenance Surface Condition Recommended Treatment Category

The RM surface condition recommended treatment category means that some level of deterioration at the pavement surface is more advanced, and a single course intervention, such as CM, is not likely to be appropriate. If the structural condition recommended treatment category is DN, PM, or CM, this rating means the structural condition of the pavement is at least fair and suggests the RM treatment is more severe than needed. Therefore, the structural modified recommended treatment category is CM. If the structural condition recommended treatment category is RM or RC, this rating means the structural condition is relatively weak, and the structural modified recommended treatment category should be RM or RC.

Reconstruction Surface Condition Recommended Treatment Category

The RC surface condition recommended treatment category indicates the surface of the pavement is highly deteriorated and will require significant intervention to bring back to an acceptable condition. However, if the structural condition recommended treatment category is DN or PM, this rating suggests the structural condition of the pavement is good, and the more severe RC treatment is not appropriate. The observed distresses can be addressed with a structural modified recommended treatment category of CM. If the structural condition recommended treatment category is CM, then the structural condition is fair, and a structural modified recommended treatment category of RM is more appropriate. If the structural condition recommended treatment category is RM or RC, this rating means that the pavement is structurally weak, in addition to being in poor condition at the surface. The structural modified recommended treatment category in this case should be RC.

RESULTS

The results section shows the distribution of RSTL on the primary and interstate networks using the 2017 dataset, an unconstrained needs analysis, and case study examples. The needs analysis and case study examples were performed separately for sections on both the primary and interstate networks. The needs were calculated using a segmentation interval of 0.01 miles. Illustrations in this section show segmentation in greater detail (10-m interval) to help with visualizing the results. In addition, this section presents suggested modifications to the main Detailed Pavement (Jasper) Report.

Distribution of RSTL on VDOT's Tested 2017 Network

The distribution of RSTL on the primary network that was tested in 2017 is shown in Figure . Approximately 7% of the tested roads had a RSTL of less than 3 years, and more than 70% of the tested roads had a RSTL greater than 14 years. Figure 99 shows the distribution of RSTL for the interstate network tested in 2017 and the BIT portions of I-64, I-81, and I-95 tested in 2017. As expected, the distribution shows that the interstate network is generally in a better structural condition than the primary network. For I-64 and I-81, more than 85% of BIT sections have an RSTL of 20 years or greater. The condition of BIT sections on I-95 is not as good as the condition on I-64 and I-81, with slightly less than 60% of those sections having a RSTL of 20 years or greater.

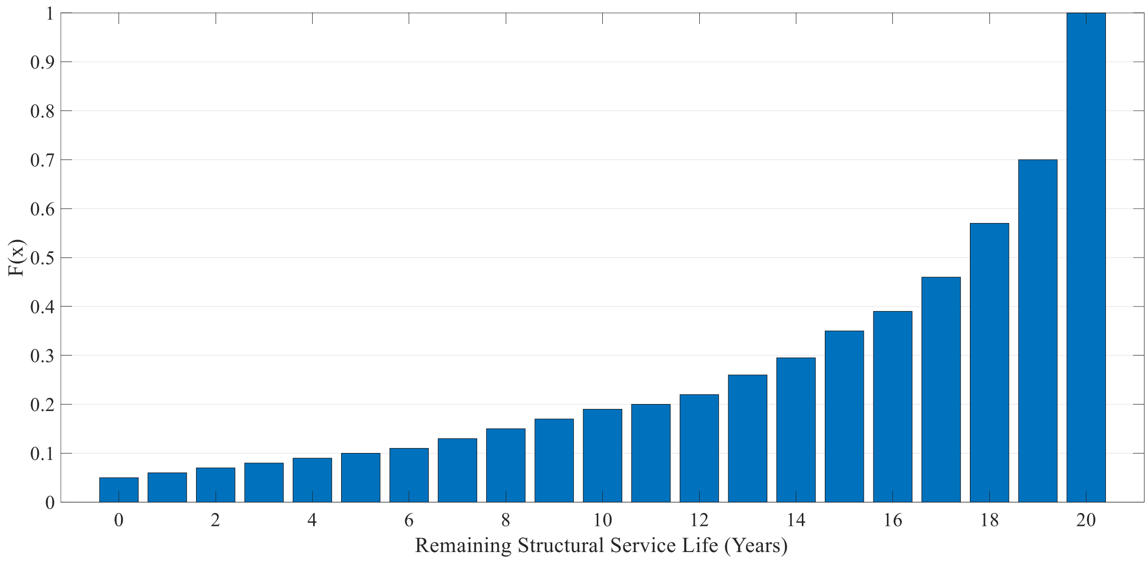


Figure 8. Cumulative Distribution of Remaining Structural Life for Primary Routes Tested in 2017

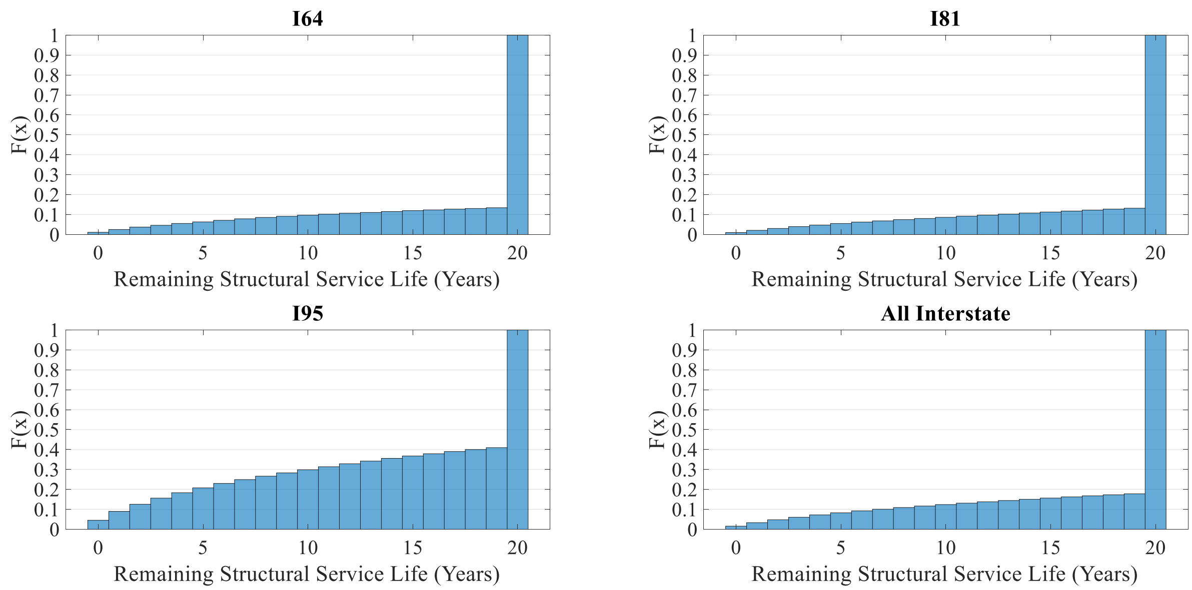


Figure 9. Cumulative Distribution of Remaining Structural Life Interstate Routes Tested in 2017

Unconstrained Needs Analysis and Case Studies

Primary Network Analysis

This section presents the total unconstrained needs of the BIT pavement sections on US 460, US 360, US 58, and US 17 tested in 2017. The needs were calculated using the per-lane-mile treatment costs shown in Table 7. Table 8 shows the needs, as defined using the surface condition recommended treatment category (original or enhanced process) and the structural modified recommended treatment category described in Table 6. In total, the needs for the primary network sections were found to increase from $167.6 million to $186.8 million when using the structural modified recommended treatment categories as compared to the treatment categories recommended based on the surface condition. This consists of $1.9 million needs increase on US 460 ($0.3 million increase Eastbound and $1.6 million increase Westbound), $2.0 million needs increase on US 360 ($1.4 million increase Eastbound and $0.6 million increase Westbound), $12.3 million needs increase on US 58 ($5.8 million increase Eastbound and $6.5 million increase Westbound), and $2.9 million needs increase on US 17 ($1.7 million increase Northbound and $1.2 million increase Southbound). Additional details of the distribution of treatments and needs for the primary network are presented in in Appendix B.

Table 7. Treatment Costs (VDOT, 2023)

Treatment Category	Cost per Lane Mile (Interstate)	Cost per Lane Mile (Primary)
Do Nothing	$0	$0
Preventive Maintenance	$35,104	$25,162
Corrective Maintenance	$136,030	$83,001
Restorative Maintenance	$257,797	$194,166
Reconstruction	$575,447	$523,011

Table 8. Calculated Needs for Primary Network Based on Surface Condition and Structural Modified Recommended Treatment Categories

Route	Direction	Needs—Surface Condition Recommended Treatment Category (millions)	Structural Modified Recommended Treatment Category
US 460	East	$22.4	$22.7
	West	$12.0	$13.6
	Subtotal	**$34.4**	**$36.3**
US 360	East	$11.2	$12.6
	West	$17.4	$18.0
	Subtotal	**$28.6**	**$30.6**
US 58	East	$28.9	$34.7
	West	$35.5	$42.0
	Subtotal	**$64.4**	**$76.7**
US 17	North	$18.3	$20.0
	South	$22.0	$23.2
	Subtotal	**$40.3**	**$43.2**
Total		**$167.7**	**$186.6**

Case Study: US 29 Northbound, Lynchburg to Charlottesville

Pavement structural data was collected on US 29 Northbound in four different sections (Figure 10): from Danville to Lynchburg, from Lynchburg to Charlottesville, from Charlottesville to Elkwood, and from Elkwood to the I-66 intersection. The calculated needs for each section, based on surface condition recommended treatment categories and recommended treatment categories modified for structure, are provided in Table 7. The structural modified recommended treatment category needs for this portion of US 29 were found to be $8.7 million less than the needs based on the surface condition recommended treatment category.

Figure 10. Four Tested Sections on US 29

Table 7. Calculated Needs for US 29 Northbound Case Study

Route	**From**	**To**	**Needs—Surface Condition Recommended Treatment Category (millions)**	**Structural Modified Recommended Treatment Category**
US 29 Northbound	Danville	Lynchburg	$4.5	$2.0
	Lynchburg	Charlottesville	$6.8	$5.2
	Charlottesville	Elkwood	$5.7	$3.4
	Elkwood	I-66	$5.7	$3.4
	Total		$22.7	$14.0

Section 2, the portion of US 29 from Lynchburg to Charlottesville, was selected for more detailed analysis. This section was selected based on discussions with the Technical Review Panel. The section consists of 64 miles: The first 14 miles are a CRC pavement, and the remaining 50 miles are a bituminous-type pavement. Figure 11a shows the existing condition of this section in terms of the CCI value.

Using the AASHTO segmentation procedure, the section was subdivided into segments with similar CCIs. The first 41 miles of the route has a CCI greater than 70. Between Station 41 and 50, the CCI drops below 50. The remainder of the route has a CCI between 50 and 70. Figure 11b shows RSTL calculated from collected TSD data for the same section of roadway. RSTL values less than 3 are seen between approximately Station 22 and 24 and again between Station 25 and 26. RSTL values ranging from 3 to 12 are found at other locations along the section but do not necessarily correspond to areas with relatively low CCI values. This observation shows that poor surface condition, as assessed by CCI, does not necessarily coincide with poor structural condition, as assessed with RSTL, and is consistent with other studies using TSD data (Flintsch et al., 2013; Huang et al., 2022; Huynh et al., 2021; Katicha et al., 2017; Maser et al., 2017; Shrestha et al. 2018) and other approaches such as FWD (Diefenderfer, 2008).

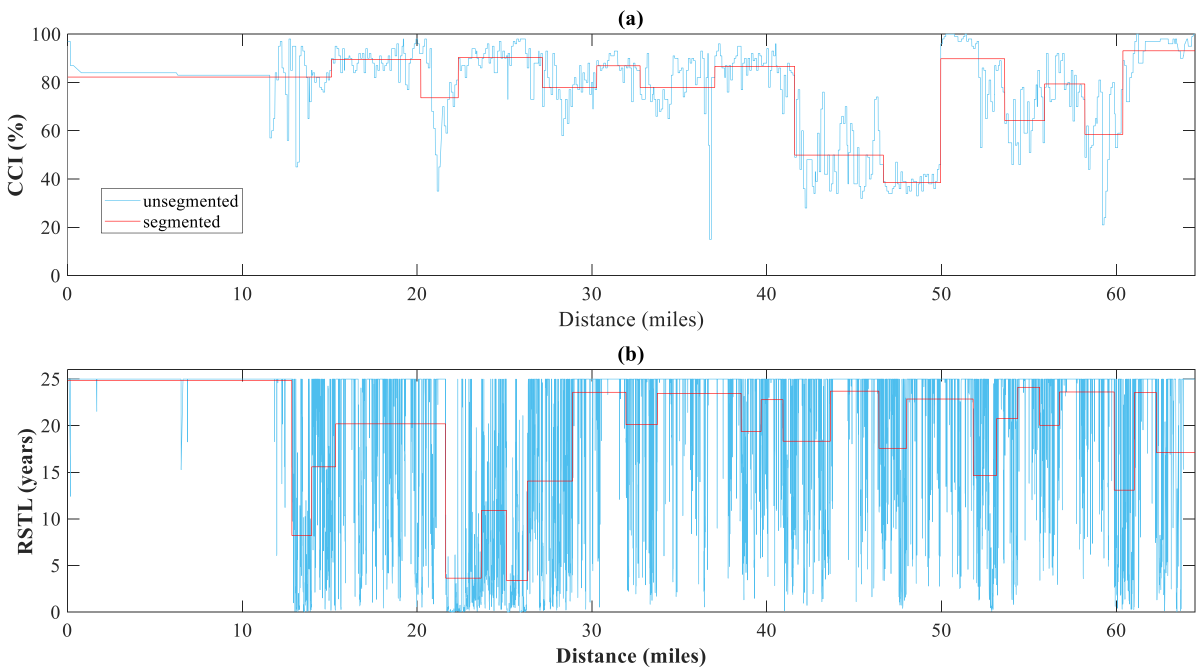


Figure 11. (a) Pavement Condition and (b) Remaining Structural Life for US 29

Figure 12 shows the percentage of each treatment category (DN, PM, CM, RM, or RC) based on the surface condition recommended treatment category and the structural modified recommended treatment category for Section 2 of US 29. Using the surface condition recommended treatment category, 34% is assigned DN, 5% PM, 55% CM, 6% RM, and 0% RC. Using the recommended surface treatment category modified for structure, the percentages change to 41% DN, 12% PM, 44% CM, 3% RM, and 0% RC. This change results in a needs reduction of \$1.6 million (from \$6.8 to \$5.2 million).

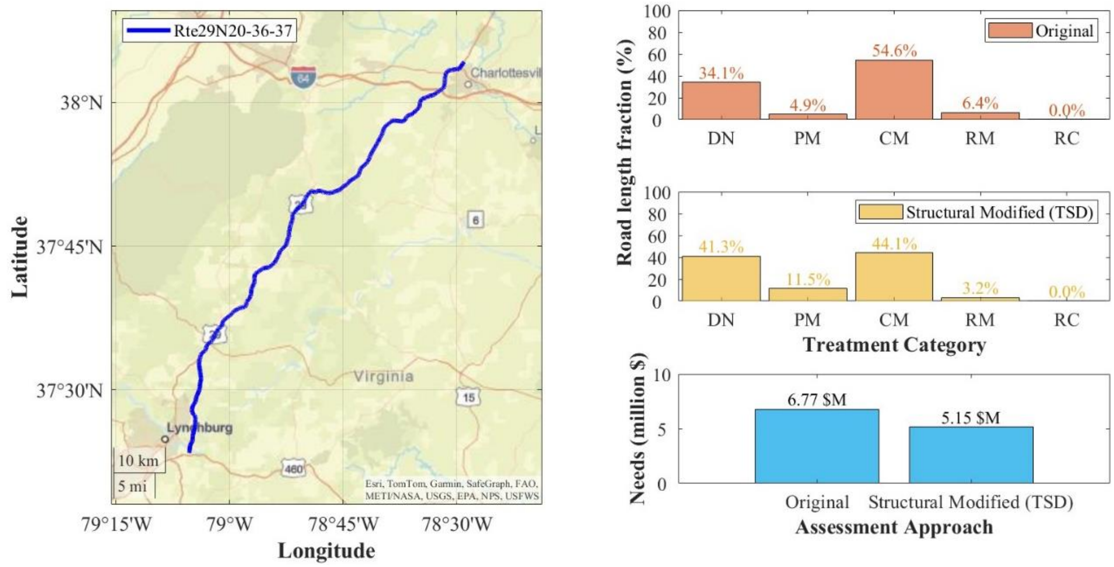


Figure 12. Surface Condition Treatment Category Recommendations, With and Without Structural Modification, and Unconstrained Needs for Case Study Portion of US 29

Interstate Network Analysis

This section presents the overall unconstrained needs analysis for the BIT sections of I-64, I-81, and I-95 tested in 2017. Table 10 shows the needs, as defined using the surface condition recommended treatment category and the structural modified recommended treatment category described in Table 6. The needs are based on the per-lane-mile treatment costs (Table 8).

Table 8. Calculated Needs for Interstate Routes Based on Surface Condition and Structural Modified Recommended Treatment Categories

Interstate	Direction	From	To	Needs—Surface Condition Recommended Treatment Category (million)	Structural Modified Recommended Treatment Category
64	East	State Border	I-81	$5.9	$8.6
		I-81	Richmond	$7.9	$7.4
		Richmond	Williamsburg	$1.9	$0.7
	Subtotal East			**$15.7**	**$16.7**
	West	State Border	I-81	$4.5	$4.1
		I-81	Richmond	$11.1	$9.6
		Richmond	Williamsburg	$3.2	$2.2
	Subtotal West			**$18.8**	**$15.9**
	Subtotal I-64			**$34.5**	**$32.6**
81	North	State Border	I-64	$21.1	$16.1
		I-64	Harrisonburg	$12.2	$7.3
		Harrisonburg	State Border	$6.2	$4.9

Interstate	Direction	From	To	Needs— Surface Condition Recommended Treatment Category (million)	Structural Modified Recommended Treatment Category
	Subtotal North			**$39.5**	**$28.3**
	South	State Border	I-64	$23.1	$18.7
		I-64	Harrisonburg	$11.4	$5.8
		Harrisonburg	State Border	$6.8	$6.7
	Subtotal South			**$41.3**	**$31.2**
	Subtotal I-81			**$80.8**	**$59.5**
95	North	State Border	Emporia	$0.5	$0.5
		Emporia	Richmond	$5.1	$7.1
		Richmond	I-495	$3.1	$0.6
	Subtotal North			**$8.7**	**$8.2**
	South	State Border	Emporia	$0.0	$0.0
		Emporia	Richmond	$8.8	$11.3
		Richmond	I-495	$2.9	$1.6
	Subtotal South			**$11.7**	**$12.9**
	Subtotal I-95			**$20.4**	**$21.1**
Total				**$135.7**	**$113.2**

Researchers divided each interstate route analyzed into three sections and calculated the needs for each section. The needs were then aggregated with respect to direction, then route, and finally reported as the total needs of the bituminous sections tested in 2017. In total, the needs were found to be $22.5 million less ($113.2 versus $135.7 million) when using the recommended surface treatment categories modified for structure. This amount consists of a $1.9 million needs reduction on I-64 ($1.0 million increase eastbound and $2.9 million decrease westbound), a $21.3 million needs reduction on I-81 ($11.2 million decrease northbound and $10.1 million decrease southbound), and a $0.7 million needs increase on I-95 ($0.5 million decrease northbound and $1.2 million increase southbound). Appendix C presents additional details of the distribution of treatments and needs for the interstate routes analyzed.

Case Study 1: I-95 Northbound from Route 54 near Richmond to I-495

The research team selected this roadway section as a case study to demonstrate a situation where incorporating structural data reduced the pavement rehabilitation severity level. For this example, including structural data reduced the needs from $3.1 to $0.6 million. This reduction resulted from changing the surface condition recommended treatment category of RM to DN to account for the structural condition recommended treatment category (Figure 13).

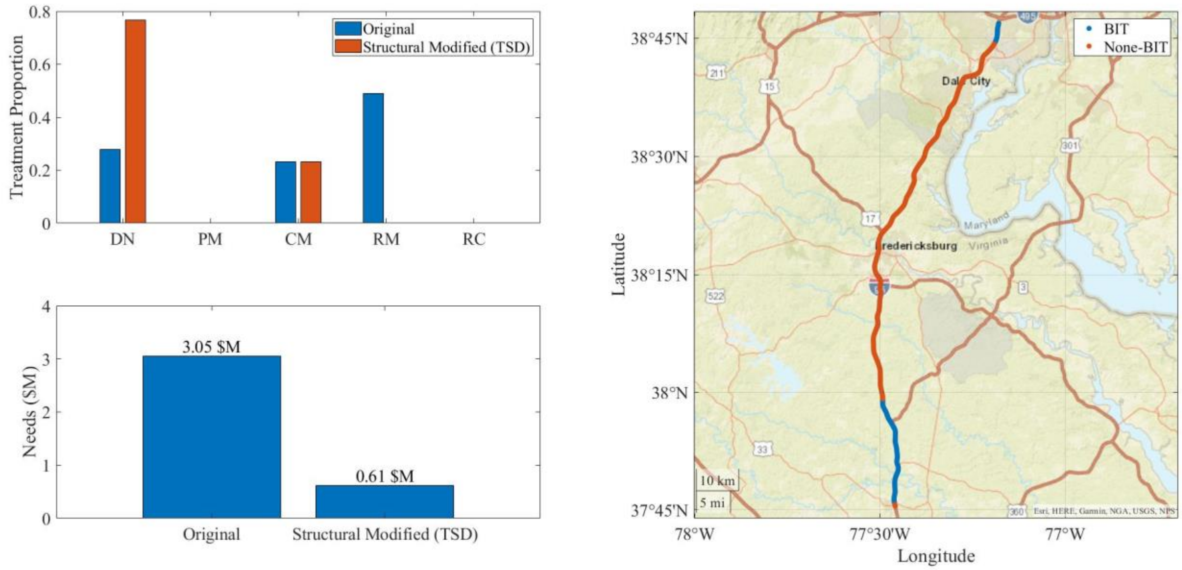


Figure 13. Section of I-95 Northbound Used in Case Study 1

To understand why RM treatments were reclassified as DN, the authors investigated the initial rehabilitation recommendation, which had been based on surface condition before being modified based on FWD data, traffic level, and age. In this case, the assigned treatment based on surface condition was DN (Figure 14).

