Civil Engineering Infrastructures Journal, 52(1): 101 – 114, June 2019
Print ISSN: 2322-2093; Online ISSN: 2423-6691
DOI: 10.22059/ceij.2019.254376.1472

Considering a New Sample Unit Definition for Pavement Condition Index

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Received: 11 Mar. 2018; Revised: 03 Oct. 2018; Accepted: 03 Oct. 2018

ABSTRACT: One of the main components of pavement management system (PMS) is pavement evaluation. Several indices have been defined for the evaluation of existing pavement. The Pavement Condition Index (PCI) is a common index used for pavement evaluation. In order to calculate PCI, a significant volume of condition data -based on distress surveying- is required. The objective of this research is to reduce the volume of required data by introducing a new sample unit definition. For this reason, "wheel path sample units" were defined and used instead of the standard sample unit (according to ASTM D6433). The analysis of results showed that not only there is no significant difference between standard and wheel path PCIs, but also there is a good correlation between standard PCI and both wheel path PCI (PCI_w) and outside wheel path PCI (PCI_{ow}), corresponding to $R^2 = 0.929$ and $R^2 = 0.874$, respectively. Also, PCI_{ow} saves a great amount of time and energy.

Keywords: Pavement Evaluation, PCI, Standard Sample Unit, Wheel Path Sample Unit.

INTRODUCTION

Highway infrastructures, especially pavements, are the largest, most valuable, and most visible assets (Shah et al., 2017) of a country. It will be in favor of government and economy to preserve the pavement for a longer time (Taherkhani, 2016a). So, the maintenance and rehabilitation of pavements to the desired level of serviceability is a challenging problem faced by pavement engineers (Shah et al., 2013). On the other hand, pavement construction, maintenance, and rehabilitation costs are rising dramatically (Taherkhani, 2016b; Babashamsi et al., 2016). Therefore, it is essential for highway agencies to utilize proper schedules to perform the mentioned work, leading to the appearance of pavement management systems (PMSs).

PMS is a decision supporting system to efficiently manage large highway networks (Suh et al., 2017). A PMS is designed to help managers and pavement engineers and provide useful data for analysis. Thus, highway managers can make consistent, cost-effective, and defensible decisions related to the preservation of a pavement network (AASHTO, 1990; Zimmerman and Peshkin, 2004). Foremost among these, PMS helps select cost-effective alternatives (Hudson et al., 1979). Within the PMS, the evaluation of pavement performance is a basic component (Shah et al., 2013). Condition data are used in the evaluation process. They form a critical component of PMSs (Pierce et al., 2013) and

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can be used to identify current maintenance and rehabilitation needs, predict future needs, and assess the overall impact on the network. Therefore, the type of condition data required and the level of details depend on the agency and pavement management process. Condition data are collected using either manual or automated data collection methods. With either method, distress data are estimated or measured (Wolters et al., 2011). In order to assess the current condition of pavement, non-destructive testing methods and various indices are employed (Hu et al., 2016). The Pavement Condition Index (PCI), Pavement Condition Rating (PCR), International Roughness Index (IRI), Pavement Surface Evaluation and Rating (PASER), and Pavement Serviceability Index (PSI) are some of indices applied in the evaluation of pavement condition (Papagiannakis et al., 2009).

The Pavement Condition Index (PCI) is the most common index in PMSs. PCI is a numerical index developed by the U.S. Army Corps of Engineers, adopted by the American Public Works Association and ASTM International, and documented in ASTM D6433 Standard Test Method for Roads and Parking Lots Pavement Condition Index. PCI is defined as ranging from 0 and 100, where a PCI value of 0 corresponds to a deteriorate pavement, while a PCI value of 100 shows an excellent pavement (Arhin et al., 2015).

There are many advantages to the PCI procedure. It is a standardized procedure which is repeatable for evaluating pavement condition. Several models based on PCI were developed in PMSs. Detailed distress information collection and using either manual or automated data collection methods are the other advantages of PCI methods. The PCI procedure is also non-destructive and requires only basic and inexpensive equipment. Furthermore, PCI covers the majority of damages occurring in the pavement.

A high safety risk, time consumption in the manual method, and the need for modern and costly technology in the automated method (image processing method) are some limitations of the PCI procedure. There are also some common misapplications of the procedure that have led to a number of validity questions for agencies and individuals users (Broten and Sombre, 2001). Further explanation for each index are presented in Table 1.

