Assessing the Agreement among Pavement Condition Indexes

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Abstract: Pavement condition indexes are numerical indicators of the structural and material integrity of a pavement. Because these indexes appear to be similar (essentially a 0–100 scale, with 100 indicating ideal condition), it can be tempting to use different indexes for comparing the performance of pavement networks in different states or jurisdictions within a state. To ascertain the level of agreement among these condition indexes, six pavement condition indexes from five DOTs in the United States are discussed and compared using distress and ride quality data obtained from the Pavement Management Information System of the Texas Department of Transportation. The computed scores were compared visually (using scatter plots) and statistically (using paired t-test). The results provide empirical evidence that there are significant differences among seemingly similar pavement condition indexes.

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Introduction

Researchers and transportation agencies around the country have developed a host of indexes to measure the structural and material integrity of pavements. These indexes are an aggregation of several distress types (e.g., cracking, rutting, bleeding, etc. in asphalt pavement; spalling, cracking, faulting, etc. in concrete pavement) and other physical measurements (such as surface roughness and friction) (McKay et al. 1999).

Traditionally, condition indexes have been used by engineers to describe the current quality of pavement networks and determine maintenance and repair needs and priorities (see a collection of papers in Saito 1997). The monitoring of these indexes over time enables the development of deterioration models, which permit early identification of maintenance and rehabilitation requirements and estimation of future funding needs (McNeil et al. 1992; AASHTO 2002). Pavement condition indexes, however, are increasingly being used for comparing infrastructure performance among different states or among different jurisdictions within a state (e.g., performance of city-maintained roadways versus performance of state-maintained roadways). These comparisons can influence strategic policies such as establishing goals for infrastructure performance levels and allocating funds to transportation agencies. Additionally, as interest in using performance-based management techniques continues to increase (Neumann and Markow 2004), the temptation to compare pavement conditions across different jurisdictions is likely to increase. The key question addressed in this paper is: are these indexes comparable? While many pavement management engineers recognize that pavement condition indexes are different, the literature is lacking empirical data to ascertain these differences and make this knowledge available to other stakeholders in this field. This paper contributes to filling this gap.

A computational experiment was conducted where distress and ride quality data for 9,642 pavement sections [typically 804 m (0.5 mi) long] were obtained from the Pavement Management Information System (PMIS) of the Texas Department of Transportation (TxDOT). These sections were then rated using six pavement condition indexes from five Departments of Transportation (DOTs) in the United States: TxDOT's condition score (CS); TxDOT's distress score (DS); South Dakota DOT's surface condition index (SCI); Ohio DOT's pavement condition rating (PCR); Pennsylvania DOT's overall pavement index (OPI); and Oregon DOT's overall index (OI). The computed scores (i.e., index values) were compared to ascertain the level of agreement among these condition indexes.

To provide the reader with a background on this subject, we begin with a discussion of the concepts and computational methods of pavement condition indexes based on a review of the literature. The remainder of the paper presents the studied condition indexes and discusses the results of their comparative analysis.

Literature Review

The pavement structural and material condition is affected by the type, severity, and density (i.e., extent of occurrence) of exhibited distresses (Shahin et al. 1978, 1980). The main challenge is how to combine these characteristics into a single index. The development of an overall condition index (CI) is even more challenging because the pavement's surface roughness is also considered, adding an extra dimension to the index.

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Early efforts in developing pavement condition indexes used direct panel ratings. This approach involves a panel of raters that drives the surveyed pavement (normally at posted speed) and subjectively rate the pavement sections either using a numeric scale or verbal descriptions such as good, fair, poor, etc. based on observed distress types and ride quality. Subjective panel ratings date back to the American Association of State Highway Officials (AASHO) road tests in the 1950s (Carey and Irick 1960). A panel subjectively rated sections of different pavement types near Ottawa, Illinois on a 0–5 scale known as the present serviceability rating (PSR). Since the PSR depends on the passenger perception of ride quality, it generally has a stronger correlation with road roughness measurements than with distress measurements. Currently, direct panel ratings are used on a limited basis to supplement other indexes such as Oregon DOT's good-fair-poor (GFP) rating method and Michigan DOT's sufficiency rating (SR) method. While panel ratings have the advantage of being simple and representative of the perception of roadway users, they are inherently subjective and do not provide sufficient engineering data that can be used to identify effective repair strategies.