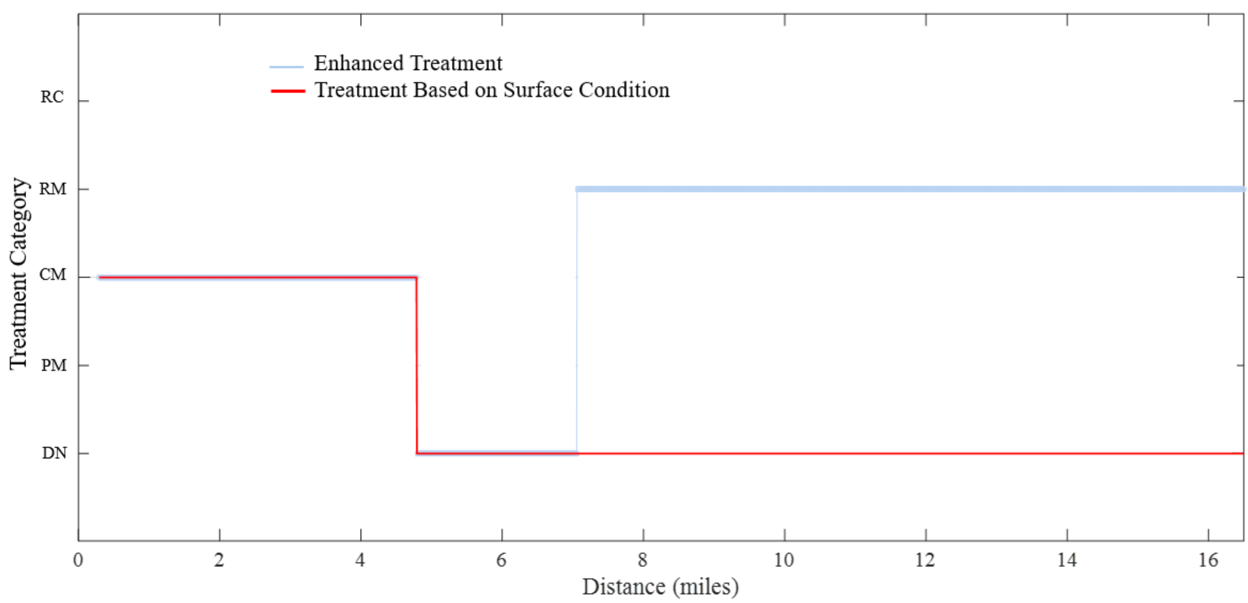


Figure 14. Treatment for BIT Section of I-95 Northbound

The fact that the initial treatment was DN and the modified treatment was RM suggests two things:

1. The surface condition of the road was very good (excellent), suggesting these sections might have been recently treated.

2. The treatment was modified to RM because of a combination of (a) the pavement was structurally weak, based on FWD data, (b) the traffic level was high, and (c) the pavement surface age was high. Because the surface condition was very good (DN treatment), (c) is unlikely, which leaves (a) and (b) as possible reasons for the treatment modification from DN to RM.

Figure 14 showed the recommended treatment of RM begins approximately 7 miles from the start of the section and extends to the end of the section (after which the pavement is not BIT). Figure shows the calculated RSTL. The RSTL average is approximately 20 years for the first nearly 10 miles of the section and then drops to below 12 years and to as low as 4 years for the remainder of the section. Based on Table 5, RSTL values less than or equal to 8 years trigger a structural treatment category of RM. About one-half of the section after 10 miles falls in that category—and, thus, would agree with the treatment category recommended by PMS.

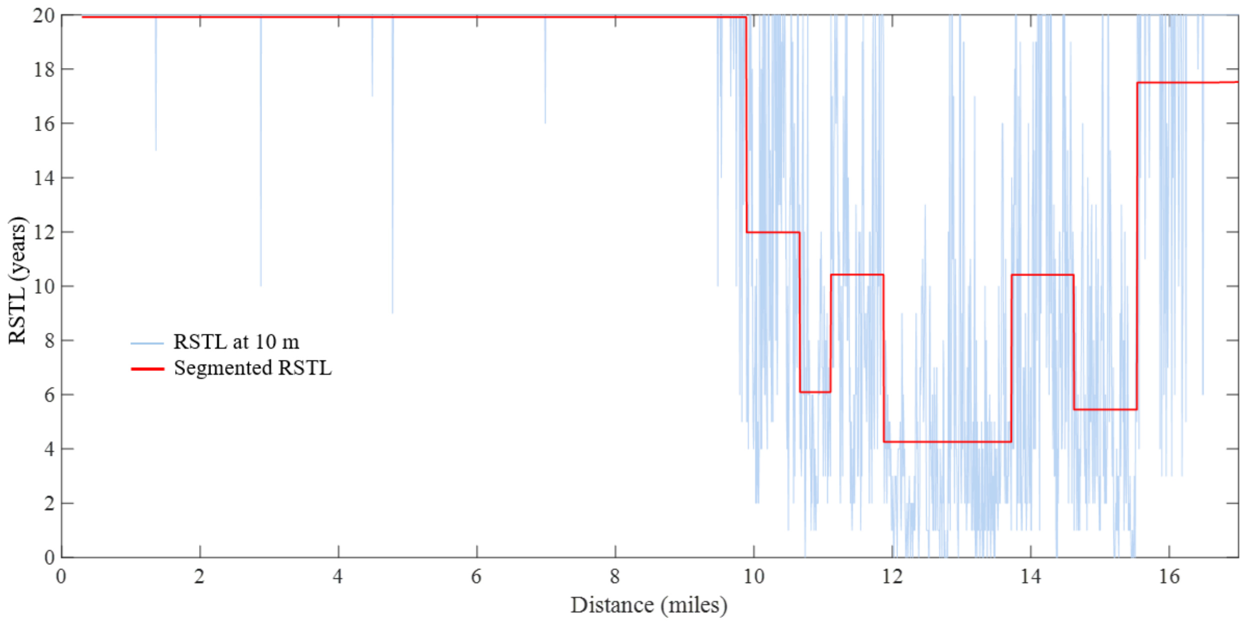


Figure 15. Remaining Structural Life for BIT Section of I-95 Northbound

The approach modified for structure still recommends DN because the surface condition recommendation was DN, which means that the surface condition was still good. If an RM treatment is applied, this application will result in the removal of the surface, which is still in good condition to perform adequately. Therefore, delaying the RM treatment to when the surface condition deteriorates further and triggers at least a CM treatment (because then the surface will be replaced) is more cost-effective. For this section, the realized savings are partly due to delaying the RM treatment until the pavement surface deteriorates. Ultimately, the RM cost will be incurred, but VDOT would have gained more life from the current pavement surface before this cost occurs.

Case Study 2: I-64 Eastbound from West Virginia Border to I-81

This roadway section was selected as a case study to demonstrate a situation in which incorporating structural data increased the pavement rehabilitation's severity level. For this example, including the structural data increased the needs from \$5.9 to \$8.6 million. This increase primarily resulted from the incorporation of RC treatments, which were recommended using the structural modified recommended treatment category (Figure 16).

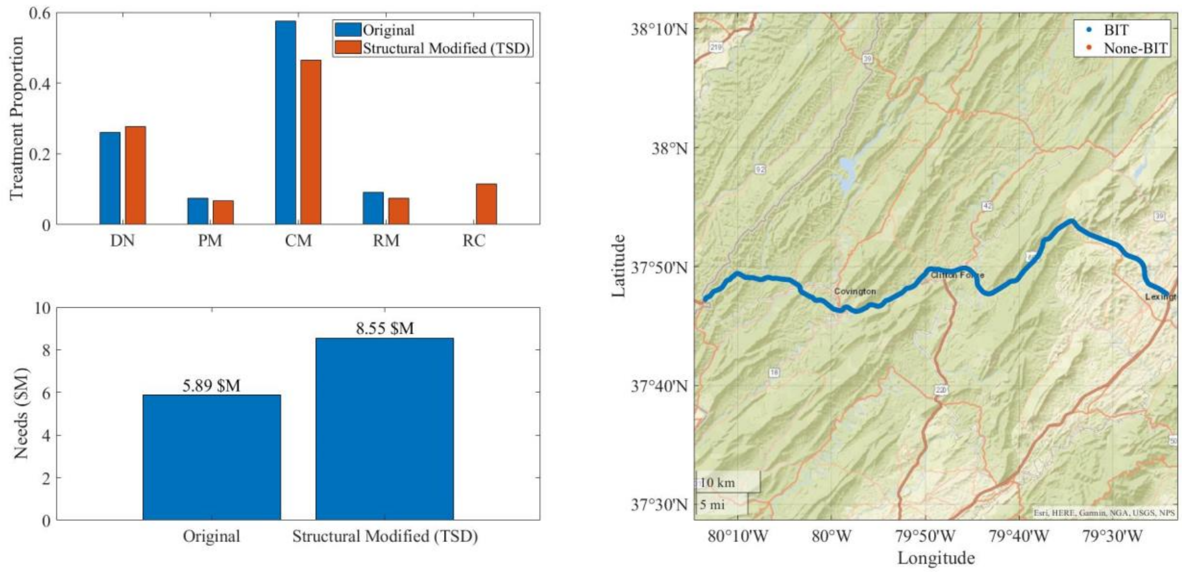


Figure 16. Section of I-64 Eastbound in Case Study 2

Figure 17 shows the surface condition recommended treatment categories with and without modification for structural condition and the locations where treatments were modified to different treatment categories. Most of the changes to RC are in the section that starts at 10 miles and ends at 16 miles.

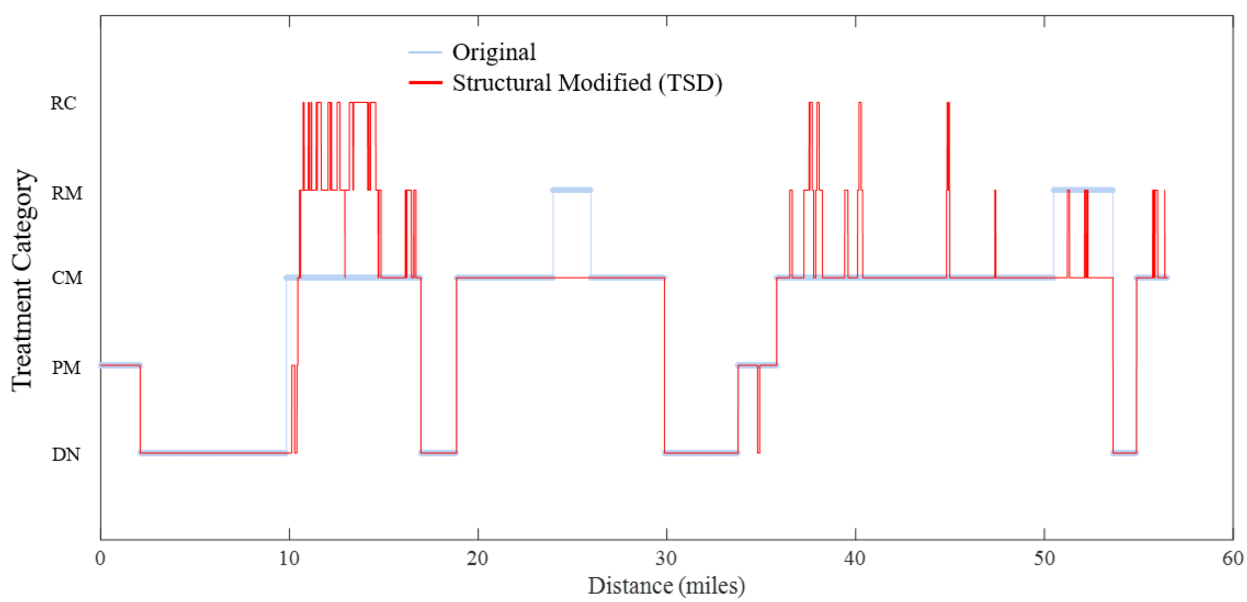


Figure 17. Treatment for the Section of I-64 Eastbound

For comparison, Figure 18 shows the SN_{eff} calculated with the TSD data collected in 2017 and the SN_{eff} calculated from the FWD data, which were mostly collected between 2006 and 2008. For the TSD data, the moving median and moving lower 5th percentile envelope are shown. The TSD and FWD data have similar trends, with the TSD SN_{eff} generally somewhat higher than FWD SN_{eff}. The SN_{eff} from both devices is relatively low compared with other locations along the pavement section, at distances of approximately 6 to 15 miles. Information obtained from the PMS reveals that the pavement surface between 10 and 16 miles was last treated with a CM treatment in 2013, before the TSD data were collected in 2017. Both TSD and FWD data agree that the pavement section is relatively weak, confirming the need for a heavier treatment than CM.

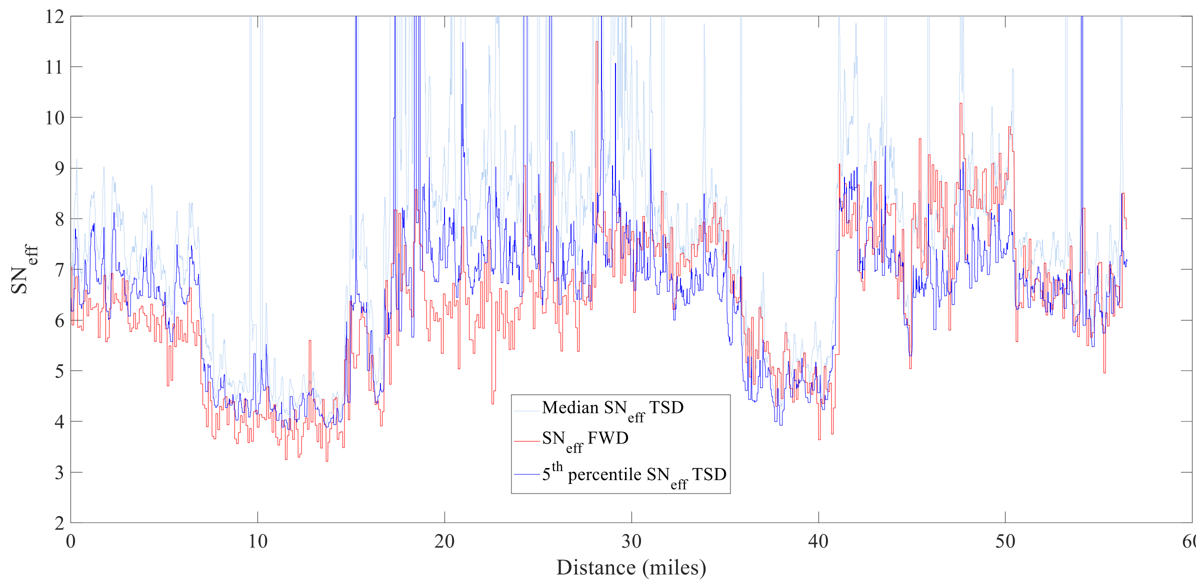


Figure 18. SN_{eff} for the Section of I-64 Eastbound

Changes to the Main Detailed Pavement (Jasper) Report

Researchers suggest the following changes to the main Detailed Pavement Report to incorporate the new pavement structural data. The subqueries used to compute the average SN_{eff} and M_r for the user-selected location were recommended to query the values from the latest available year of data in the PMS_VA_TSD_DATA table. Figures 19 and 20 show the original and updated portions of the query in main.jrxml, respectively.

```
            (SELECT AVG (f.va_corr_res_modulus)
                  FROM pms_va_fwd f, setup_loc_ident lf
                 WHERE      f.loc_ident = lf.loc_ident
                       AND lf.sourse_table = 'PMS_VA_FWD'
                       AND lf.route_id = sli.route_id
                       AND (lf.lane_dir = sli.lane_dir OR sli.lane_dir = 0 OR lf.lane_dir = 0)
                       AND lf.offset_from >= sli.offset_from
                       AND lf.offset_to <= sli.offset_to)
                  AS va_corr_res_modulus,
               (SELECT AVG (f.va_eff_sn)
                  FROM pms_va_fwd f, setup_loc_ident lf
                 WHERE      f.loc_ident = lf.loc_ident
                       AND lf.sourse_table = 'PMS_VA_FWD'
                       AND lf.route_id = sli.route_id
                       AND (lf.lane_dir = sli.lane_dir OR sli.lane_dir = 0 OR lf.lane_dir = 0)
                       AND lf.offset_from >= sli.offset_from
                       AND lf.offset_to <= sli.offset_to)
                  AS va_eff_sn
```

Figure 19. Original *SN_{eff}* and *M_r* Query for Falling Weight Deflectometer Data

```
              (SELECT AVG (f.VA_RES_MODULUS)
                  FROM pms_va_tsd_data f, setup_loc_ident lf
                 WHERE      f.loc_ident = lf.loc_ident
                       AND lf.sourse_table = 'PMS_VA_TSD_DATA'
                       AND lf.route_id = sli.route_id
                       AND (lf.lane_dir = sli.lane_dir OR sli.lane_dir = 0 OR lf.lane_dir = 0)
                       AND lf.offset_from >= sli.offset_from
                       AND lf.offset_to <= sli.offset_to
                       and lf.data_year=(select max(eff_year) from pms_va_tsd_data f))
                  AS va_corr_res_modulus,
               (SELECT AVG (f.va_eff_sn)
                  FROM pms_va_tsd_data f, setup_loc_ident lf
                 WHERE      f.loc_ident = lf.loc_ident
                       AND lf.sourse_table = 'PMS_VA_TSD_DATA'
                       AND lf.route_id = sli.route_id
                       AND (lf.lane_dir = sli.lane_dir OR sli.lane_dir = 0 OR lf.lane_dir = 0)
                       AND lf.offset_from >= sli.offset_from
                       AND lf.offset_to <= sli.offset_to
                       and lf.data_year=(select max(eff_year) from pms_va_tsd_data f))
                  AS va_eff_sn
```

Figure 20. New Traffic Speed Deflectometer-Based Calculation for *SN_{eff}* and *M_r*

Figure 21 illustrates the recommended Location Detail Page changes to show the Average SN_{eff} and M_r. However, these fields could be modified to show RSTL and the structural modified recommended treatment category if desired.

Detailed Pavement Data Report
Location Detail
Report Date: 01/17/2024

Location Detail

ROUTE	DIRECTION	STATE BEGIN MP	STATE END MP	COUNTY	COUNTY BEGIN MP	COUNTY END MP	LANE MILES
IS00064EB	Increasing	0.00	0.30	003-Alleghany	0.00	0.30	0.60

Management Info (based on most recent, overlapping management section which may extend beyond report limits)

Collection Year: 2023
Pavement Type: BIT
Surface Mix: SMA-12.5(70-22)
Last Treatment: RM-BIT
Year of Last Rehab: 2015

Begin MP: 0.000 (County MP 0.000)
End MP: 0.299 (County MP 0.299)
Total Lanes: 2
Divided / Undivided: Divided
Total Lane Miles: 0.60

Begin Landmark: VIRGINIA STATE LINE
End Landmark: MM 2.1
Notes:
HMG Key: 03-00IS00064E-BIT-0000996

2023 Condition Data (based on distress summarized on most recent, overlapping management section's limits)

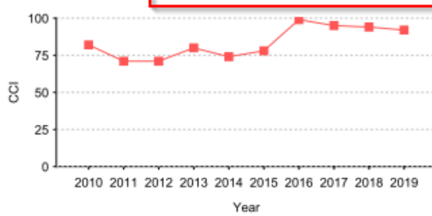
CCI: 83 Alligator Freq (R/O/F): R Rutting Freq (N/<10%/>=10%): >=10%
LDR: 95 Alligator Sev (NS/S/VS): NS Rutting Sev (<0.5" / >=0.5"): <0.5"
NDR: 83 Patching Freq (Y/N): Y Transverse Cracks/Mile: 1.0
Average IRI: 61 Patching Sev (=<10%/>10%): =<10% Trans. Cracks Sev (NS/S/VS): NS

2023 Treatment Recommendation (estimated costs are based on the reported section limits)
Modified Treatment: CM-BIT | *Estimated Mainline Material Cost:* $81,345.98 ($136,030./LM)

Supporting Information
AADTT: Level 1 (1126 Trucks) | *Age:* Old (>6 IS >10 PR) | *Structure:* (SN= 6.6 / MR= 16988.)