In this study, a new method was defined for choosing the sample unit position. Since the need for rapidly and cost-effectively evaluating the present condition of pavement infrastructure is a critical issue (Ceylan et al., 2012), the present study proposed wheel paths (both right and left) and outside (only right) wheel path instead of the whole width of pavement as the width of the sample unit. However, the area of standard and proposed sample unit must be in accordance with ASTM D6433-07 (225±90 m^2).

The proposed method can constitute a useful method for fast surveys, to be offered in place of standard surveys, which usually are slower. For example assume a road with 3.65 m width. If the standard sample unit were used, the number of sample unit for unit length of road (1 km) will be in the range of 12-27; while in the new method the number of sample unit decrease to 5-11 for wheel paths and 3-6 for only outside wheel path. So, the outside (right) wheel path survey allows inspectors to quickly collect the data in a convenient and safe situation. Also, it is clear that decreasing of the sample unit width leads to a precise survey, reduces the difficulty of data collection, and improves the accuracy of automated surveying methods. Furthermore, the proposed sample units, especially the outside wheel path sample unit, facilitated the use of PCI as an index in PMSs at the network level.

Table 1. Pavement surveying index

Name of index	Symbol	Rating method	Limitation	References
Pavement condition rating	PCR	Visual inspection of pavement distress	Possible negative values where multiple distresses were present; better fit with the age of the pavement	Saraf (1998); Papagiannakis et al. (2009)
International roughness index	IRI	A computer-based virtual response-type system	For the roads with irregular forms of unevenness, the IRI index cannot be used	Múčka (2013); Kropáč and Múčka (2005)
Pavement surface evaluation and rating	PASER	Visual inspection to evaluate pavement surface conditions	Ratings cannot be disaggregated into component distress data; the metric cannot be used in mechanistic-empirical transportation asset management programs	Walker et al. (2013); Dennis et al. (2014)
Pavement serviceability index	PSI	Visual observation	Correlate highly with surface roughness and, to a lesser extent with rutting, cracking and patching	Prozzi and Madanat (2002)

RESEARCH METHODOLOGY

Definition of Sample Units

Based on the above discussion, three kinds of sample unit were used in this research study. Figure 1 illustrates the width of the standard sample unit and wheel path on a lane. Wheel paths are part of the pavement surface over which the wheel of vehicles pass (Luo et al., 2012). The wheel paths of the pavement were defined regarding the method introduced by AASHTO (Figure 2) (AASHTO, 2001). As illustrated in Figure 2, there were two wheel paths on each lane, named the "inside wheel path" and the "outside wheel path". The wheel path near the lateral lane was called the "inside wheel path" and the other one, beside the road right shoulder, was called the "outside wheel path" (AASHTO, 2001; Miller and William, 2003).

As most of distresses related to traffic loading and by surveying of distresses on the wheel path some of those located outside the wheel paths will be missed; but all the distresses related to traffic loading will be surveyed. However, the PCIw/PCIow are not possibly as same as PCI but the different is not significant. So it justified the surveying of wheel paths.