To address the shortcomings of panel ratings, researchers developed mathematical models that capture the effect of distress type, severity, extent, and ride quality on the CI through deduct values. The general expression for computing a CI using deduct values is as follows:

$$\mathrm{CI} = C - (a_1 d_1 + a_2 d_2 + a_3 d_3 + \cdots + a_n d_n + a_r d_r) \quad (1)$$

where C=maximum value of the CI (perfect score); $a_1, a_2, a_3, \ldots, a_n$=adjustment factors for distress types 1 through n; and $d_1, d_2, d_3, \ldots, d_n$=deduct values for distress types 1 through n. Normally, d depends on the distress type, severity, and extent (i.e., density). a_r and d_r=roughness adjustment factor and deduct value, respectively.

A widely used CI that is derived from deduct values is the pavement condition index (PCI) developed in the late 1970s by the U.S. Army Corps of Engineers. The PCI scale ranges from 0 to 100, with 100 representing the perfect score (i.e., a pavement in excellent condition). In 2000, the American Society for Testing and Materials (ASTM) adopted the PCI method as a standard practice for conducting pavement condition surveys for roads and parking lots (ASTM Standard D6433-99). The general expression for computing PCI is as follows (Shahin et al. 1978, 1980):

$$\mathrm{PCI} = C - \sum_{i=1}^{P} \sum_{j=1}^{m_i} a(T_i, S_j, D_{ij}) F(t, q) \quad (2)$$

where C=maximum value of the CI (i.e., perfect score of 100); $a(T,S,D)$=deduct value function that varies with distress type (T), severity (S), and density (D). $a(T,S,D)$ functions are usually polynomial for a concrete pavement and "multiple discrete" natural logarithmic for an asphalt pavement. $F(t,q)$=an adjustment function that varies with total deduct value (t) and number of deducts (q). i and j=counters for distress types and severity levels, respectively. p=total number of observed distress types. m_i =number of severity levels for the ith distress type. Typically, three levels of severity are used (low, medium, and high).

Today, many DOTs use condition indexes that are derived from deduct values. Examples of these indexes include Oregon DOT's OI; Minnesota DOT's surface rating (SR); Tennessee DOT's pavement distress index (PDI); and Ohio DOT's PCR. TxDOT uses condition indexes derived from utility functions.

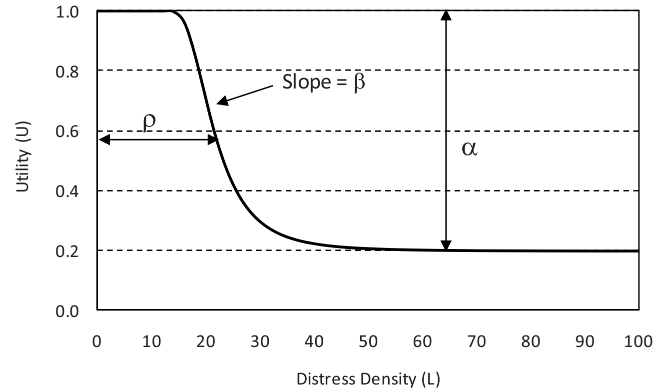


Fig. 1. General shape of utility curves used for computing TxDOT's DS and CS

Studied Pavement Condition Indexes

This section of the paper discusses the concepts and mathematical forms of the studied pavement condition indexes: TxDOT's CS; TxDOT's DS; South Dakota DOT's SCI; Ohio DOT's PCR; Pennsylvania DOT's OPI; and Oregon DOT's OI. These indexes are fairly representative of current practices among DOTs throughout the United States (Papagiannakis et al. 2009).

TxDOT's DS and CS

TxDOT measures the pavement condition in terms of the following indexes (Stampley et al. 1995):

- DS: a 1–100 index (with 100 representing no or minimal distress); and
- CS: a 1–100 index (with 100 representing no or minimal distress and roughness).