Ten Year Performance History

Year	LDR	NDR	CCI
2010	94	82	82
2011	75	71	71
2012	89	71	71
2013	98	80	80
2014	88	74	74
2015	90	78	78
2016	100	99	99
2017	97	95	95
2018	100	94	94
2019	97	92	92



Most Recent Five Layers in Maintenance History

Pavement Layer	Material	Thickness (in.)	Year Completion	Contract ID
Layer 1	SM-12.5D	1.5	2015	2755178
Layer 2	SMA-12.5(70-22)	2.0	2015	2755180
Layer 3	IM-19.0D	2.0	2015	2755180
Layer 4	MILLING/DEMO	1.5	2015	2755178
Layer 5	MILLING/DEMO	4.0	2015	2755180

2

Figure 21. Updated Detailed Pavement Data Report Showing SN_{eff} and M_r Calculations on Location Detail Pages

The research team recommended the original FWD Summary Sub Report within the Detailed Pavement Data Report Summary (Figure 22) be replaced with an updated sub report that queries the TSD data RSTL statistic. The report calculates the length of data from the TSD data table in each of the RSTL categories defined in the setup table. Then, the report displays that length to the total user-requested length for the report and calculates a percentage length in each category and a percentage of the length that has no TSD-tested data. Figure 23 features an example output of this process. Figure 24 shows the query for this updated sub report.

Detailed Pavement Data Report
Summary

Report Date: 01/17/2024

Report Input Limits

ROUTE	DIRECTION	STATE BEGIN MP	STATE END MP	COUNTY FROM	COUNTY TO	COUNTY BEGIN MP	COUNTY END MP
IS00064EB	Increasing	0.00	10.00	003	003	0.00	10.00

Management Information Summary (based on most recent, overlapping management sections)

Total Lane Miles: 20.00 Lane Miles

Summary of Pavement Characteristics

Number of Lanes	*Directional Miles*	*Lane Miles*
1		
2	*10.00*	*20.00*
3		
4		
5+		
Total	*10.00*	*20.00*

Pavement Type	*Lane Miles*	*% Lane Miles*
CRCP	*0.00*	*0.00 %*
JRCP	*0.00*	*0.00 %*
BIT	*20.00*	*100.00 %*
BOC	*0.00*	*0.00 %*
BOJ	*0.00*	*0.00 %*
NPM	*0.00*	*0.00 %*
PM	*0.00*	*0.00 %*
Total	*20.00*	*100.00%*

Last Treatment Category	*Lane Miles*	*% Lane Miles*
CM	*0.00*	*0.00 %*
DN	*0.00*	*0.00 %*
PM	*0.00*	*0.00 %*
RC	*0.00*	*0.00 %*
RM	*20.00*	*100.00 %*
Total	*20.00*	*100%*

Condition Data Summary *(based on most recent, overlapping management sections)*

Percent Lane Miles Sufficient CCI **100 %** ***Lane Mile Weighted Average CCI*** **92**

Percent Lane Miles Sufficient IRI **100 %** ***Lane Mile Weighted Average IRI*** **53**

Summary of Pavement Surface Condition Data

CCI	*Lane Miles*	*% Lane*
1 - Excellent	*11.52*	*57.61 %*
2 - Good	*8.48*	*42.39 %*
3 - Fair	*0.00*	*0.00 %*
4 - Poor	*0.00*	*0.00 %*
5 - Very Poor	*0.00*	*0.00 %*
Total	*20.00*	*100%*

IRI Condition	*Lane Miles*	*% Lane Miles*
1 - Excellent	*15.42*	*77.09 %*
2 - Good	*4.58*	*22.91 %*
3 - Fair	*0.00*	*0.00 %*
4 - Poor	*0.00*	*0.00 %*
5 - Very Poor	*0.00*	*0.00 %*
Total	*20.00*	*100%*

Treatment Recommendation Summary (estimated costs are based on the reported section limits)

Modified Treatment Name	*Lane Miles*	*Estimated Mainline Material Cost*
DN- Do nothing	11.522	
PM-Preventive Maintenance	4.276	Â$ 150,104
CM - Corrective Maintenance	4.202	Â$ 558,201
RM - Restorative Maintenance		
RC- Reconstruction		

Supporting Information (as summarized from overlapping management section)

AADTT (Truck Traffic)		
Average	*1224*	Trucks/Day
Minimum	*1194*	Trucks/Day
Maximum	*1254*	Trucks/Day

Surface Age (Years)		
Average:	*6.9*	*Years*
Minimum:	*6.0*	*Years*
Maximum	*23.0*	*Years*

Pavement Structure (FWD)		
Strong:	*0.00*	*LM*
Weak:	*0.00*	*LM*
No Test:	*20.00*	*LM*

1

Figure 22. Detailed Pavement Data Report—Falling Weight Deflectometer Sub Report (Red Outline)

TSD RSTL (years)	1.4% Untested
> 20	0.0%
≤ 20 to >12	57.3%
≤ 12 to >8	21.3%
≤ 8 to >3	17.9%
≤3	2.1%

Figure 23. Example TSD RSTL Summary Sub Report. RSTL = remaining structural life; TSD = traffic speed deflectometer.

```
SELECT va_rstl_cat_id,
       va_rstl_cat_name AS str,
       len              AS len_tested,
       coalesce(len,0)/
          (SELECT SUM(least(la.offset_to,$P{OFFSET_TO})-
greatest(la.offset_from,$P{OFFSET_FROM}))
                FROM   network_master a,
                              setup_loc_ident la
               WHERE  a.loc_ident = la.loc_ident
                 AND  la.sourse_table = 'NETWORK_MASTER'
                 AND  la.route_id = $P{ROUTE_ID}
                 AND  la.offset_from < $P{OFFSET_TO}
                 AND  la.offset_to > $P{OFFSET_FROM}
                 AND  (la.lane_dir = $P{LANE_DIR}
                 OR la.lane_dir = 0
                 OR $P{LANE_DIR} = 0)
          ) AS pct_cat
FROM  (SELECT r_cat.va_rstl_cat_name,
              r_cat.va_rstl_cat_id,
              (SELECT SUM(least(la.offset_to,ld.offset_to,$P{OFFSET_TO})-
                      greatest(ld.offset_from,la.offset_from,$P{OFFSET_FROM}))
                              FROM network_master a,
                                      setup_loc_ident la,
                                      pms_va_tsd_data  t,
                                      setup_loc_ident ld
                             WHERE  a.loc_ident = la.loc_ident
                               AND  t.loc_ident=ld.loc_ident
                               AND  ld.sourse_table='PMS_VA_TSD_DATA'
                               AND  la.sourse_table = 'NETWORK_MASTER'
                               AND  la.route_id = $P{ROUTE_ID}
                               AND  la.offset_from < $P{OFFSET_TO}
                               AND  la.offset_to > $P{OFFSET_FROM}
                               AND  (la.lane_dir = $P{LANE_DIR}
                                        OR la.lane_dir = 0
                                        OR $P{LANE_DIR} = 0)
                               AND  ld.route_id = la.route_id
                               AND  ld.offset_from < la.offset_to
                               AND  ld.offset_to > la.offset_from
                               AND  ld.offset_from<$P{OFFSET_TO}
                               AND  ld.offset_to>$P{OFFSET_FROM}
                               AND  (ld.lane_dir = $P{LANE_DIR}
                                        OR ld.lane_dir = $P{LANE_DIR}
                                        OR $P{LANE_DIR} = 0)
                               AND  ((t.va_rstl >r_cat.va_rstl_cat_low_bound
                                            AND t.va_rstl<=r_cat.va_rstl_cat_up_bound)
                                        OR (t.va_rstl IS NULL AND r_cat.va_rstl_cat_id=0)
                                       )
                        ) AS len
         FROM   setup_va_rstl_cat r_cat
         )
```

Figure 24. Query for Traffic Speed Deflectometer Summary Sub Report

Summary

- Previous research identified in the literature indicated that including structural pavement condition is a more cost-effective approach to pavement management than using observed surface condition alone.

- RSTL was a good indicator to characterize the structural condition of asphalt pavement sections at the network level.

- The RSTL distribution on the primary roads tested in 2017 showed that less than 10% of the tested primary roads had a RSTL of less than 3 years. Also, more than 75% of the primary roads tested in 2017 had a RSTL greater than 12 years.

- The RSTL distribution of the interstate network tested in 2017 showed that more than 82% of the network has a RSTL of 20 years or more. More than 85% of I-81 and I-64 had a RSTL of 20 years or more, whereas slightly less than 60% of I-95 had a RSTL of 20 years or more.

- Comparing RSTL of the interstate network tested in 2017 and the primary network tested in 2017 showed that the interstate roads are in a better structural condition compared with the primary roads. This comparison is true even after considering the truck traffic level.

- Researchers found a difference in the unconstrained needs when using the RSTL approach to recommend pavement rehabilitation treatment categories versus when comparing the original or enhanced approaches. The difference in needs varies, depending on the condition of the pavement.

CONCLUSIONS

- *The RSTL approach may be used to characterize the structural condition of asphalt pavement sections at the network level for more cost-effective pavement management. This approach was based on the AASHTO 1993 Pavement Design Guide and is calculated using SN_{eff} and M_r calculated from TSDD data collected on the pavement network and traffic information.*

- *The RSTL approach may be used to recommend pavement rehabilitation treatment categories using the recommended treatment categories modified for structure, as shown in Table 6.*

- *Including RSTL in the Detailed Pavement Report can assist district pavement managers with using structural pavement testing results.*

- *Additional data collection is needed to use the RSTL approach for the remaining portions of VDOT's pavement network.*

- *Pavement thickness data are needed to include the RSTL approach in VDOT's PMS for those sections tested using the TSD between 2018 and 2022.*

RECOMMENDATIONS

1. *VDOT's Maintenance Division should include the TSDD data in VDOT's PMS.*

2. *VDOT's Maintenance Division should add a new Detailed Pavement Report that includes RSTL information from TSDD-based structural condition data for ease of use by district practitioners.*

3. *VDOT's Maintenance Division, Materials Division, and Virginia Transportation Research Council (VTRC) should develop recommendations for future data collection using a TSDD. These recommendations should be based on frequency of network testing, location, and cost.*

IMPLEMENTATION AND BENEFITS

The researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

Regarding Recommendations 1 and 2, VDOT's Maintenance Division will initiate the process to incorporate TSDD data into VDOT's PMS and add a new Detailed Pavement Report by December 2026.

Regarding Recommendation 3, VDOT's Maintenance Division, Materials Division, and VTRC will develop recommendations for when and where to collect additional pavement structural data using the TSDD and pavement thickness data. This action will be completed by December 2026.

Benefits

The benefits of implementing Recommendations 1 and 2 are that VDOT's field-level staff will more easily be able to use pavement structural condition data for selecting pavement rehabilitation treatments. Based on the findings from the literature review, by taking the structural condition data into consideration when determining pavement rehabilitation strategies, VDOT should experience an increase in the service lives of its pavement surfaces and experience significant long-term life-cycle cost savings for its entire pavement network.

Implementing Recommendation 3 will allow VDOT to gather an increased amount of pavement structural condition data in a manner that is useful and cost-effective. This effort will further help VDOT to implement the RSTL approach and to better select pavement rehabilitation treatments.

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APPENDIX A: LOCATION OF PAVEMENT STRUCTURAL DATA COLLECTED BY TRAFFIC SPEED DEFLECTOMETER IN VIRGINIA

Table A1. Location of Pavement Structural Data Collected by TSD between 2017 and 2023

2017		2018		2019		2020		2022		2023	
ROUTE 17	398.366	I-81 A	8.699	I-66	132.644	IH264	49.181	I-64	77.034	I-95	0.362
ROUTE 220	126.019	I-81 B	4.119	I-81	119.481	IH395_1	19.066	I-664	18.361	I-95_RAMP	0.373
ROUTE 28	29.05	US-11 A	92.902	total	252.125	IH395_2	19.068	I-81	26.448	SH-123	12.493
ROUTE 286	52.409	US-11 B	0.914			IH464	11.583	I-95	66.542	SH-150	1.719
ROUTE 288	65.64	US-250	107.264			IH495_1	44.262	SH-620	15.974	SH-20	8.929
ROUTE 29	426.861	US-33	91.797			IH495_2	44.262	US-15	38.357	SH-2000	2.064
ROUTE 360	264.576	US-50	0.149			US001	267.314	US-220	50.049	SH-207	11.887
ROUTE 460	315.069	US-522	107.204			US013	135.428	US-50	6.955	SH-208	24.844
ROUTE 58	560.565	VA-211	66.973			US050	83.977	US-501	40.086	SH-22	10.529
ROUTE 60	232.677	VA-262	14.773			US060	67.473	US-58	110.598	SH-231	9.582
ROUTE 64	702.856	VA-37	3.629			US301	96.256	total	450.404	SH-234	14.514
ROUTE 7	87.252	VA-42	37.278			US460	100.817			SH-241	1.149
ROUTE 81	647.316	VA-7	34.17			VA003	71.092			SH-2480	1.075
ROUTE 95	340.751	total	569.871			VA028	49.062			SH-286	0.736
total	4249.407					VA030	86.598			SH-286_RA	0.391
						VA033	28.443			SH-294	14.624
						VA150	26.988			SH-3	61.439
						VA200	38.355			SH-3_BUS	0.828
						VA208	45.672			SH-30	16.551
						VA234	45.684			SH-45	15.228
						VA286	62.891			SH-600	0.03
						I-64	50.032			SH-608	4.688
						I-81	74.971			SH-610	3.074
						I-81	185.104			SH-611	9.093
						total	1703.579			SH-612	3.785
										SH-619	15.317
										SH-620	5.035
										SH-639	2.119
										SH-640	5.221
										SH-641	2.58
										SH-642	2.106
										SH-645	10.509
										SH-657	3.408
										SH-663	4.72
										SH-784	6.04
										SH-846	0.563
										SH-849	0.9
										US-1	30.356
										US-1_Ramp	0.734
										US-15	19.354
										US-250	10.406
										US-29	12.99
										US-29_Ram	0.351
										US-29_Ram	0.28
										US-301	18.079
										US-33	13.641
										US-360	70.454
										US-360_Ra	0.15
										US-460	11.509
										US-460_BU	2.778
										US-50	0
										US-522	19.508
										US-60	44.531
										US-60_Ram	0.12
										total	543.746

APPENDIX B: ANALYSIS OF ROUTES ON PRIMARY NETWORK

US 460 Eastbound

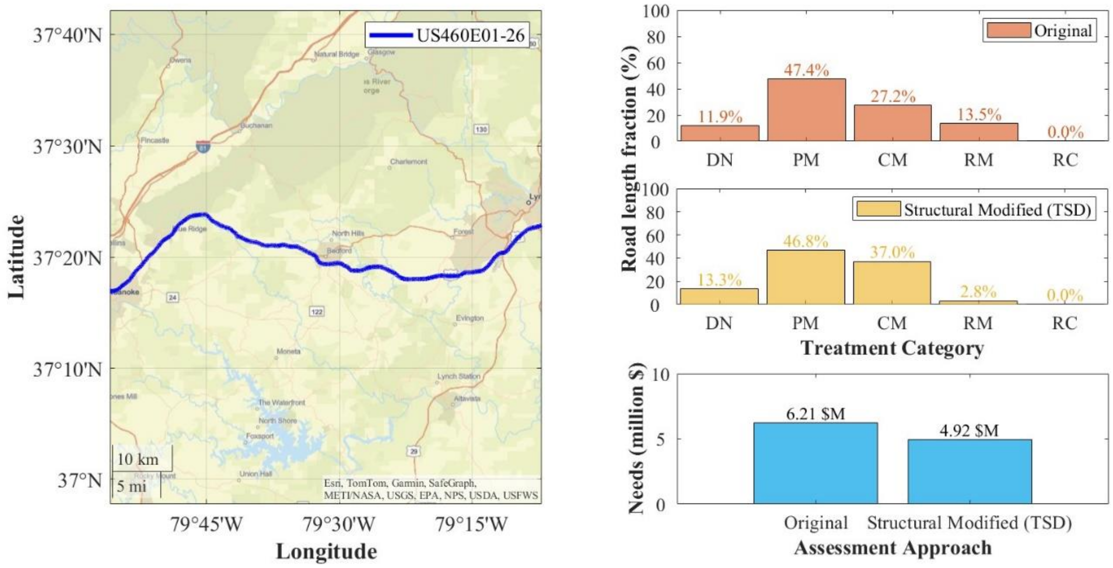

Figure B1. A Section of US 460 Eastbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

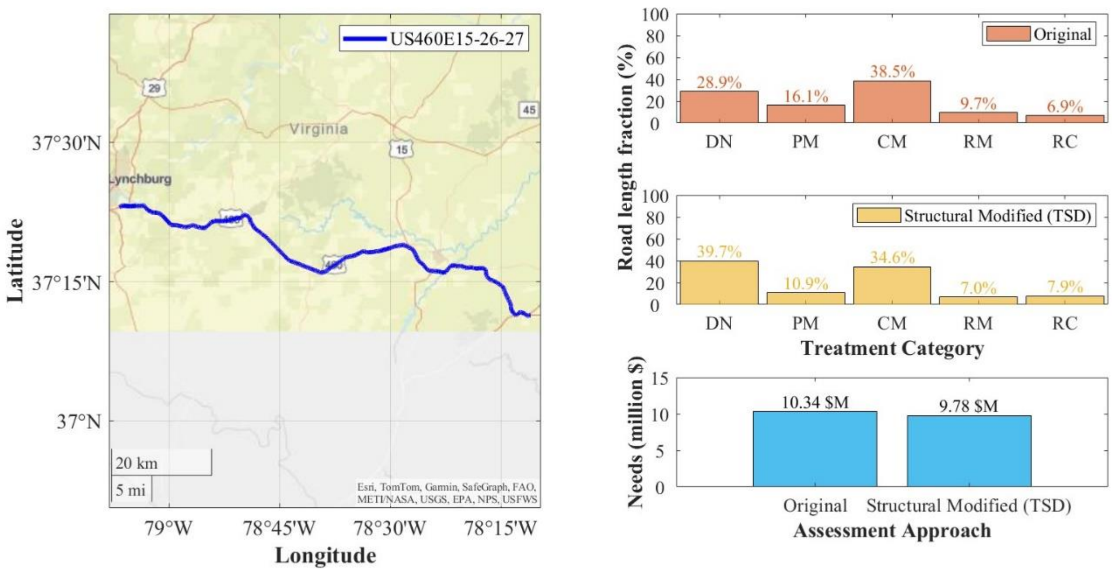

Figure B2. A Section of US 460 Eastbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

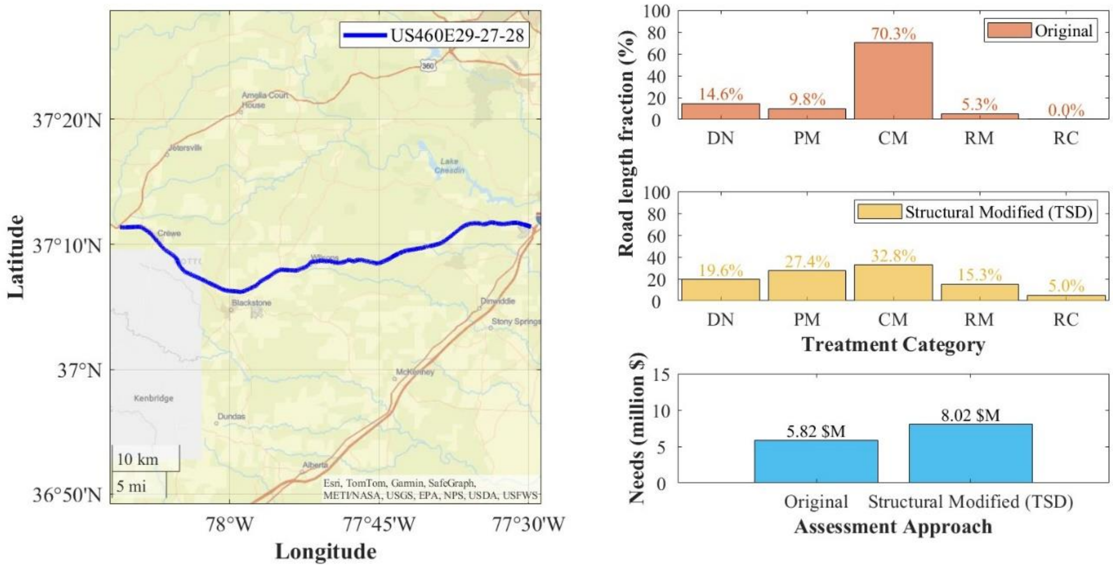

Figure B3. A Section of US 460 Eastbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