Both the DS and CS are implemented in TxDOT's PMIS and are computed as follows:

$$\mathrm{DS} = 100 \times \prod_{i=1}^{n} U_i \quad (3)$$

$$\mathrm{CS} = U_{\mathrm{Ride}} \times \mathrm{DS} \quad (4)$$

where U_i=utility value for distress type i and is computed as follows:

$$U_i = \begin{cases} 1.0 & \text{when } L_i = 0 \\ 1 - \alpha e^{-(\rho/L_i)^{\beta}} & \text{when } L_i > 0 \end{cases} \quad (5)$$

U_i ranges between 0 and 1.0 and represents the quality of a pavement in terms of overall usefulness (e.g., a U_i of 1.0 indicates that distress type i is not present and thus is most useful). L_i represents the density of the distress in the pavement section (i.e., quantity of distress per mile, quantity of distress per section area, quantity of distress per 100 ft, etc.). α (maximum loss factor), β (slope factor), and ρ (prolongation factor) control the location of the utility curve's inflection point and the slope of the curve at that point, as illustrated in Fig. 1. The coefficients for asphalt concrete pavement (ACP) Type 5 (2.5- to 5.5-in.-thick ACP layer) are shown in Table 1 as an example. Different pavement types have different utility curve coefficients.

Table 1. TxDOT's DS and CS Utility Curve Coefficients for ACP

Distress	α (maximum loss factor)	β (slope factor)	ρ (prolongation factor)
Shallow rut	0.31	1.0	19.72
Deep rut	0.69	1.0	16.27
Patching	0.45	1.0	10.15
Failure	1.0	1.0	4.70
Alligator cracking	0.53	1.0	8.01
Longitudinal cracking	0.87	1.0	184.0
Transverse cracking	0.69	1.0	10.39
Block cracking	0.49	1.0	9.78
Ride quality (CS only)	1.818 (low traffic), 1.76 (medium traffic), 1.73 (high traffic)	1.0	58.50 (low traffic), 48.10 (medium traffic), 41.00 (high traffic)

Oregon DOT's OI

Oregon DOT measures the pavement condition in terms of the OI, a 0–100 index with 100 representing no or minimal distress. The OI is computed as follows (Mullis et al. 2005):

$$\mathrm{OI} = \min\left\{ \begin{matrix} \mathrm{INDEX}_{i=\mathrm{Rut}} \\ \prod_{i=1}^{k} \mathrm{INDEX}_i \end{matrix} \right\} \tag{6}$$

where INDEX_i is a 0–100 index for the ith distress type and is calculated using Eq. (7)

$$\mathrm{INDEX}_i = \frac{\sum_{j=1}^{s_i} \left[1 - a\left(\frac{E_j}{M}\right)^b \right] E_j}{\sum_{j=1}^{s_i} E_j} \tag{7}$$

where j is a counter for the severity levels of the ith distress type. s_i=number of severity levels for the ith distress type. Typically, three levels of severity are used (low, medium, and high). E=distress extent (measured in the field); and M=maximum possible extent of the measured distress in a 10th-mi pavement section. The coefficient a can range in value from 0 to 1.0 and establishes the importance of a particular severity level and distress type relative to the other severity levels and distress types. The exponent b also ranges in value from zero to 1.0 and sets the curvature of the equation, which controls the relative effect of small quantities for a particular distress type. When b=1.0, the equation generates a straight line with slope a. As b approaches zero, the equation becomes highly nonlinear (Mullis et al. 2005). The coefficients a, b, and M for the ACP are shown in Table 2. Different pavement types have different coefficients.

South Dakota DOT's SCI

South Dakota DOT measures the pavement condition using the SCI, a 0–5 index with 5 representing no or minimal distress. The SCI is computed as follows (SDDOT 2000; Zimmerman et al. 2002):

$$\mathrm{SCI} = \mu - 1.25\sigma \tag{8}$$

where μ=mean of all contributing individual distress indexes; and σ=standard deviation of these individual indexes. The individual index for distress type i (INDEX_i) is computed as follows:

$$\mathrm{INDEX}_i = 5 - D_i \tag{9}$$

where D_i=deduct value for distress type i, determined as a function of the extent and severity (low, medium, and high) of the distress. The D_i values for the ACP are shown in Table 3. Different pavement types have different deduct curves and tables. The rutting and IRI deduct values are determined on a continuous linear scale as illustrated in Fig. 2.

Pennsylvania DOT's OPI

Pennsylvania DOT measures pavement condition in terms of the OPI, a 0–100 index with 100 representing the best possible condition. For the ACP, the OPI is computed as follows (PennDOT 2008; Morian and Cumberledge 1997):

Table 2. Oregon DOT's OI Model Coefficients for ACP

Distress	Severity	Coefficient (a)	Exponent (b)	Maximum extent (M)
Rutting	Low	0.050	1.00	NA
	Medium	0.450	1.00	
	High	0.700	1.00	
Fatigue	Low	0.600	0.10	304.8 m (1,000 ft)
	Medium	0.800	0.10	
	High	1.000	0.10	
Longitudinal	Low	0.000	1.00	457.2 m (1,500 ft)
	Medium	0.000	1.00	
	High	0.000	1.00	
Transverse	Low	0.333	0.50	44 EA
	Medium	0.667	0.50	
	High	1.000	0.50	
Block crack	Low	0.333	0.50	557.4 m^2 (6,000 ft^2)
	Medium	0.667	0.40	
	High	1.000	0.30	
Patch/pothole	Low	0.550	0.10	557.4 m^2 (6,000 ft^2)
	Medium	0.800	0.10	
	High	1.000	0.10	
Raveling	Low	0.500	0.50	457.2 m (1,500 ft)
	Medium	0.750	0.50	
	High	1.000	0.50	
Bleeding	No	0.000	1.00	NA
	Yes	0.050	1.00	

Note: NA=not available.

Table 3. South Dakota DOT's SCI Deduct Values for ACP

Distress	Severity	Extent: Low	Medium	High	Extreme
Patching	Low	0.4	0.8	1.4	2.0
	Medium	0.8	1.7	3.1	5.0
	High	1.1	2.7	5.0	5.0
Fatigue cracking	Low	0.4	0.8	1.4	2.0
	Medium	0.8	1.7	3.1	5.0
	High	1.1	2.7	5.0	5.0
Block cracking	Low	0.7	1.2	2.0	NA
	Medium	0.8	1.6	3.0	NA
	High	0.9	2.2	5.0	NA
Transverse cracking	Low	0.1	0.2	0.5	NA
	Medium	0.2	0.6	1.5	NA
	High	1.0	2.2	5.0	NA

Note: NA=not available.

$$OPI_{ACP} = (0.15 \times FCI) + (0.125 \times TCI) + (0.10 \times MCI) + (0.10 \times EDI) + (0.05 \times BPI) + (0.05 \times RWI) + (0.175 \times RUT) + (0.25 \times RUF) \quad (10)$$

where the fatigue cracking index (FCI); transverse cracking index (TCI); miscellaneous cracking index (MCI); edge deterioration index (EDI); bituminous patching index (BPI); raveling/weathering index (RWI); and rut depth index (RUT) are individual indexes ($INDEX_i$) computed as follows:

$$INDEX_i = 100 - D_{high} - [(1 - D_{high}/100) \times D_{med}] - [(1 - D_{high}/100) \times (1 - D_{med}/100) \times D_{low}] \quad (11)$$

D_{high}, D_{med}, and D_{low} (deduct values for each $INDEX_i$) are computed as functions of extent and severity (low, medium, and high) of the distress using Eqs. (12)–(14), respectively

$$D_{high} = 20 \times (\text{extent})^{0.3495} \quad (12)$$

$$D_{med} = 10 \times (\text{extent})^{0.3495} \quad (13)$$

$$D_{low} = 5 \times (\text{extent})^{0.3495} \quad (14)$$

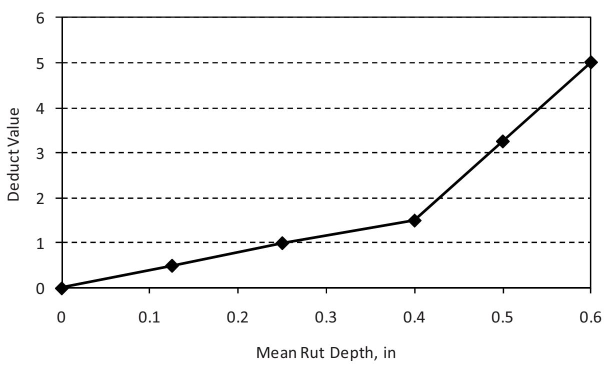
The roughness index (RUF) is computed as follows:

$$RUF = 100 - [(0.27 \times IRI) - 11] \quad (15)$$

where IRI=international roughness index.