US 460 Westbound

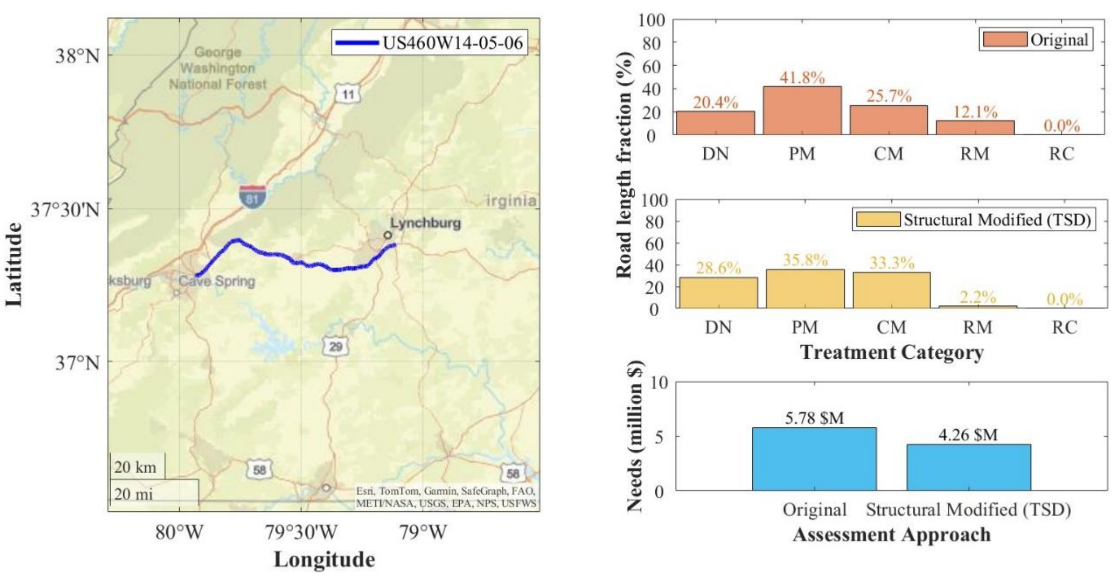

Figure B4. A Section of US 460 Westbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

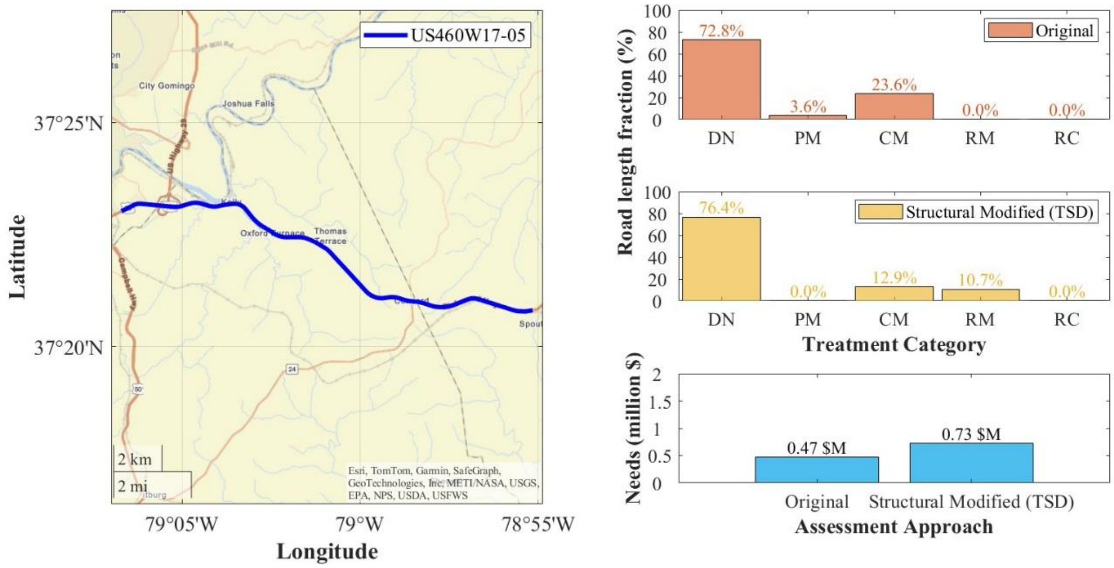

Figure B5. A Section of US 460 Westbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

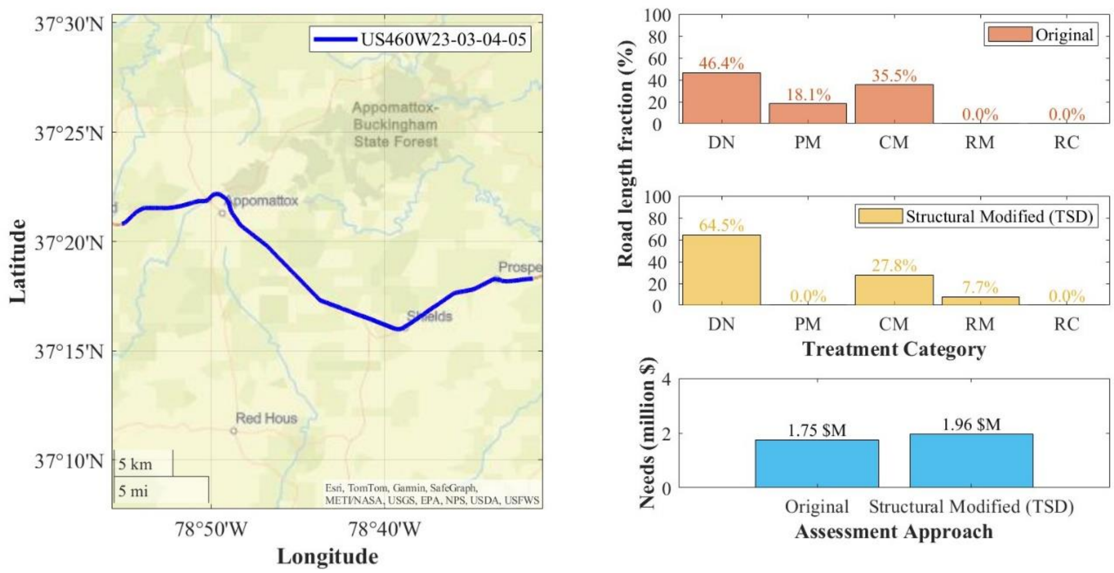

Figure B6. A Section of US 460 Westbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

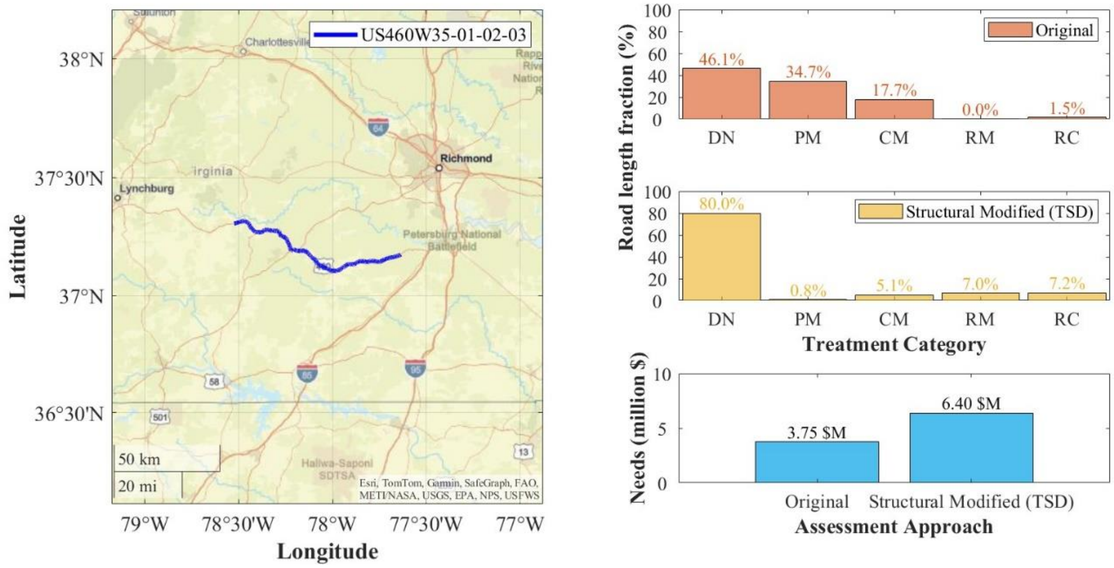

Figure B7. A Section of US 460 Westbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

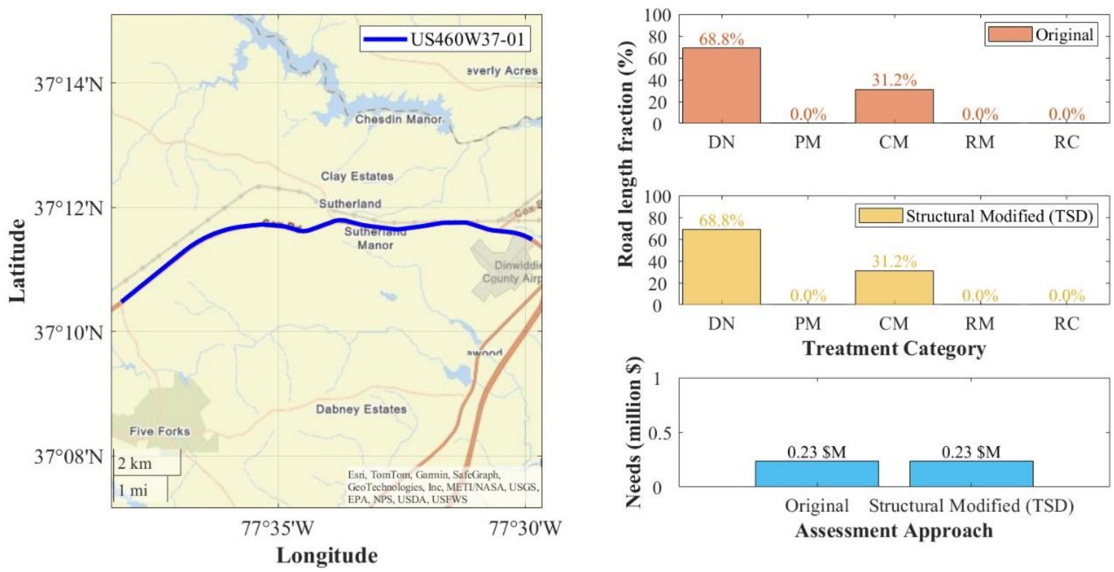

Figure B8. A Section of US 460 Westbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

US 360 Eastbound

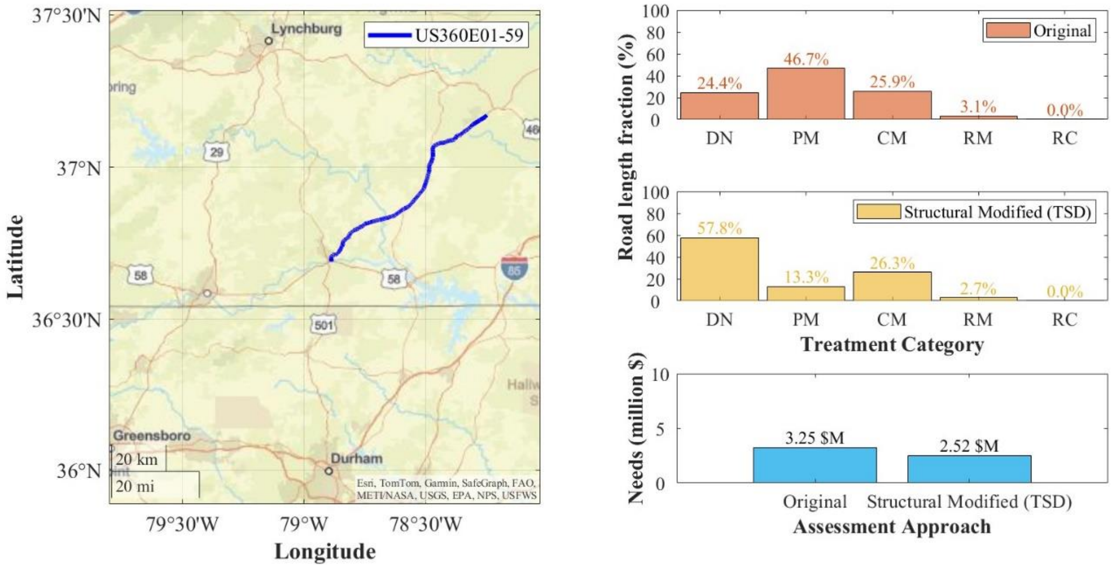

Figure B9. A Section of US 360 Eastbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

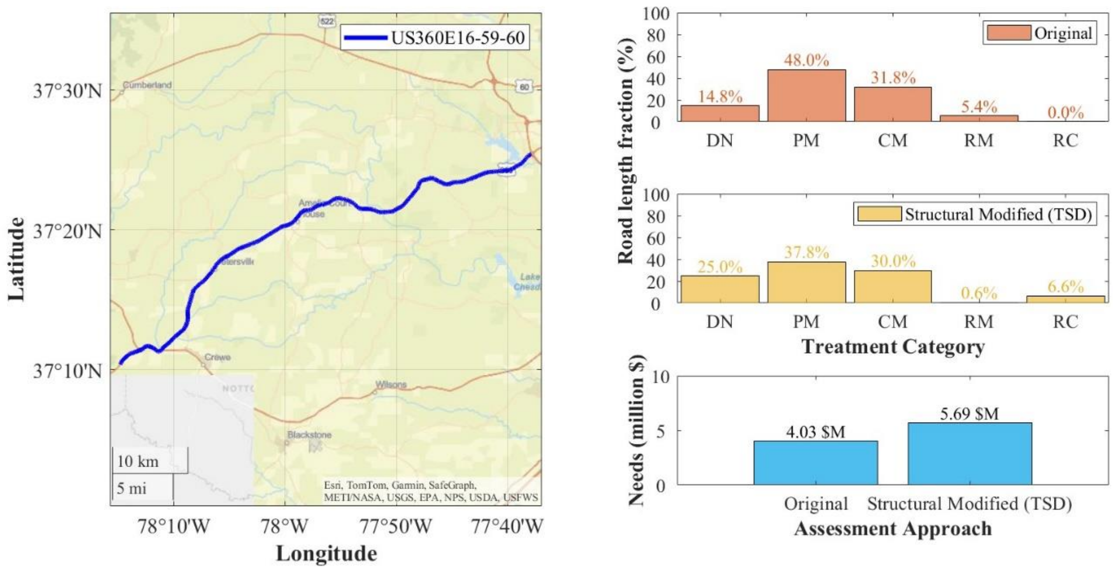

Figure B10. A Section of US 360 Eastbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

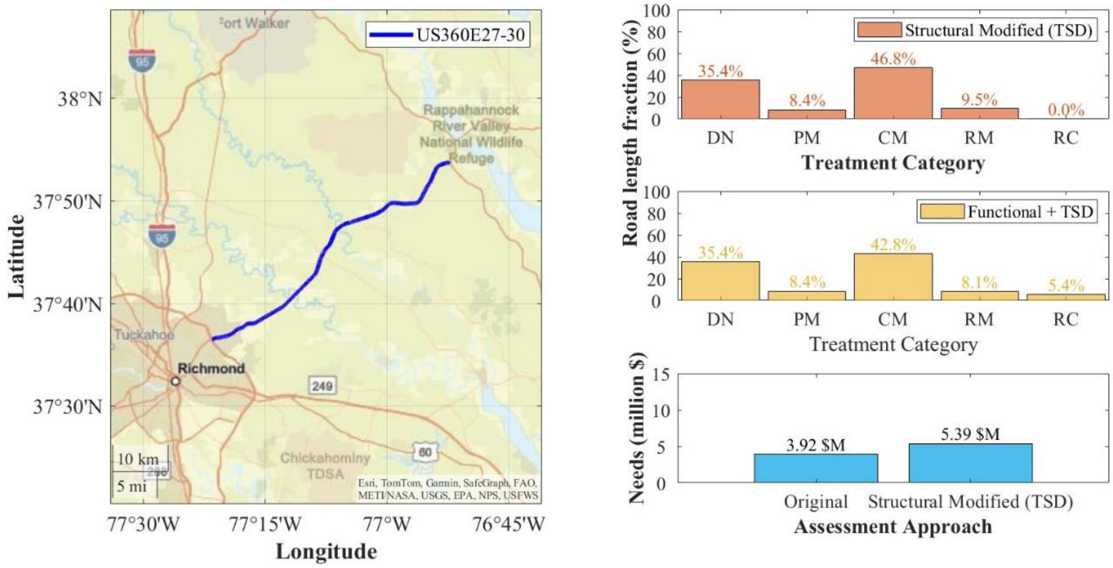

Figure B11. A Section of US 360 Eastbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

US 360 Westbound

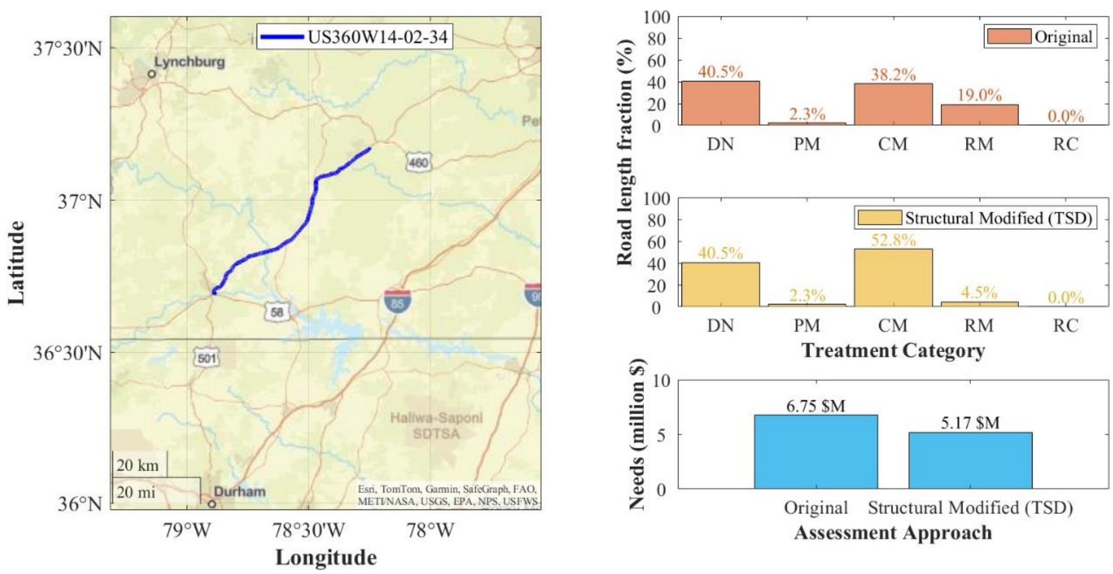

Figure B12. A Section of US 360 Westbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

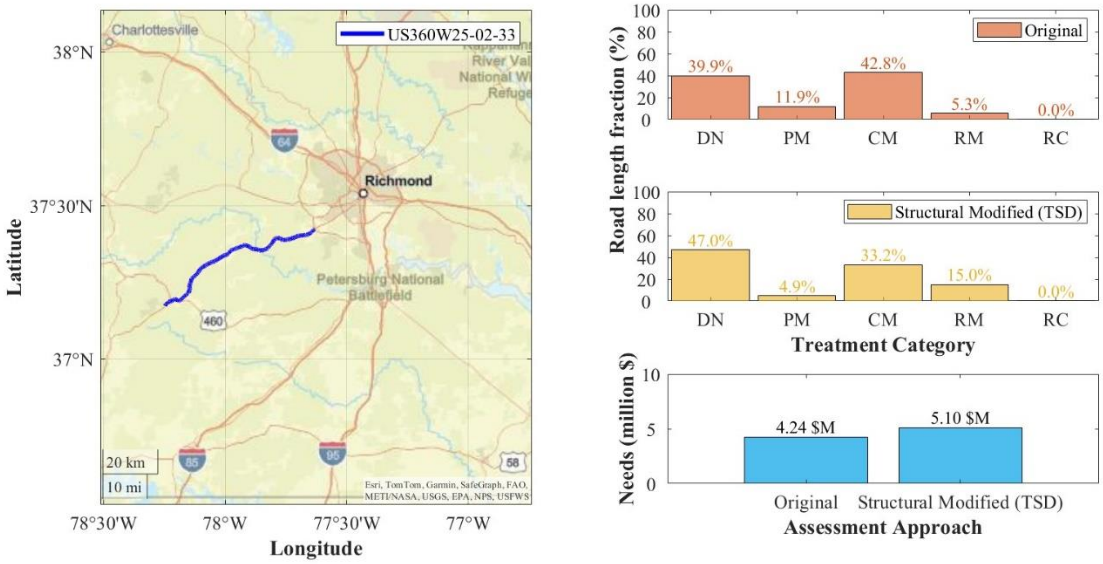

Figure B13. A Section of US 360 Eastbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

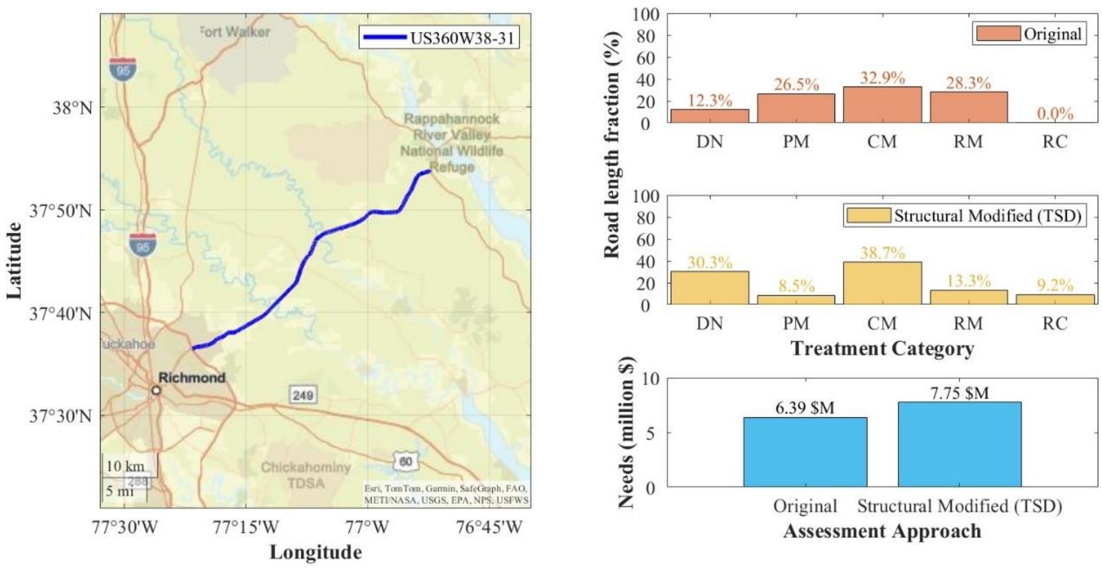

Figure B14. A Section of US 360 Eastbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