Ohio DOT's PCR

Ohio DOT measures the pavement condition using the PCR, a 0–100 index with 100 representing no or minimal distress. The PCR is computed as follows (ODOT 2004):



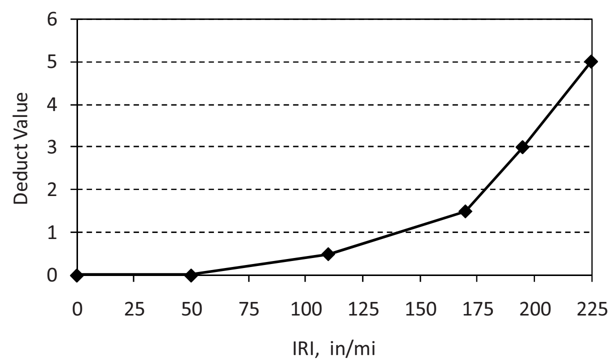


Fig. 2. SCI deduct values for rutting and IRI

Table 4. Ohio DOT's PCR Deduct Weights for ACP

Distress	Distress weight	Severity weight: Low	Medium	High	Extent weight: O	F	E
Raveling	10	0.3	0.6	1	0.5	0.8	1
Bleeding	5	0.8	0.8	1	0.6	0.9	1
Patching	5	0.3	0.6	1	0.6	0.8	1
Debonding	5	0.4	0.7	1	0.5	0.8	1
Crack sealing deficiency	5	1	1	1	0.5	0.8	1
Rutting	10	0.3	0.7	1	0.6	0.8	1
Potholes	10	0.4	0.8	1	0.5	0.8	1
Wheel track cracking	15	0.4	0.7	1	0.5	0.7	1
Block and transverse cracking	10	0.4	0.7	1	0.5	0.7	1
Longitudinal cracking	5	0.4	0.7	1	0.5	0.7	1
Edge cracking	10	0.4	0.7	1	0.5	0.7	1
Thermal cracking	10	0.4	0.7	1	0.5	0.7	1

Note: O=occasional; F=frequent; and E=extensive.

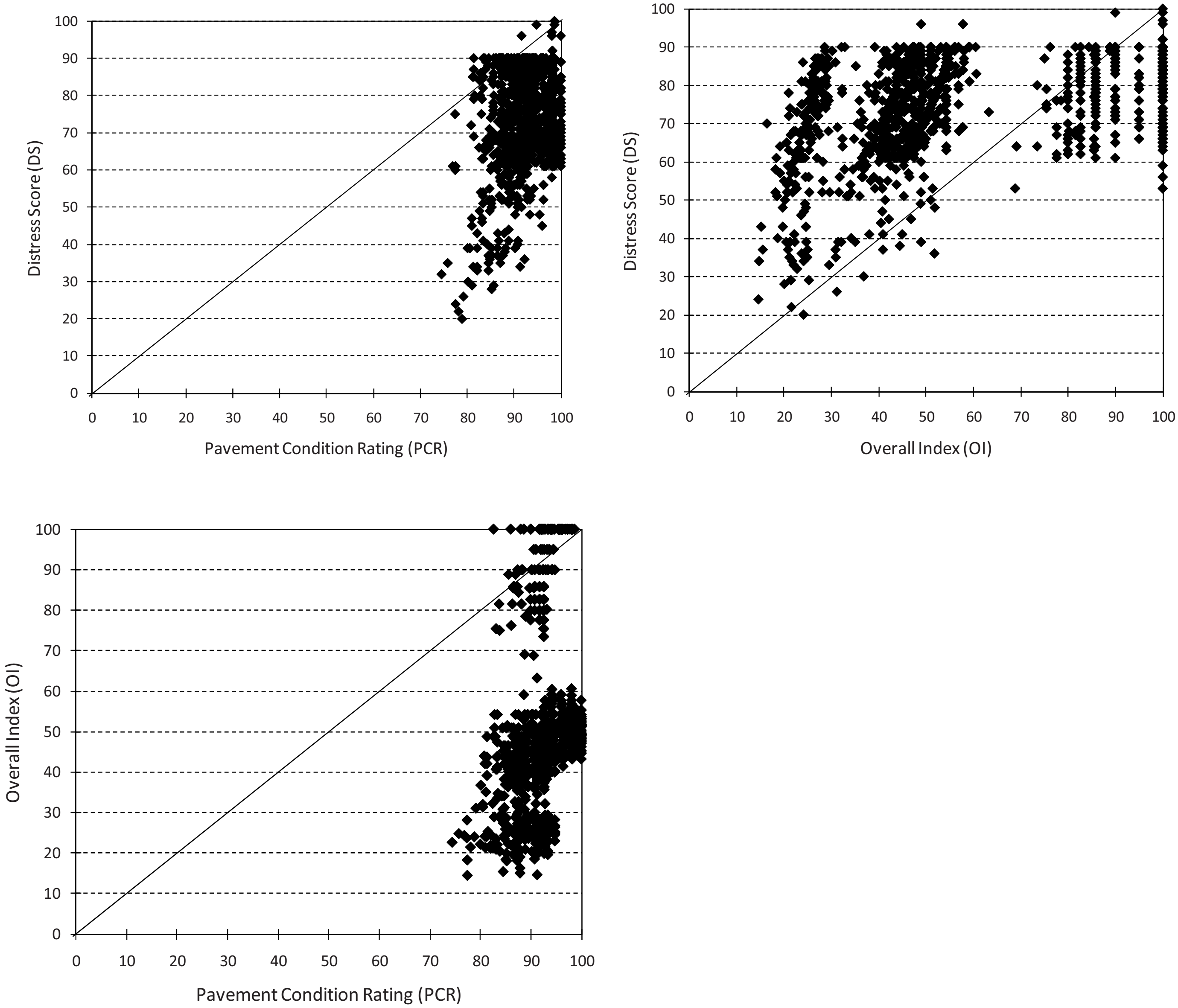


Fig. 3. Distress-based scores for IH pavement sections

$$\mathrm{PCR} = 100 - \sum_{i=1}^{n} \mathrm{deduct}_i \qquad (16)$$

where n=number of observable distresses; and deduct_i=(weight for distress i)×(weight for severity)×(weight for extent).

For each distress type, weights are defined for three levels of severity (low, medium, and high) and three levels of extent (occasional, frequent, and extensive). The distress, severity, and extent weights for the ACP are shown in Table 4. Different pavement types have different weight tables.

Discussion of Analysis and Results

A set of 9,642 roadway ACP sections [each is 804 m (0.5 mi)] from Texas were rated using the six condition indexes discussed earlier. Of these sections, 1,479 are located on interstate highways (IH); 2,949 are located on secondary farm-to-market (FM) roads; and 5,214 are located on other roads (Other). The CIs were computed for each pavement section using distress and ride quality data extracted from the PMIS database. The results were compared visually (using scatter plots) and statistically (using paired t-tests) as follows:

- Distress-based indexes:
- TxDOT's DS versus Ohio DOT's PCR;
- TxDOT's DS versus Oregon DOT's OI; and
- Ohio DOT's PCR versus Oregon DOT's OI.
- Distress- and roughness-based indexes:
- TxDOT's CS versus South Dakota DOT's SCI;
- TxDOT's CS versus Pennsylvania DOT's OPI; and
- South Dakota DOT's SCI versus Pennsylvania DOT's OPI.

Visual Comparisons (Scatter Plots)

Figs. 3 and 4 show the disagreement among the studied indexes in terms of the scatter and shift of scores around the equality line. While these plots are for interstate sections only, similar trends have been observed for noninterstate sections. For distress-based