US 58 Eastbound

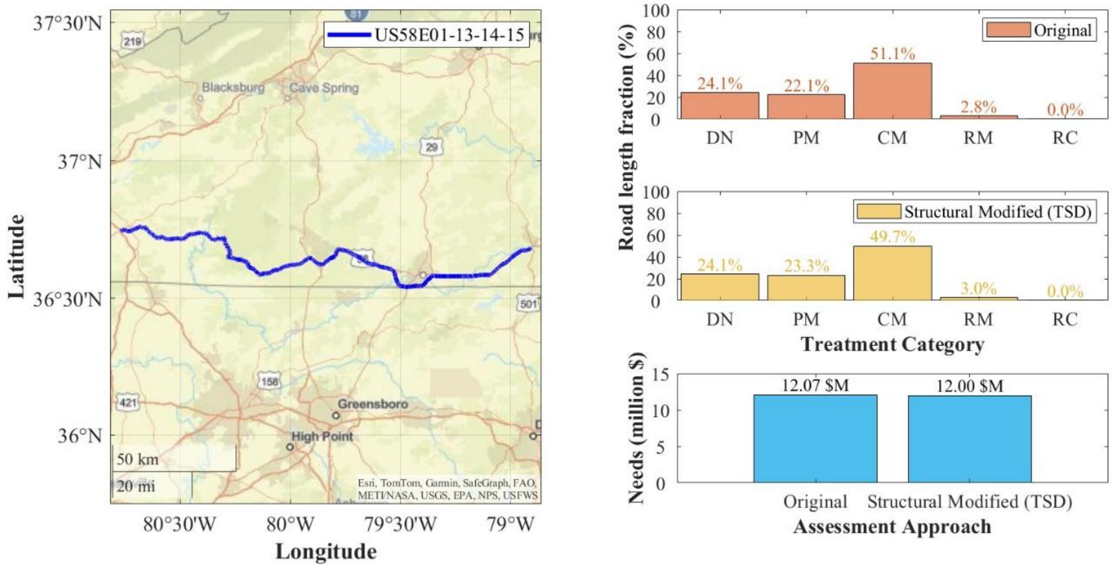

Figure B15. A Section of US 58 Eastbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

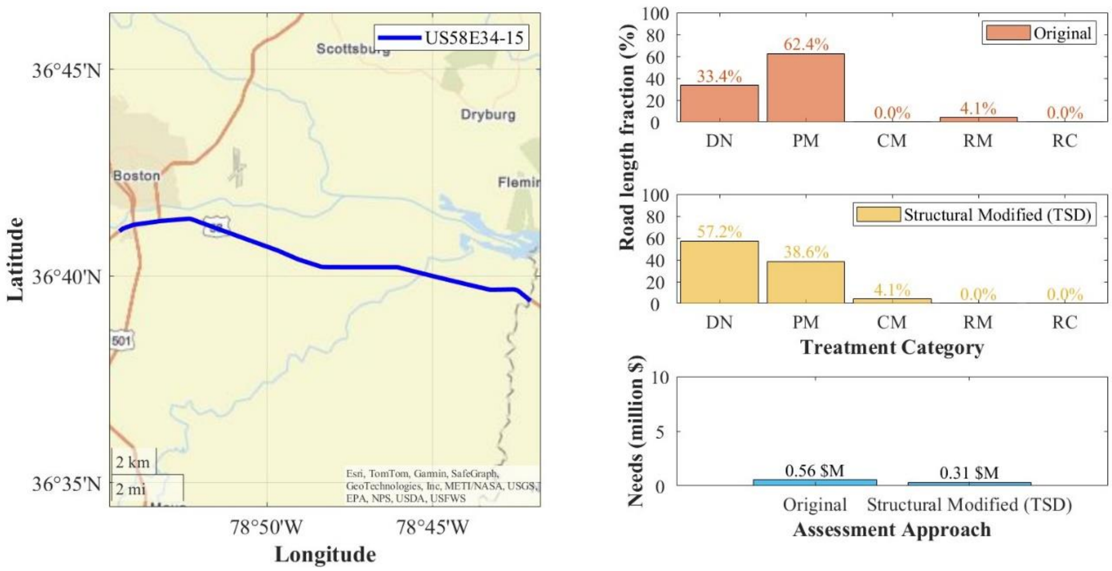

Figure B16. A Section of US 58 Eastbound, Surface Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

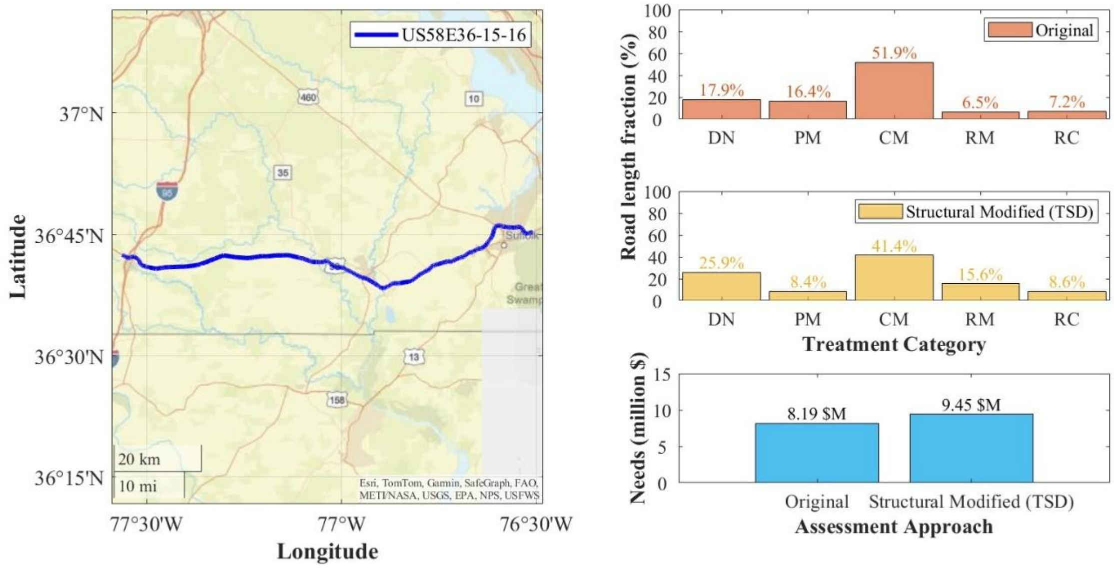

Figure B17. A Section of US 58 Eastbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

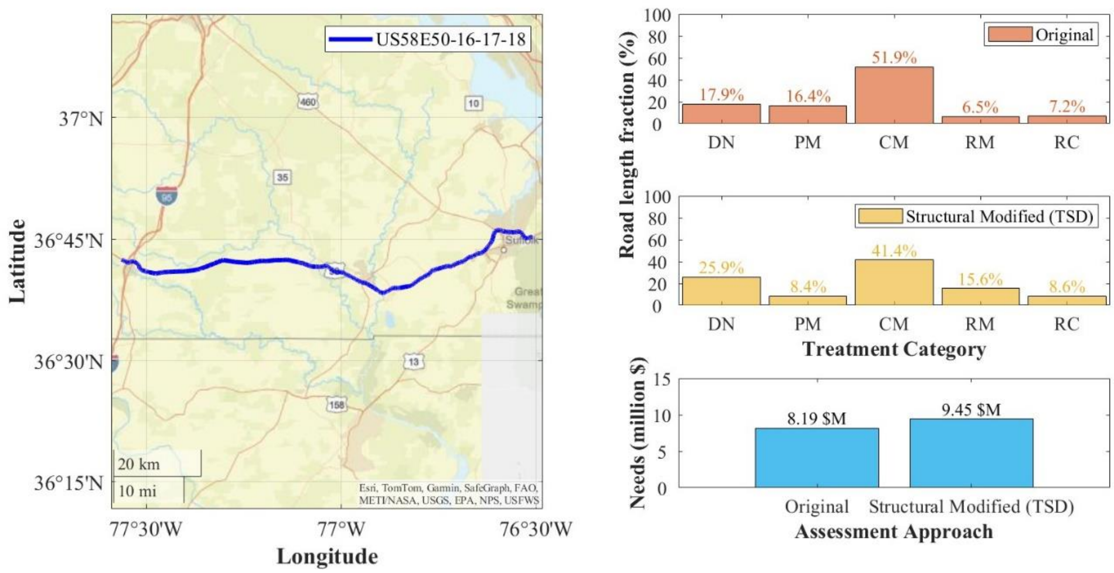

Figure B18. A Section of US 58 Eastbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

US 58 Westbound

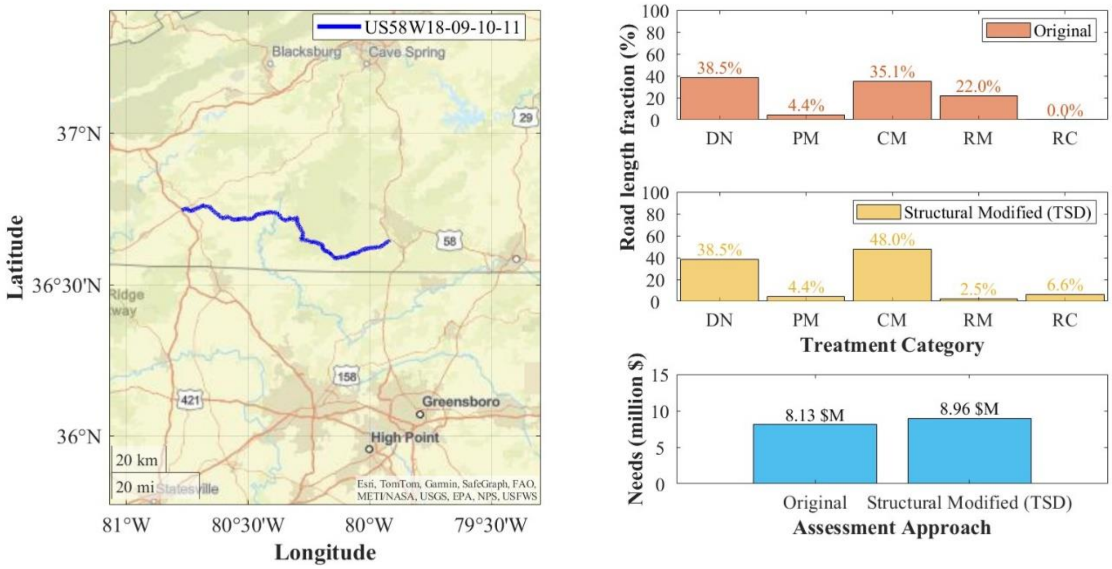

Figure B19. A Section of US 58 Westbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

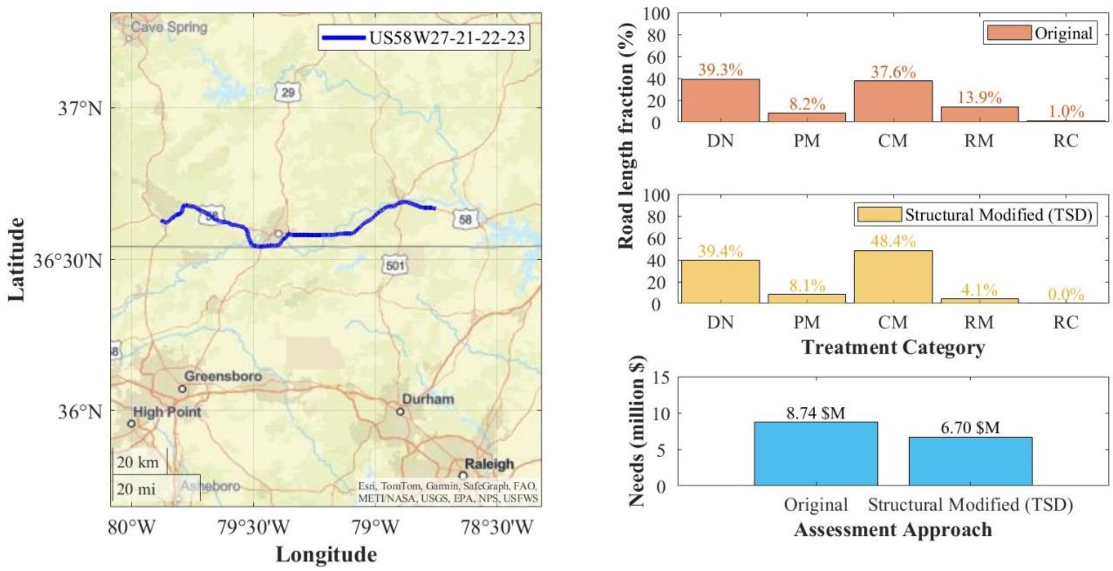

Figure B20. A Section of US 58 Westbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

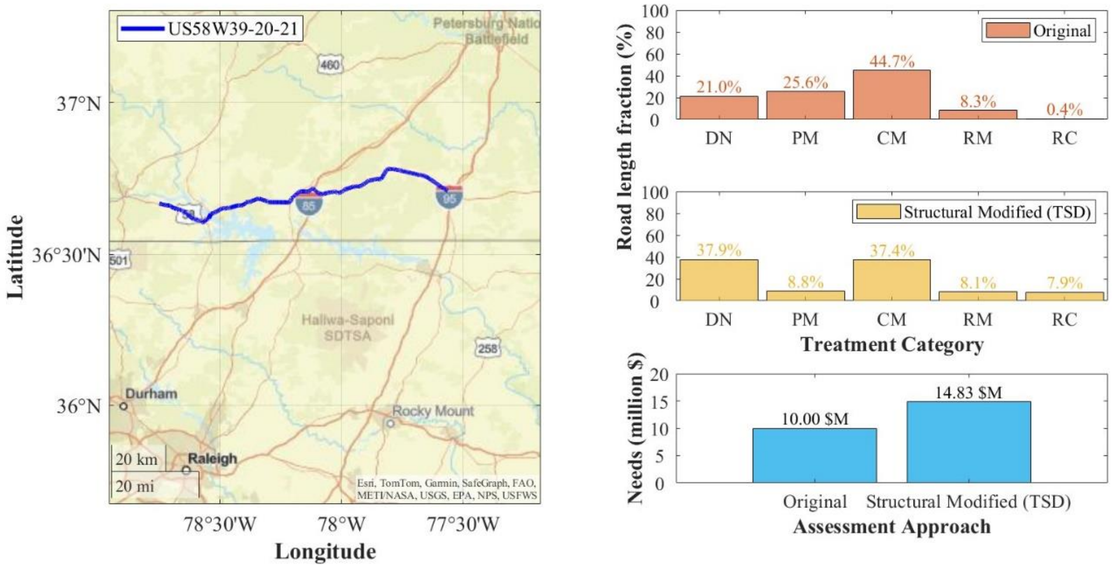

Figure B21. A Section of US 58 Westbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

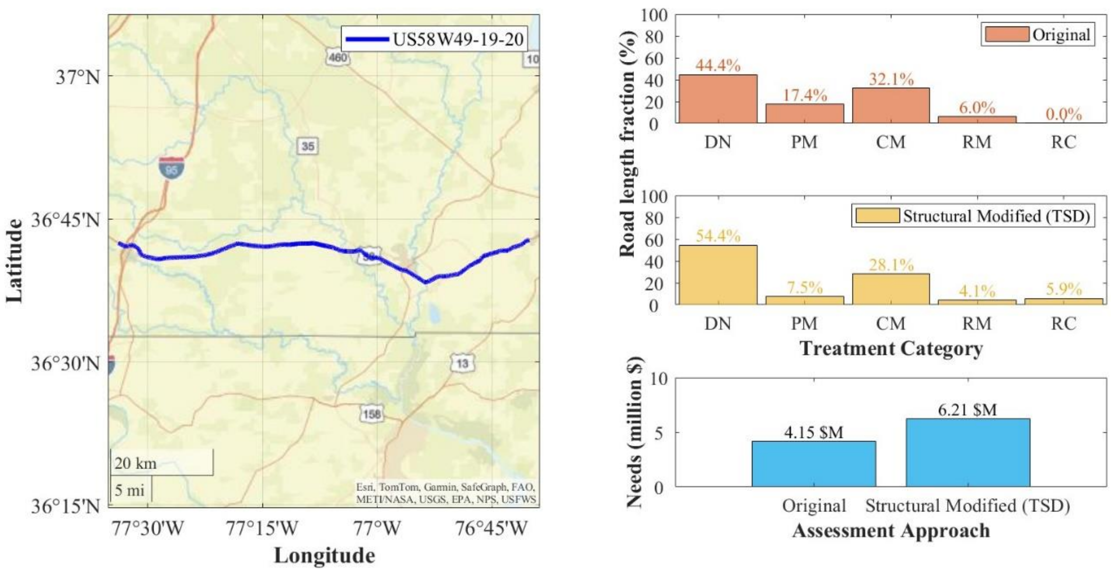

Figure B22. A Section of US 58 Westbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

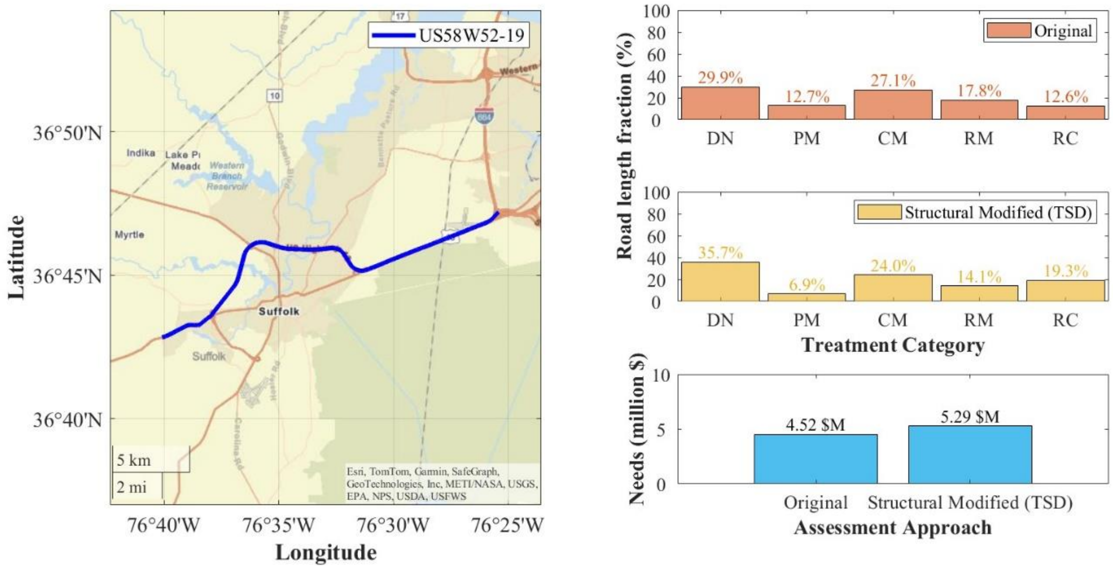

Figure B23. A Section of US 58 Westbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

Route 17 Northbound

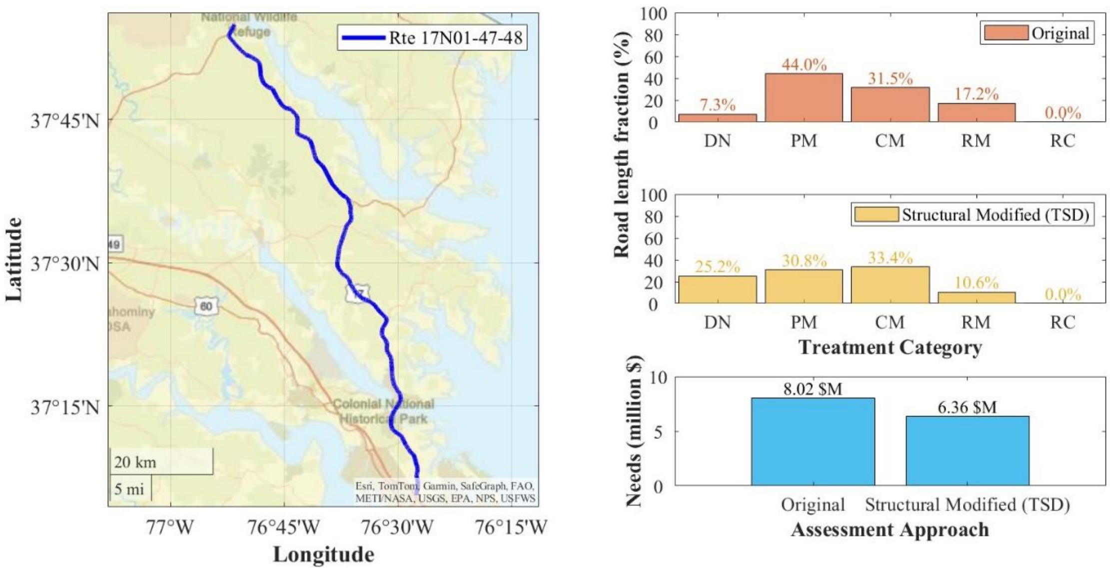

Figure B24. A Section of Route 17 Northbound, Original and Structural Modified (TSD) Treatment Categories, and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

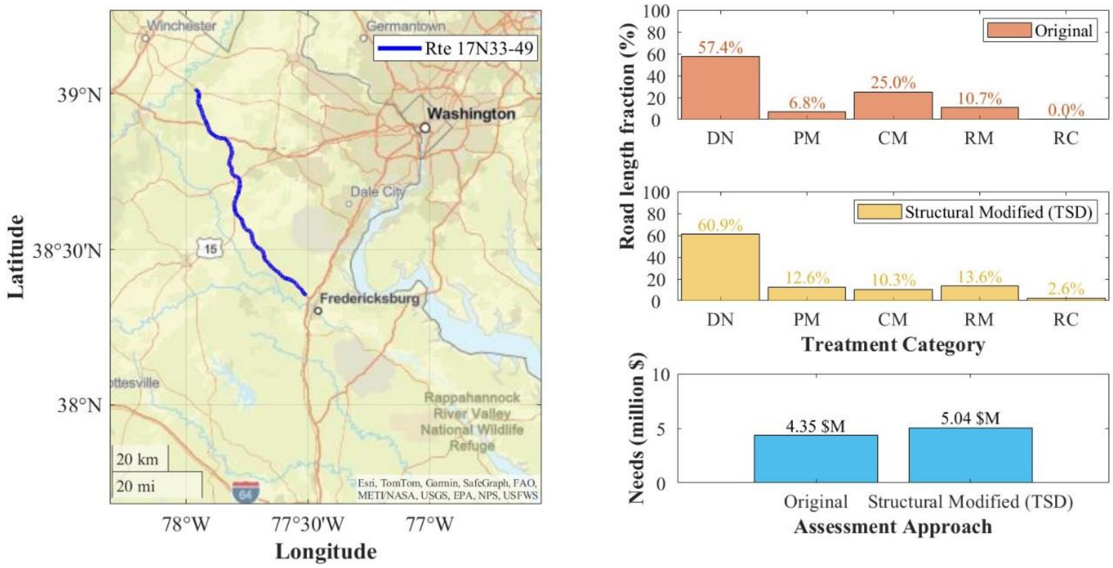

Figure B25. A Section of Route 17 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

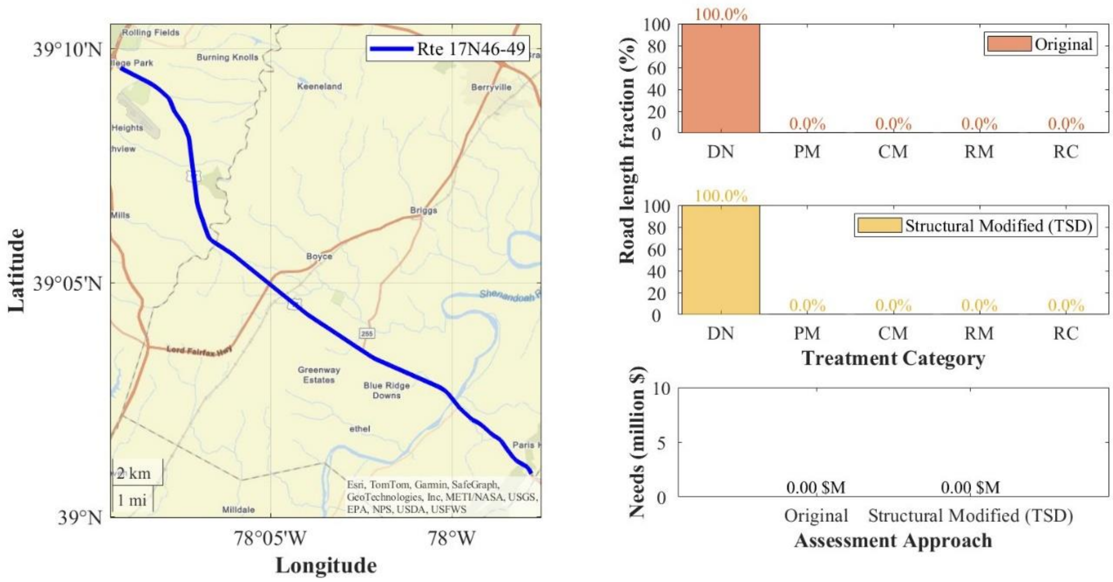

Figure B26. A Section of Route 17 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

Route 17 Southbound

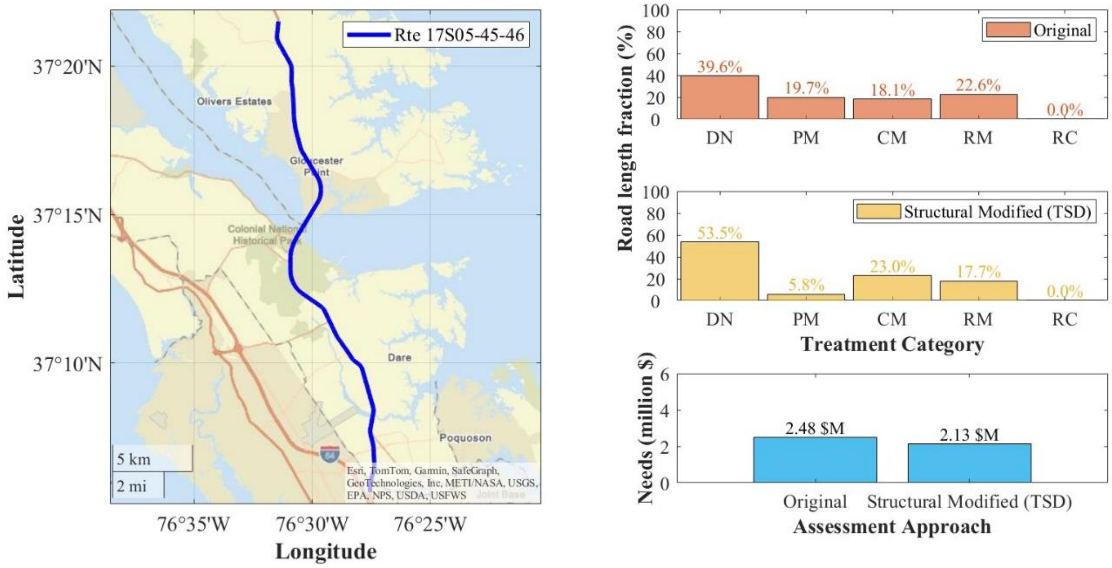

Figure B27. A Section of Route 17 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

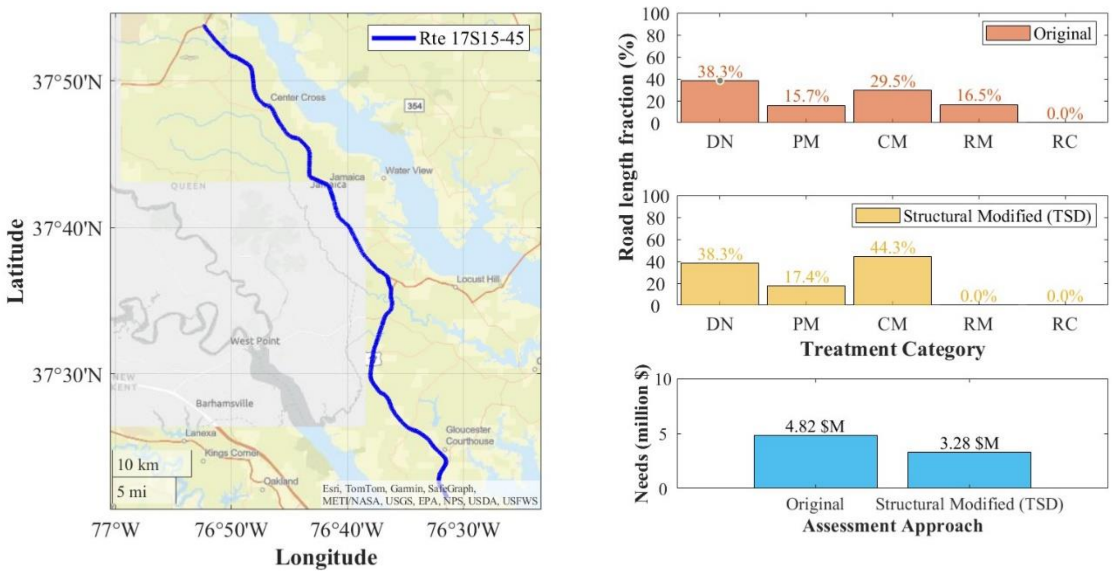

Figure B28. A Section of Route 17 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

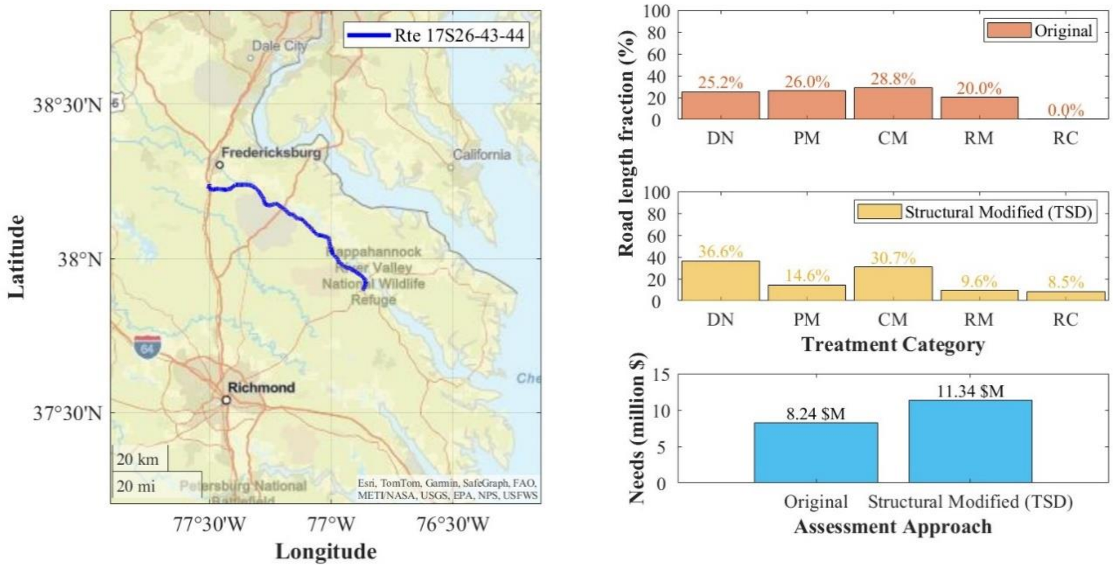

Figure B29. A Section of Route 17 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

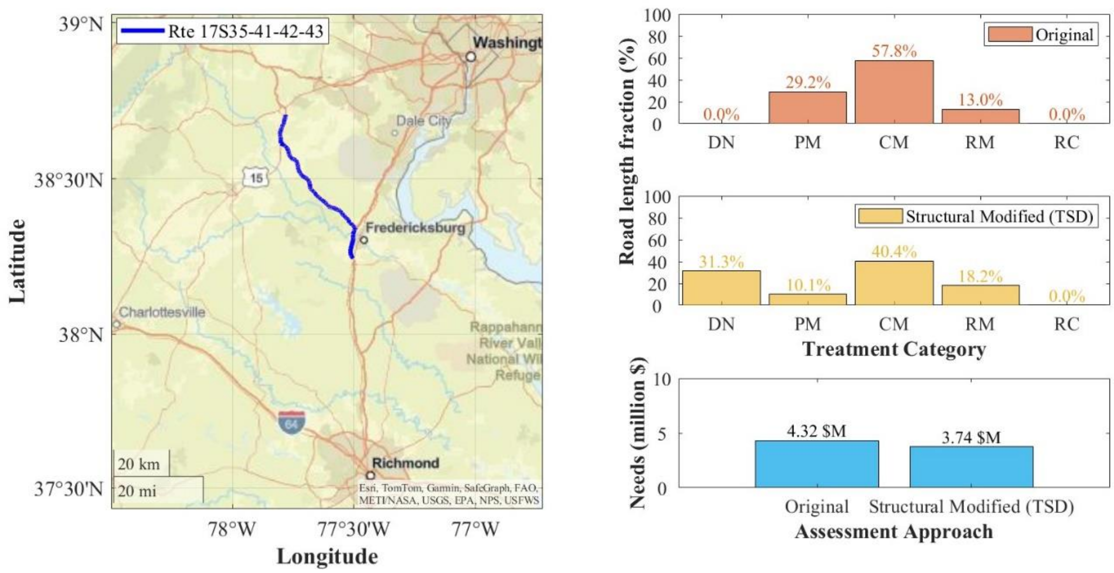

Figure B30. A Section of Route 17 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

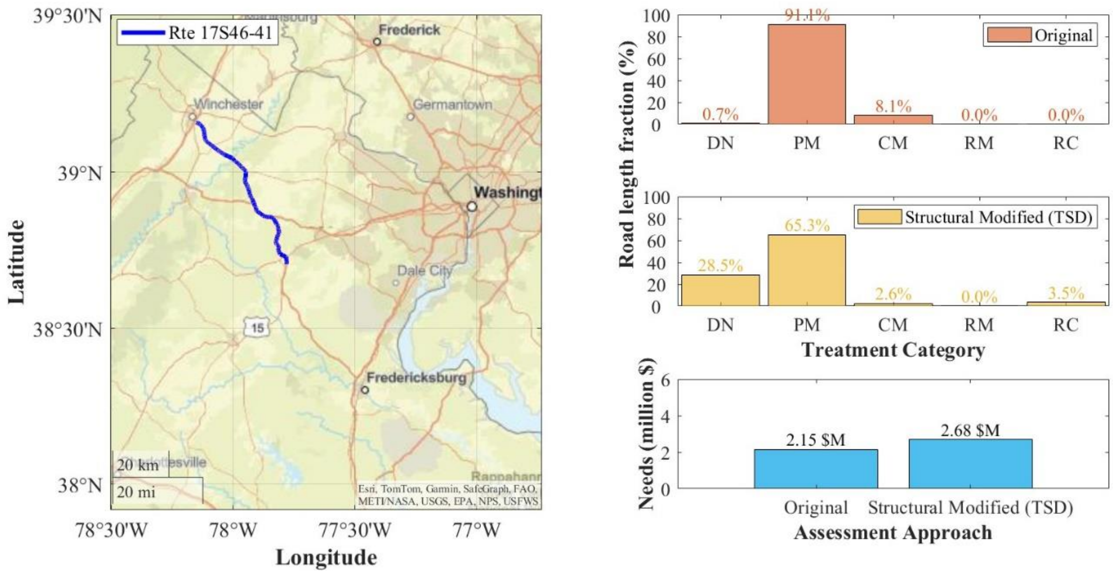

Figure B31. A Section of Route 17 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

Route 29 Northbound

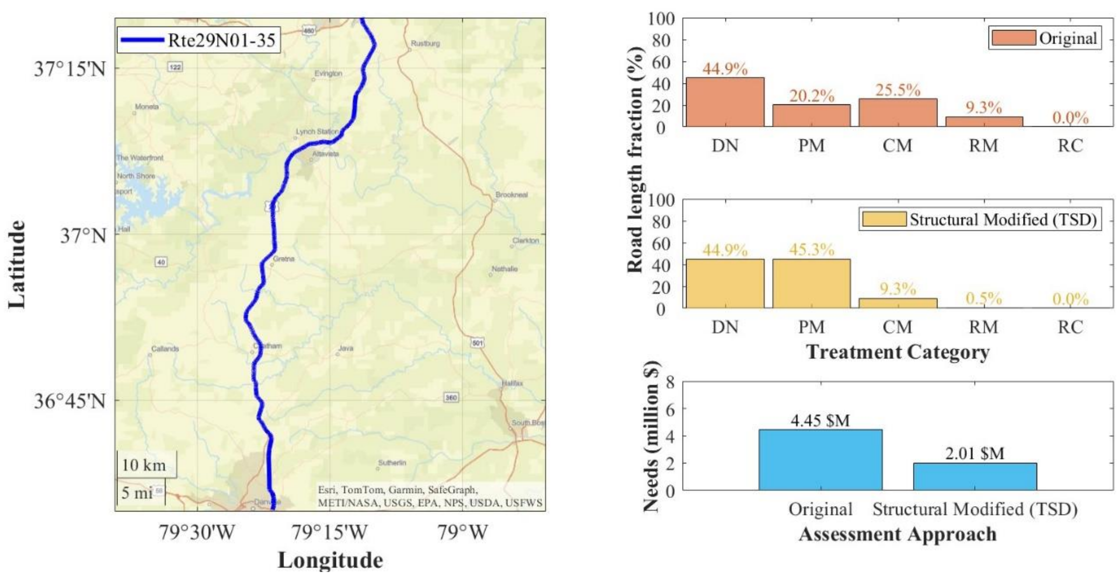

Figure B32. A Section of Route 29 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

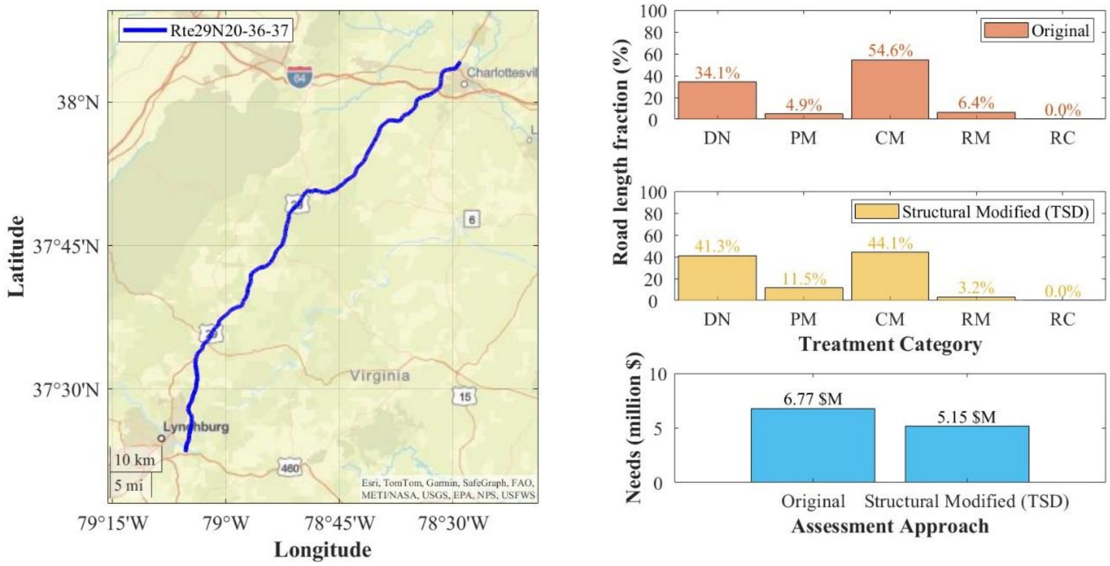

Figure B33. A Section of Route 29 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

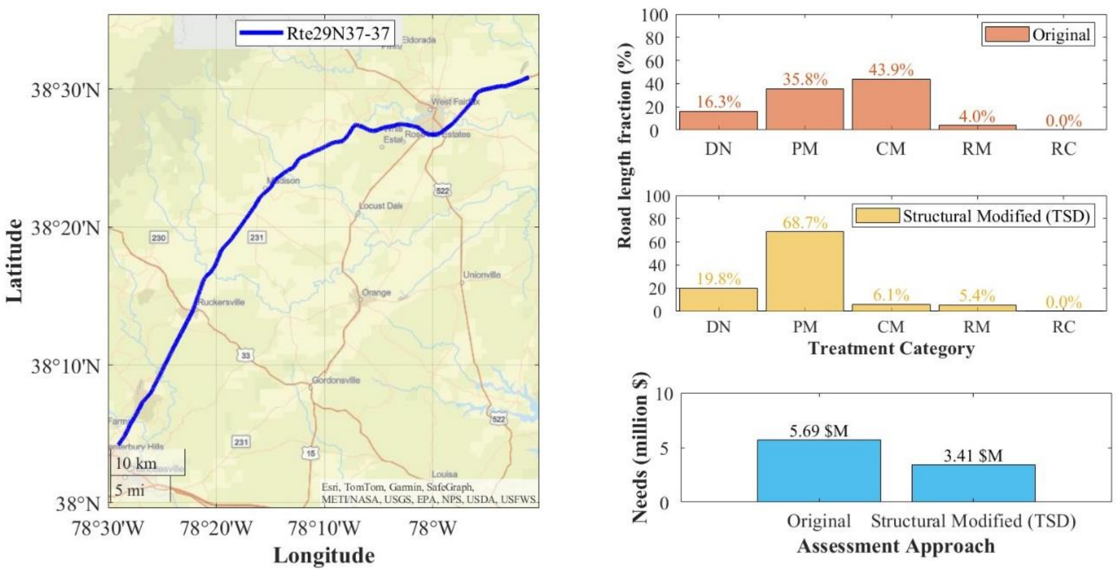

Figure B34. A Section of Route 29 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