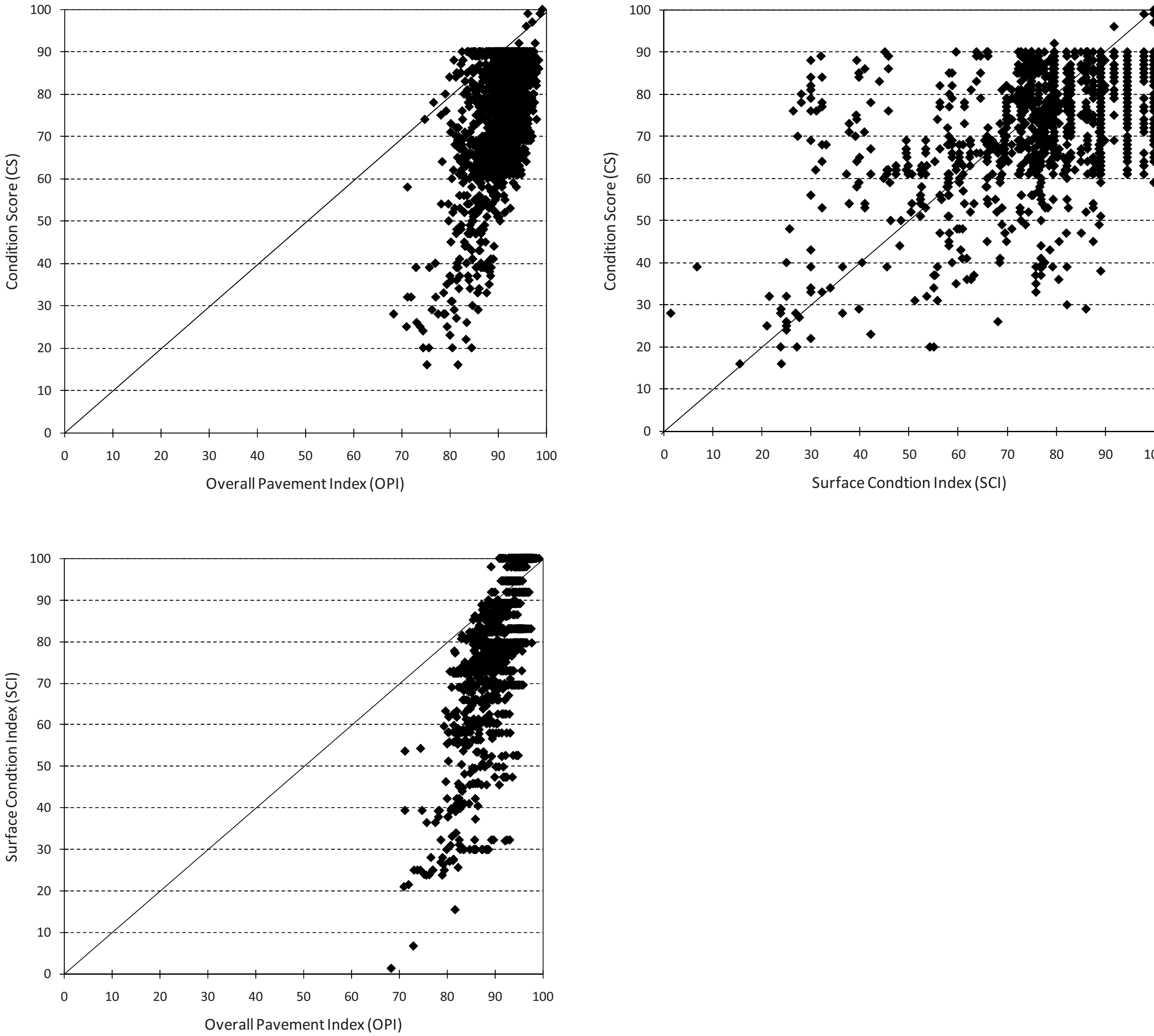


Fig. 4. Distress- and roughness-based indexes for IH pavement sections

indexes (Fig. 3), the PCR values are clearly higher than the DS and OI values. For example, the percentage of sections that received a score of 90 or more is 78% using the PCR; 28% using the OI; and 11% using the DS. The average score for all studied sections is 93 using the PCR; 76 using the DS; and 63 using the OI. Similar observations can be made for distress- and roughness-based indexes (Fig. 4), where the OPI values are clearly higher than the CS and SCI values. The percentage of sections that received a score of 90 or more is 61% using the OPI; 26% using the SCI; and 9% using the CS. The average score for all studied sections is 91 using the OPI; 79 using the SCI; and 75 using the CS.

Statistical Comparisons (Paired t-Test)

A paired t-test was conducted to determine whether there is a significant difference between the means of the studied indexes. The paired t-test is used to test the null hypothesis that the mean difference between paired observations is zero, at a specified significance level. Thus, the null hypothesis for any two indexes is expressed as $\mu_1 - \mu_2 = 0$, where μ_1=mean of the first index; and μ_2=mean of the second index. A significance level of 5% (i.e., 95% confidence) was used in this analysis. If the p-value is less than the significance level (i.e., p-value <0.05), we conclude that there is a significant difference between the two means and that there is evidence to reject the null hypothesis.

The results of the t-tests are presented in Tables 5 and 6. The null hypothesis is rejected for 17 of the 18 comparisons. The only case where there was no sufficient evidence to reject the null hypothesis was when the DS and SCI were compared for FM roads.