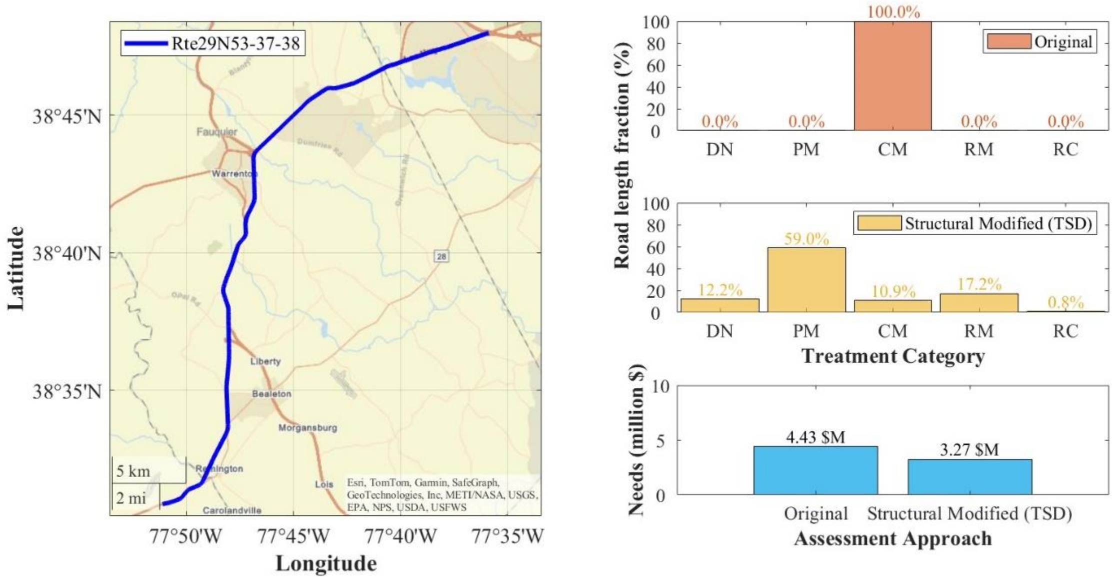

Figure B35. A Section of Route 29 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

APPENDIX C: ANALYSIS OF ROUTES ON INTERSTATE NETWORK

Interstate 64 Eastbound

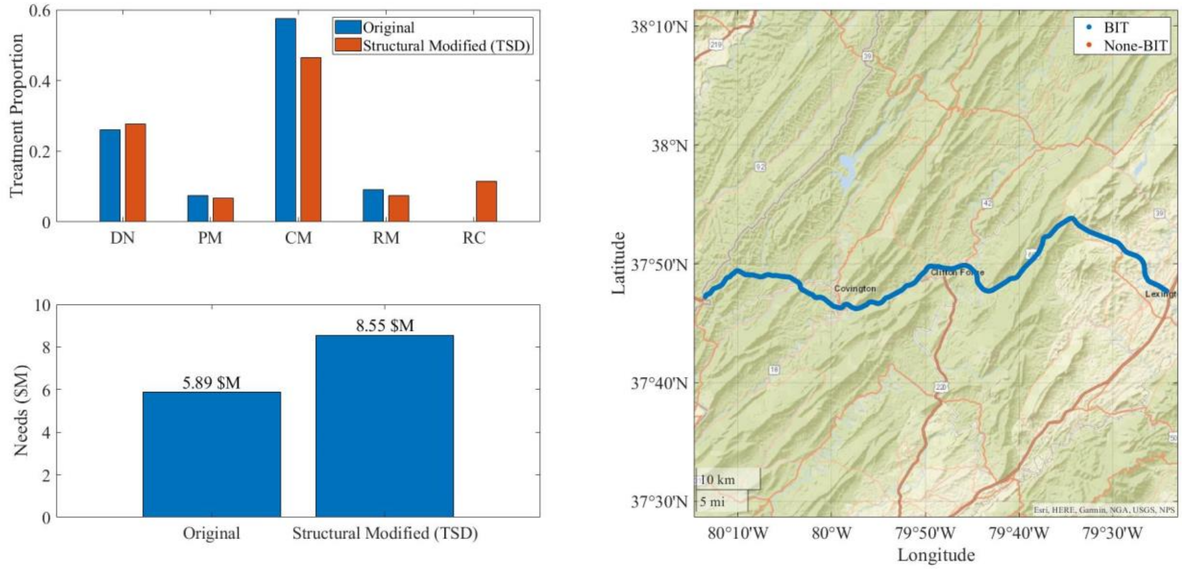

Figure C1. A Section of Interstate 64 Eastbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

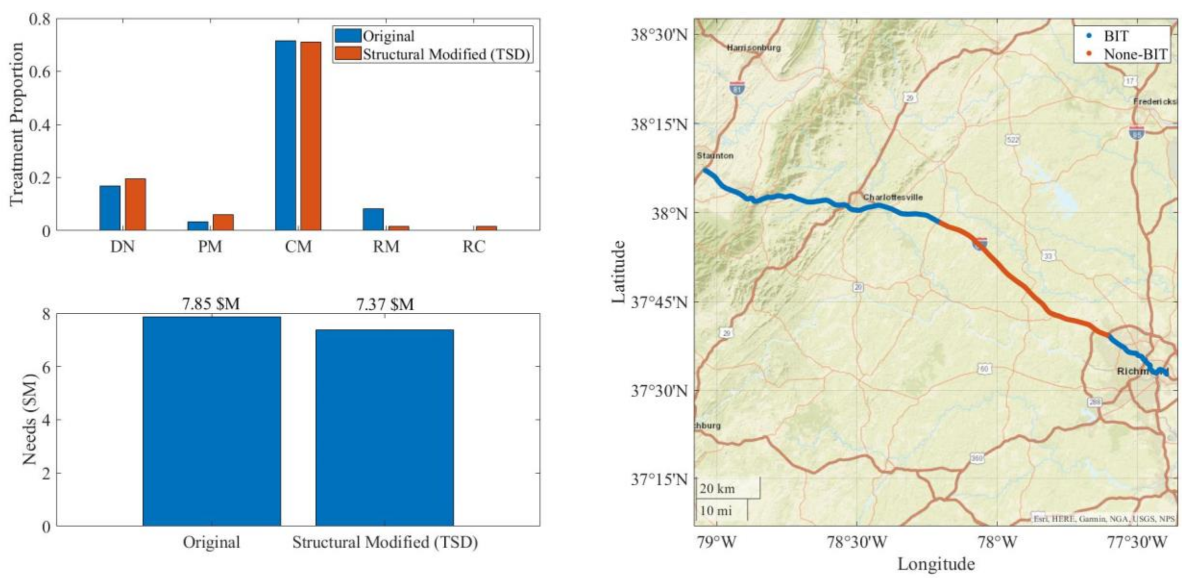

Figure C2. A Section of Interstate 64 Eastbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

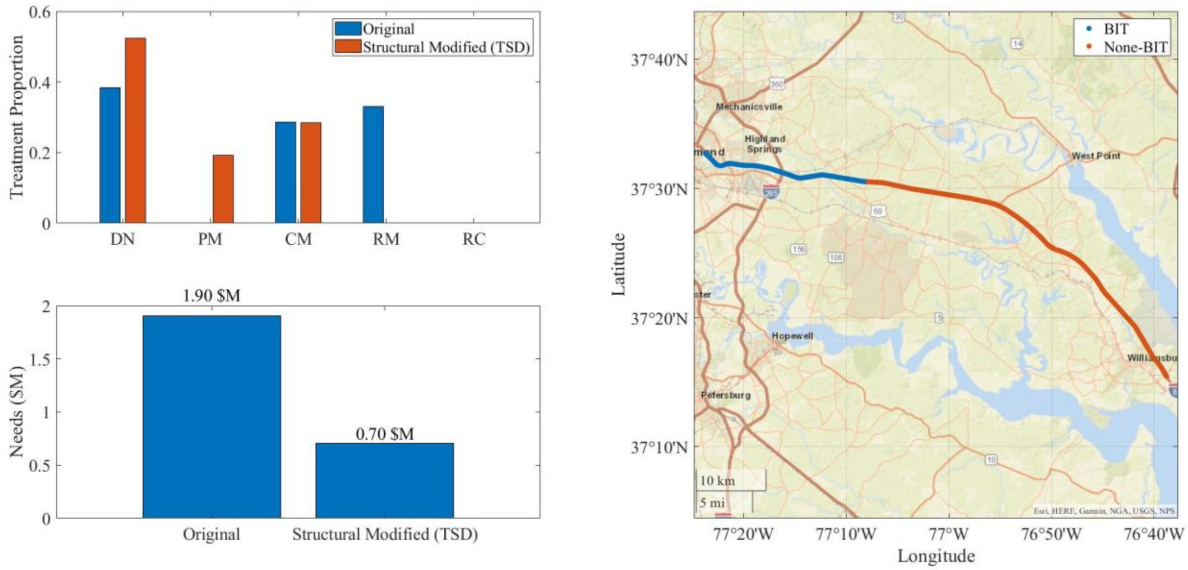

Figure C3. A Section of Interstate 64 Eastbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

Interstate 64 Westbound

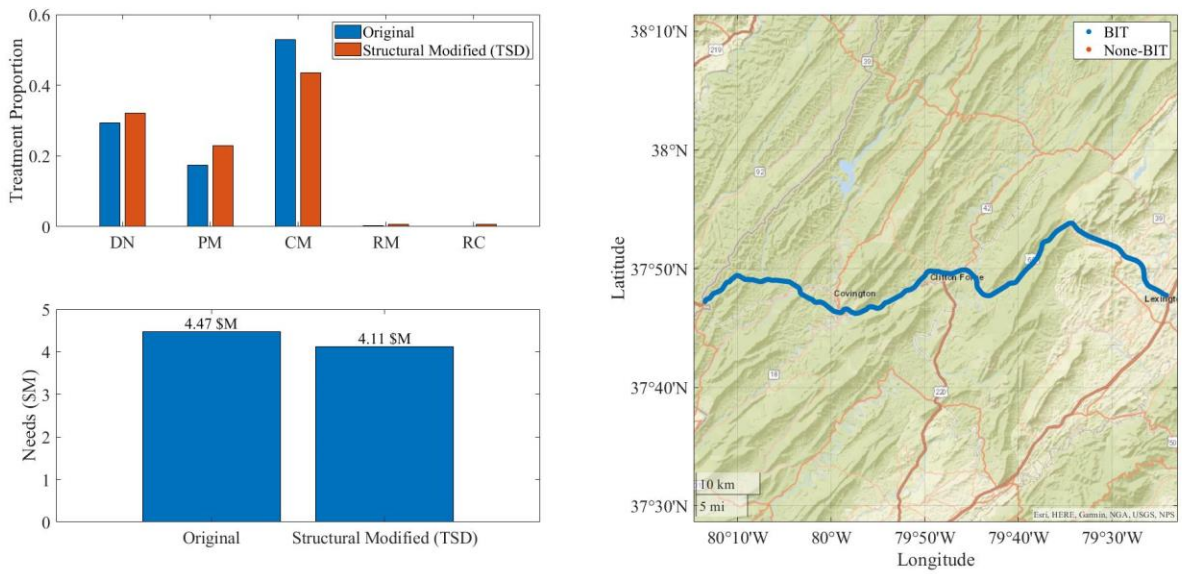

Figure C4. A Section of Interstate 64 Westbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

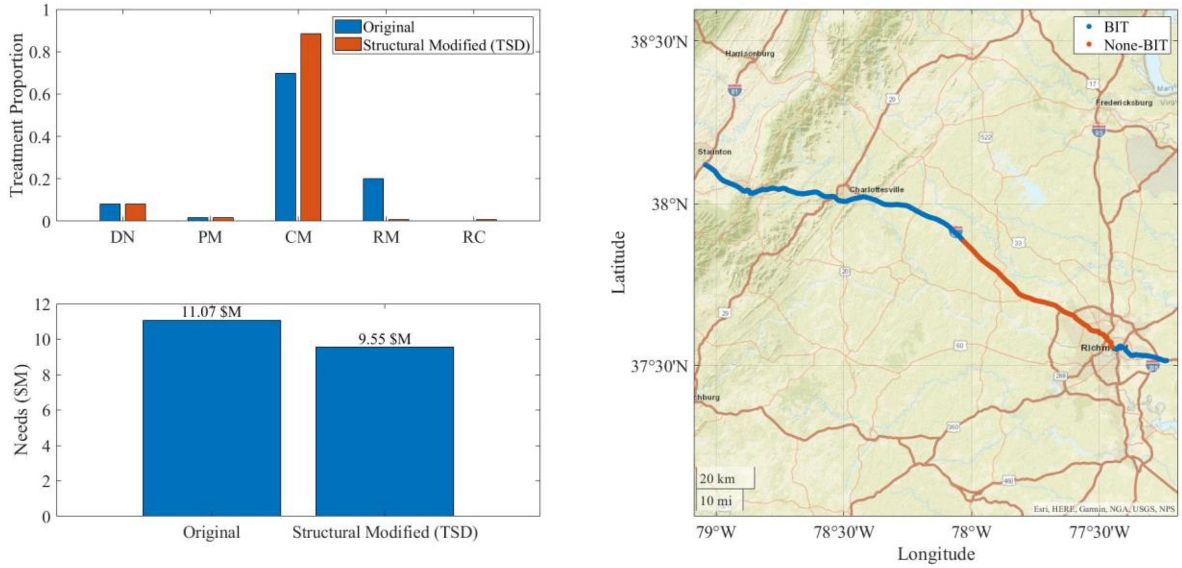

Figure C5. A Section of Interstate 64 Westbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

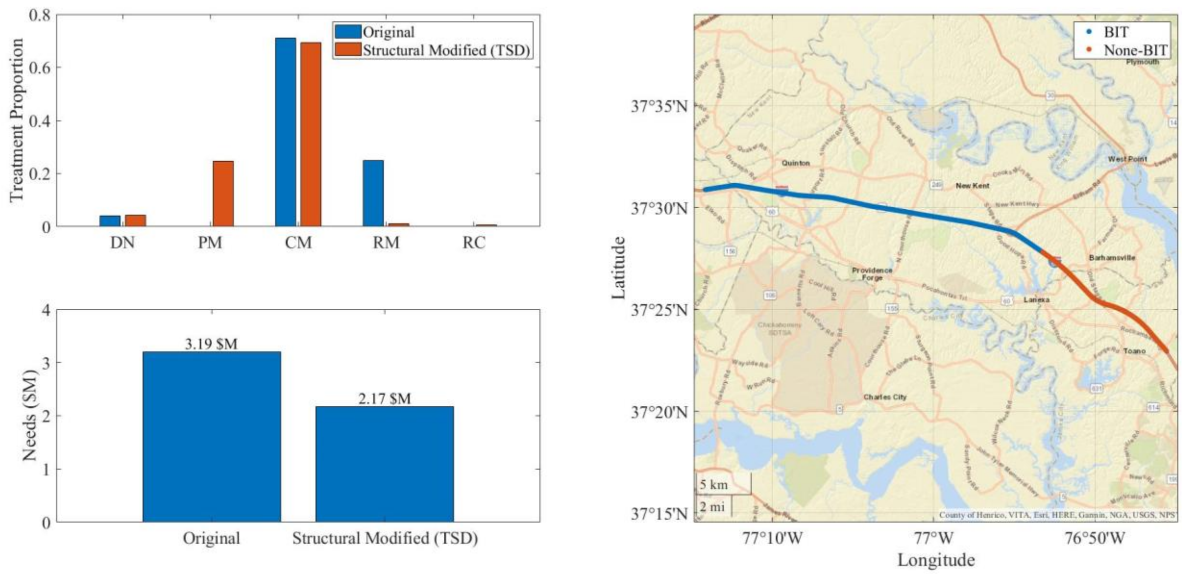

Figure C6. A Section of Interstate 64 Westbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

Interstate 81 Northbound

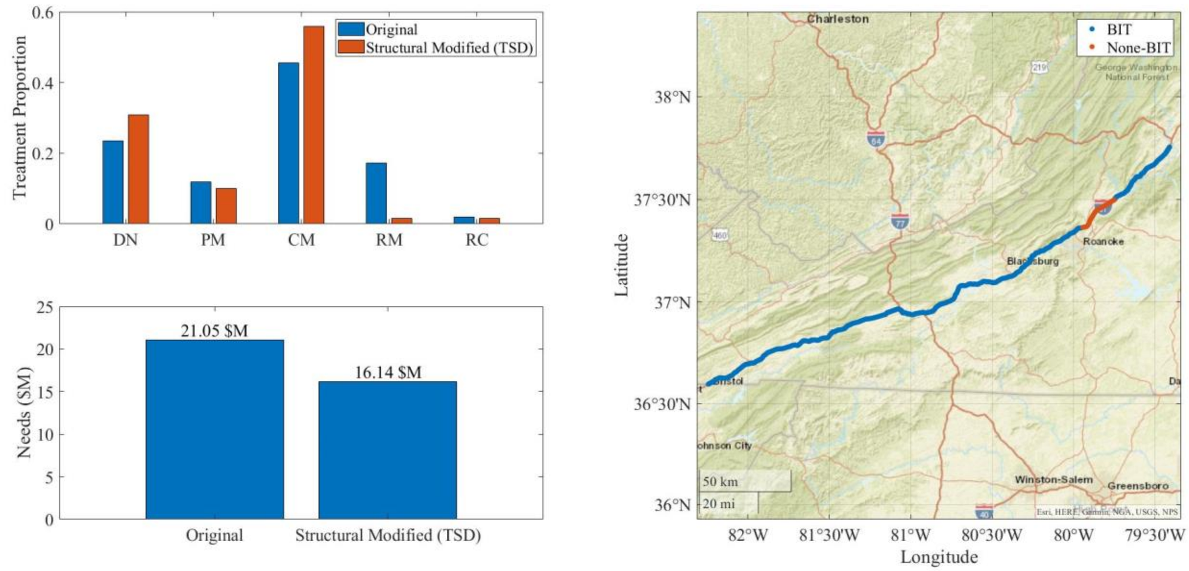

Figure C7. A Section of Interstate 81 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

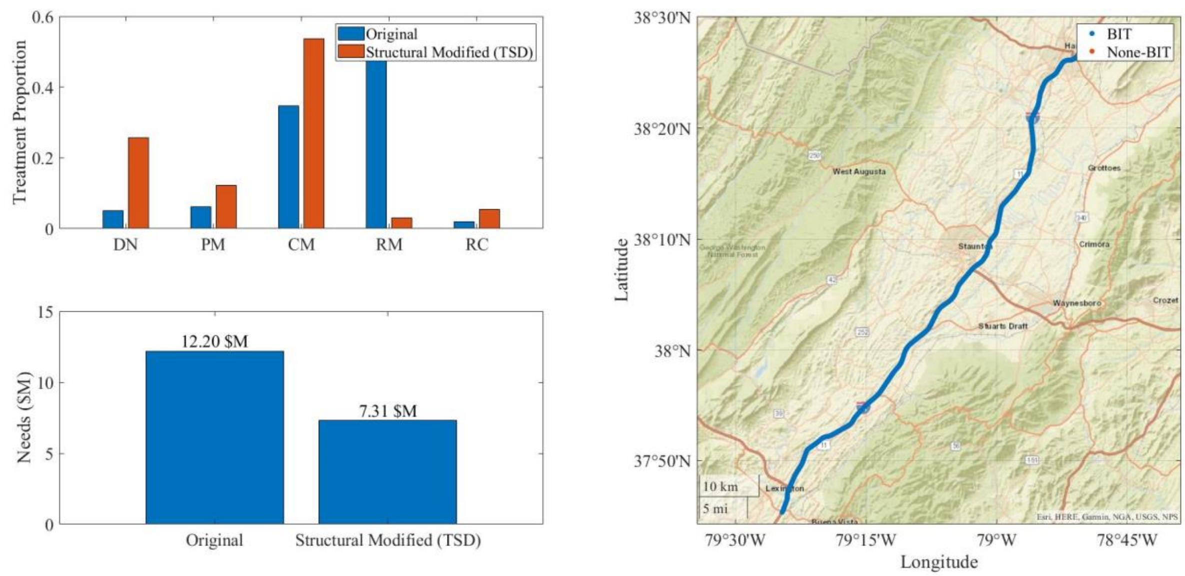

Figure C8. A Section of Interstate 81 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

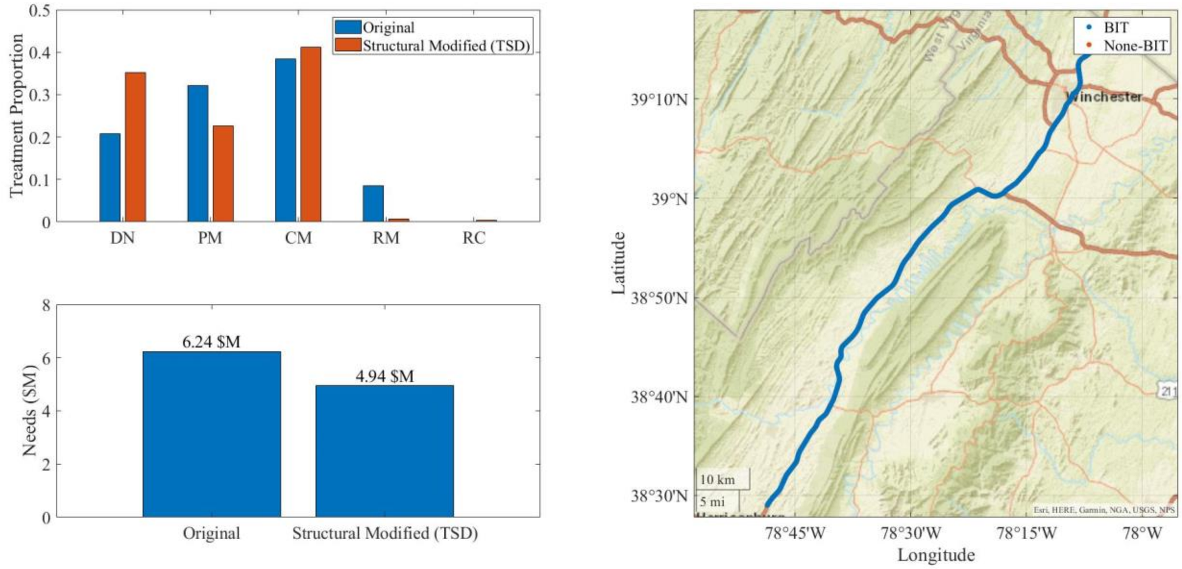

Figure C9. A Section of Interstate 81 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

Interstate 81 Southbound

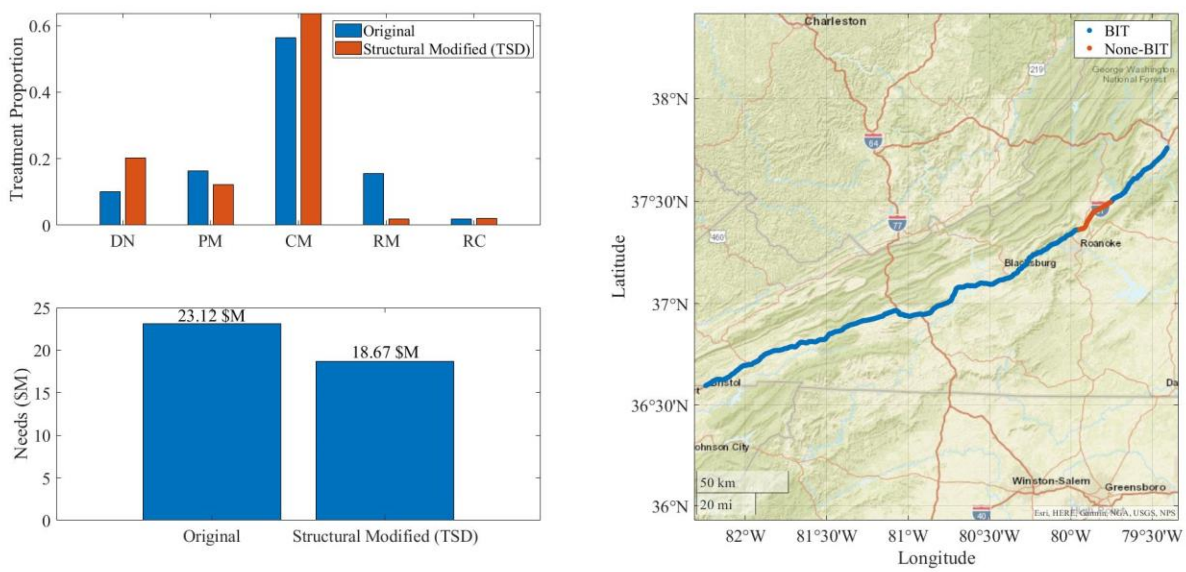

Figure C10. A Section of Interstate 81 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

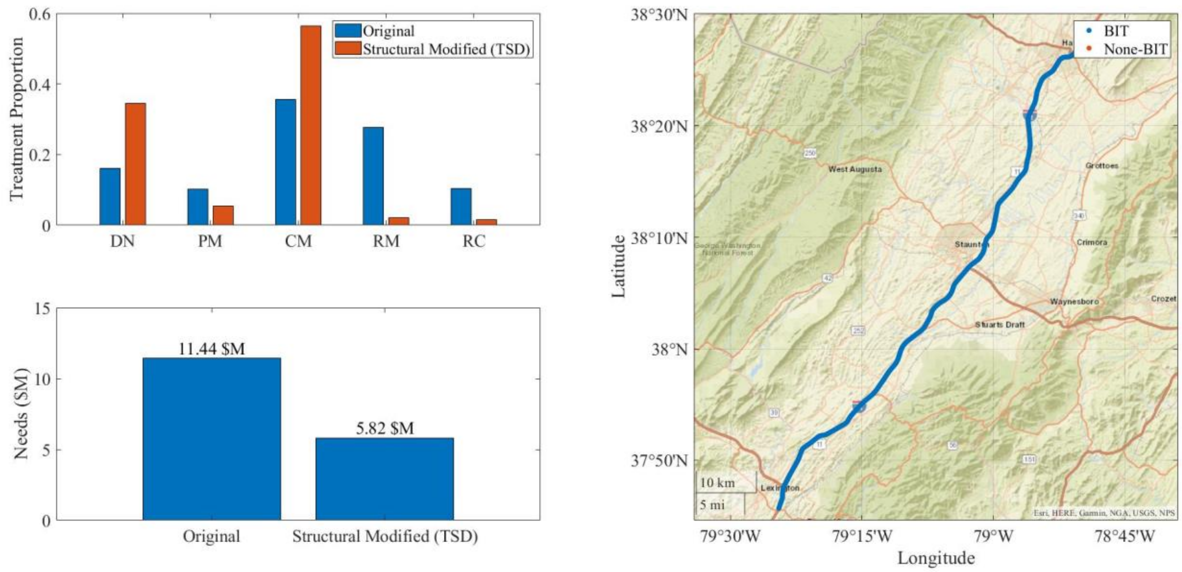

Figure C11. A Section of Interstate 81 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

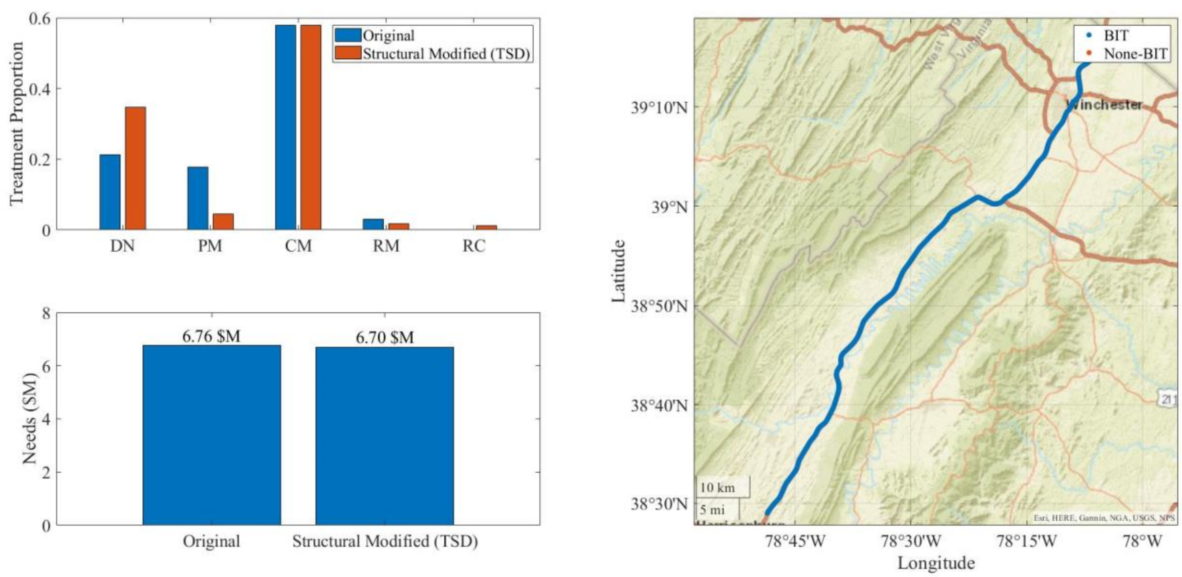

Figure C12. A Section of Interstate 81 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

Interstate 95 Northbound

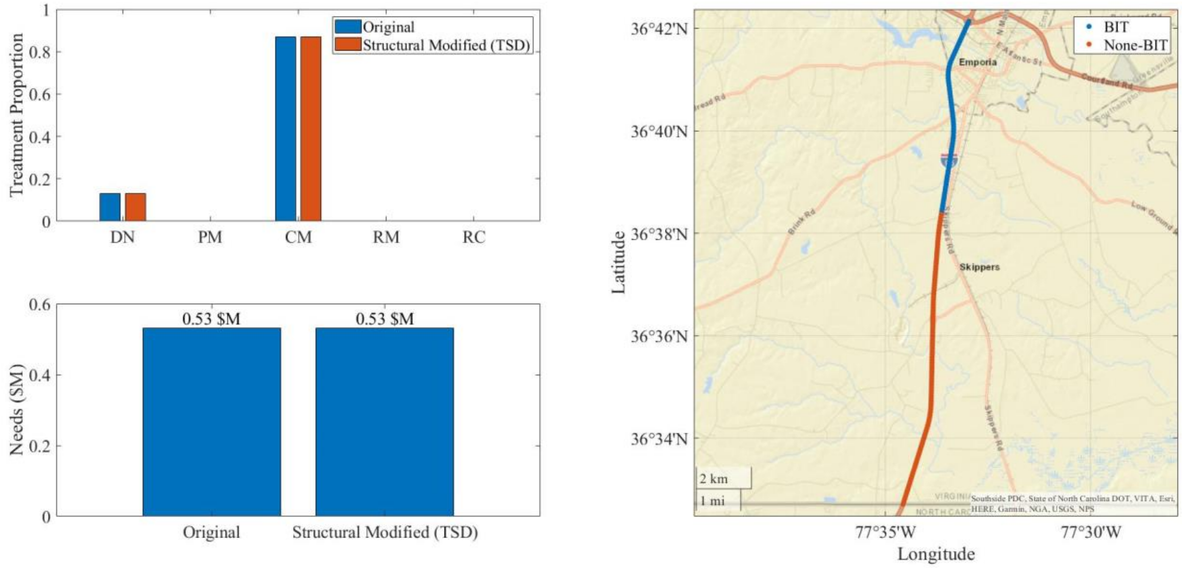

Figure C13. A Section of Interstate 95 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

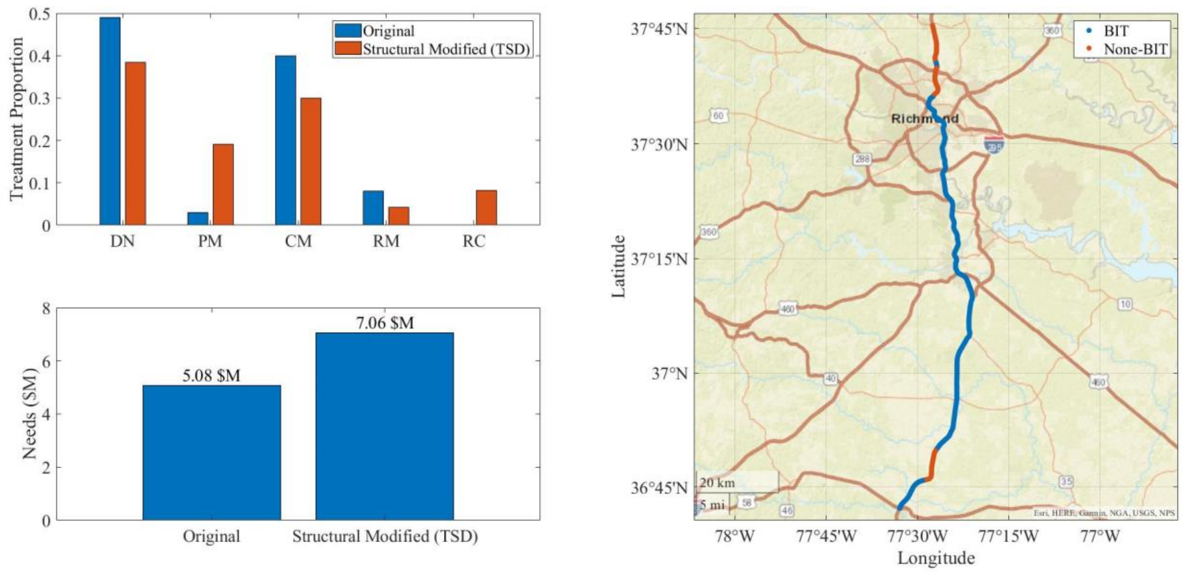

Figure C14. A Section of Interstate 95 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

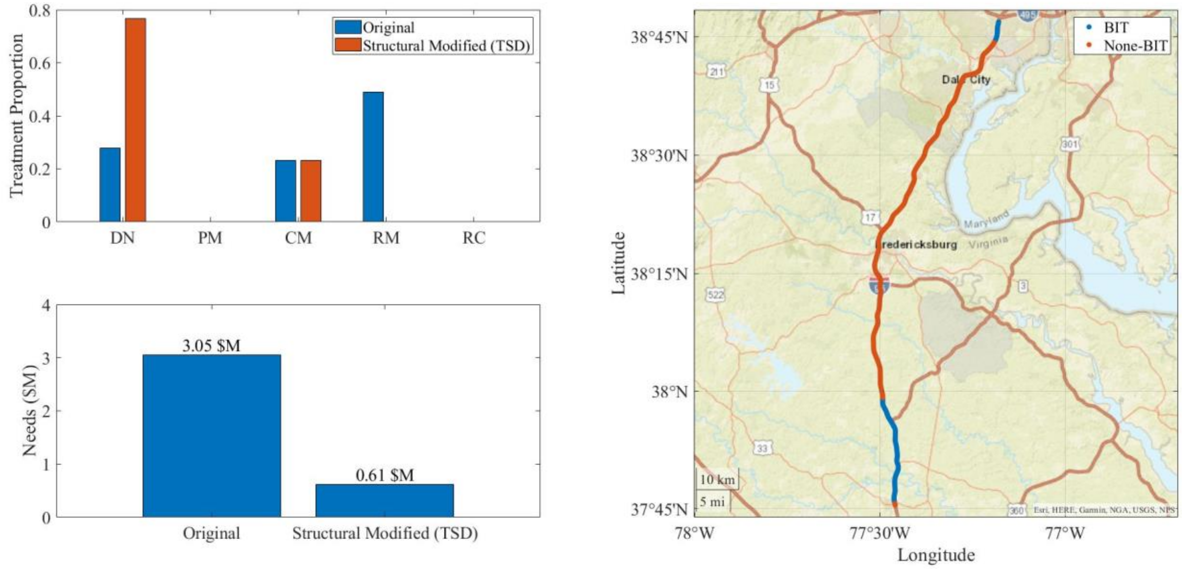

Figure C15. A Section of Interstate 95 Northbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

Interstate 95 Southbound

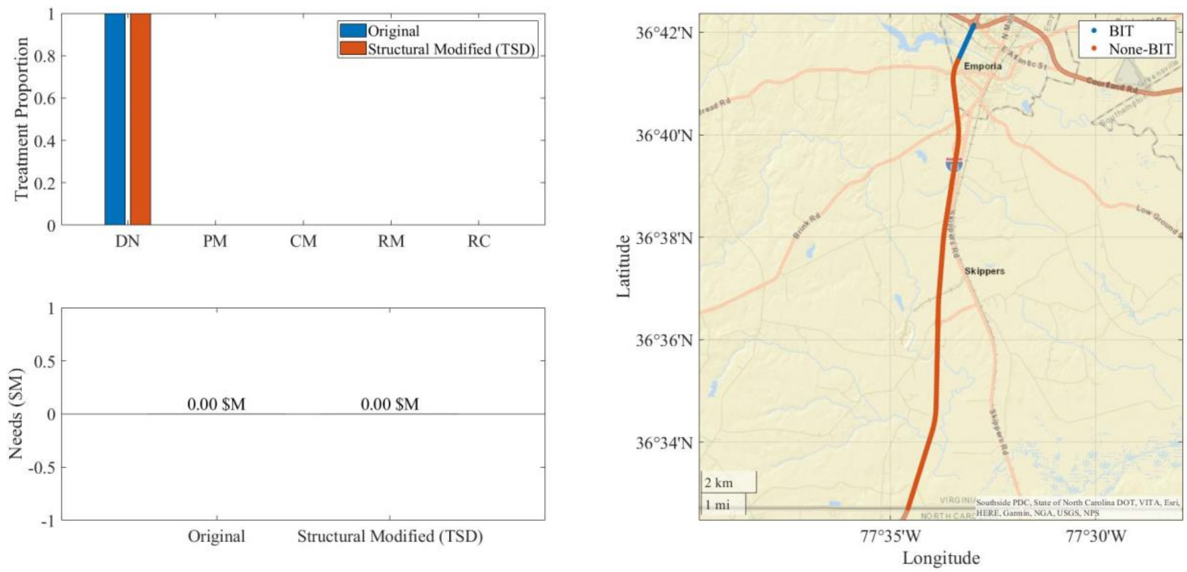

Figure C16. A Section of Interstate 95 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

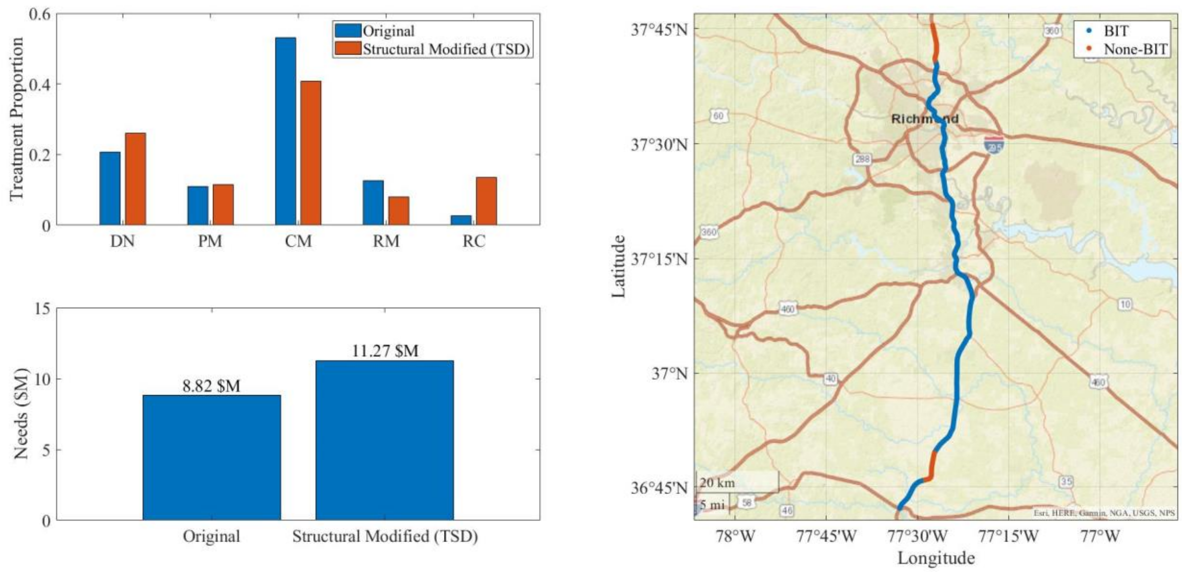

Figure C17. A Section of Interstate 95 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.

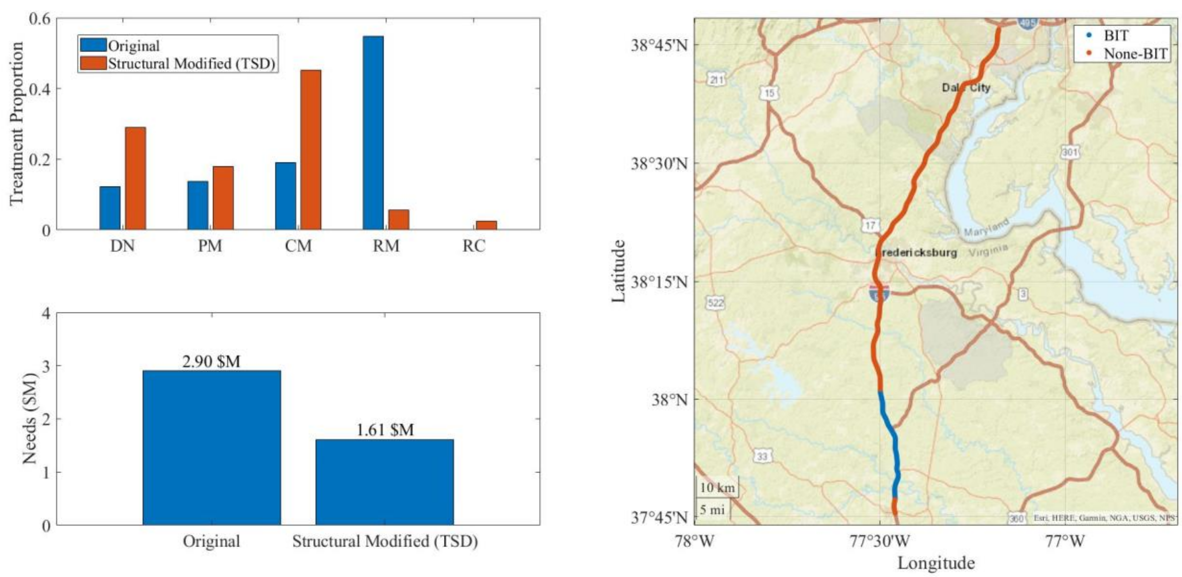

Figure C18. A Section of Interstate 95 Southbound, Original and Structural Modified (TSD) Treatment Categories and Needs. CM = Corrective Maintenance. DN = Do Nothing. PM = Preventive Maintenance. RC = Reconstruction. RM = Restorative Maintenance; TSD = traffic speed deflectometer.