Discussion of Results

Generally, the disagreement among the indexes can be explained by the differences in the distress types and severity levels consid-

Table 5. Paired *t*-Test Results for Distress-Based Indexes ($\alpha = 0.05$)

Comparison	Roadway type	DF[a]	*t*-statistic	*p*-value	Reject null hypothesis?
DS versus PCR	IH	1,479	−55.33	<0.0001	Yes
	FM	2,949	−82.05	<0.0001	Yes
	Other	5,214	−103.9	<0.0001	Yes
DS versus OI	IH	1,479	21.15	<0.0001	Yes
	FM	2,949	64.1	<0.0001	Yes
	Other	5,214	73.22	<0.0001	Yes
PCR versus OI	IH	1,479	44.89	<0.0001	Yes
	FM	2,949	104.51	<0.0001	Yes
	Other	5,214	125.33	<0.0001	Yes

[a]Degree of freedom (DF) = sample size − 1.

ered, deduct values, weight factors, and mathematical forms of the indexes. These differences can be attributed to variations in agency policies, climatic conditions, and local material types (e.g., local aggregate types). The specific factors that contribute to this disagreement include the following:

- The indexes differ in classifying patching as a distress. The PCR does not consider large patched areas (>15 yd^2) as a distress; whereas other indexes do.
- The indexes differ in considering raveling and bleeding. These distress types are major contributors to the PCR, OI, and OPI score deductions; but they do not affect the SCI, CS, and DS.
- The DS and CS do not consider distress severity (except for rutting). Thus, they are impacted by the presence of distresses more severely than other indexes that account for the severity of the distress.
- The index becomes more lenient as it considers more distress types and severity levels. The PCR (which considers 36 combinations of distress types and severity levels) is more lenient than OI (which considers 23 combinations of distress types and severity levels). The OI, on the other hand, is more lenient than the DS (which considers eight combinations of distress types and severity levels). A similar observation can be made for distress- and roughness-based indexes (OPI, SCI, and CS).
- The indexes differ in measuring rutting. For example, the OI uses the average rut depth over the pavement section; whereas the DS uses the percent area with shallow, deep, and severe rutting. Thus, the OI is less sensitive to rutting than the DS. Also, the SCI is very sensitive to rut depth. If the rut depth is greater than 0.5 in., the rutting index of the SCI is reduced to zero (regardless of the length of the rut).
- Only the SCI considers the standard deviation of the contributing individual distress indexes. This can cause significant extra deductions from the SCI when the variability among the individual indexes is high.
- Only the CS considers the traffic volume. The ride utility factor of the CS is a function of both the IRI and the annual average daily traffic (AADT).
- Indexes that consider roughness in an additive manner are less impacted by excessive roughness than ones that consider roughness in a multiplicative manner. For example, the maximum loss in the OPI due to roughness is 25 points; whereas there is no limit on the roughness impact on the CS (even if the section has no or minimal distresses).

Summary and Conclusions

Pavement condition indexes are aggregated measures of the structural and material integrity of pavements. Because these indexes appear to be similar (essentially a 0–100 scale, with 100 indicating ideal condition), it can be tempting to use them for comparing the performance of pavement networks in different states or jurisdictions within a state. To ascertain the level of agreement among these indexes, six pavement condition indexes from five DOTs in the United States were discussed and compared using distress and ride quality data obtained from the PMIS of the TxDOT. The results of this study show that significant differences exist among seemingly similar pavement condition indexes. Generally, the disagreement among these indexes can be attributed to differences in

Table 6. Paired *t*-Test Results for Distress- and Roughness-Based Indexes ($\alpha = 0.05$)

Comparison	Roadway type	DF[a]	*t*-statistic	*p*-value	Reject null hypothesis?
CS versus OPI	IH	1,478	−50.83	<0.0001	Yes
	FM	2,945	−74.89	<0.0001	Yes
	Other	5,208	−100.4	<0.0001	Yes
CS versus SCI	IH	1,478	−10.93	<0.0001	Yes
	FM	2,945	1.22	0.2218	No
	Other	5,208	−24.45	<0.0001	Yes
OPI versus SCI	IH	1,478	31.86	<0.0001	Yes
	FM	2,945	70.72	<0.0001	Yes
	Other	5,208	75.39	<0.0001	Yes

[a]Degree of freedom (DF) = sample size − 1.

the distress types considered, weighting factors, and the mathematical forms of the indexes.

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