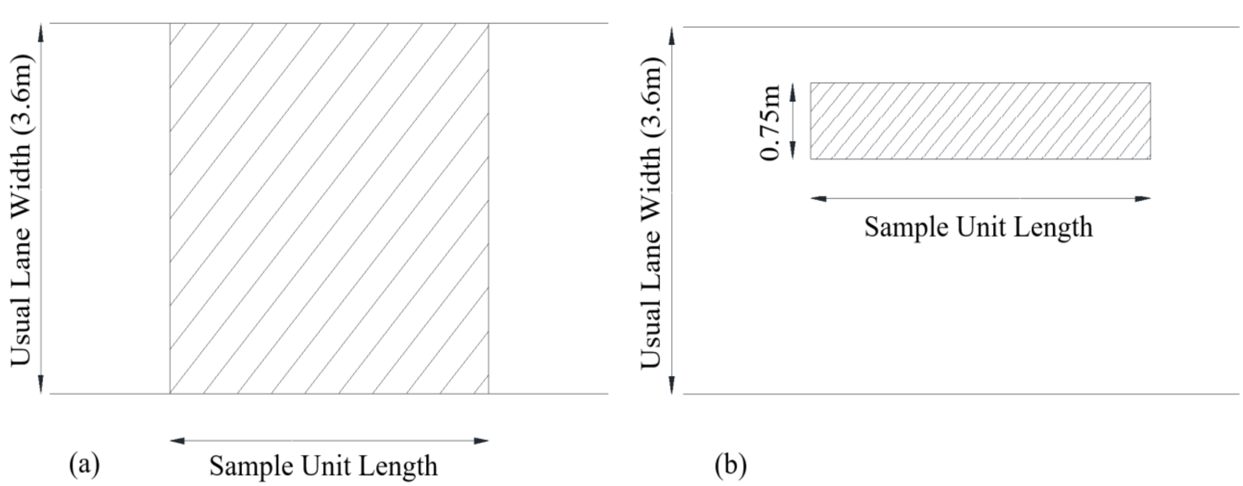


Fig. 1. Width of sample units: a) Standard sample unit, b) Wheel path sample unit

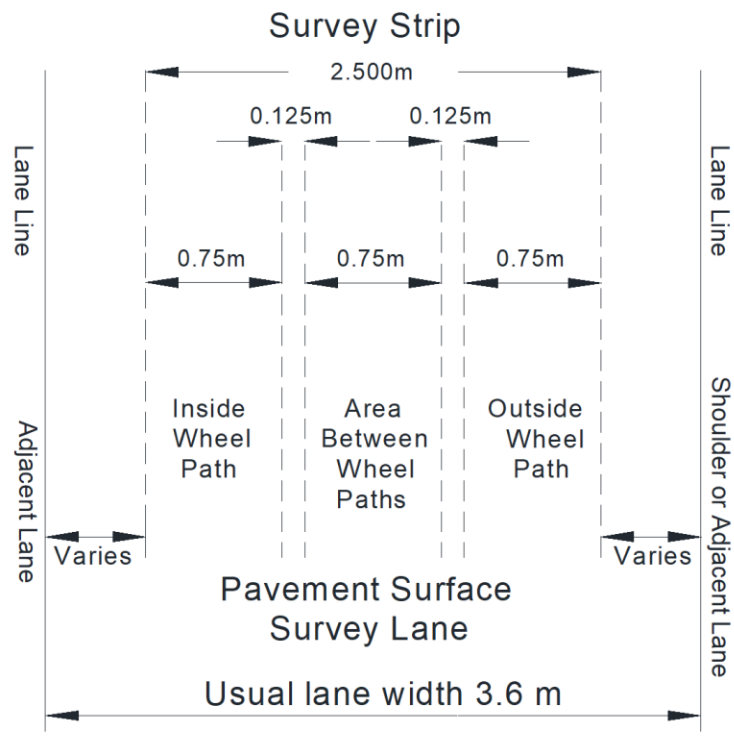


Fig. 2. Wheel paths on the road lane (AASHTO, 2001)

Methodology Steps

This study was conducted in the following two steps:

1. Pre-Analysis Step: This step showed the capability of PCI_w/ PCI_{ow} as the representative of the standard PCI at the sample units. Twenty sample unites in Zanjan, Iran, were surveyed. The standard PCI, PCI_w, and PCI_{ow} were calculated for all sample units. The length of the surveyed sample unites was 20 m. First, the distribution of data series was investigated. Then, in order to choose a proper statistical test, F-test was run. Based on F-test results, the suitable t-test was employed to investigate the difference among data series.

2. Modeling Step: The second step followed a statistical approach to correlate the PCI calculated based on the whole pavement surface data (assumed as the standard PCI) with the PCI calculated from the total wheel path data (PCI_w) and only outside (right) wheel path data (PCI_{ow}). Using PCI_w/PCI_{ow} instead of the standard PCI considerably decreases the volume of data helps save time and energy in real applications. Furthermore, the utilization of this approach is more efficient in fast digital surveys. If there is no digital survey equipment available, gathering outside wheel path data (PCI_{ow}) from the right shoulder or the roadside is highly safe, fast, and easy. As a result, a two-lane road 4000 m in length and 5.5 m in width (2.75 m per direction) which was divided into two distinct sections by 0-2,000 m and 2,000-4,000 m was considered. Each section was divided into 100 sample units. Then, 200 sample unit data were surveyed while 10% of data were discarded for cross-validation. Also, the derived equations were controlled for other road types, including freeways and major roads.

Figure 3 shows the framework of this study. Also, for all the statistical analysis SPSS (Statistical Package for the Social Sciences) software version 16.0 were used.

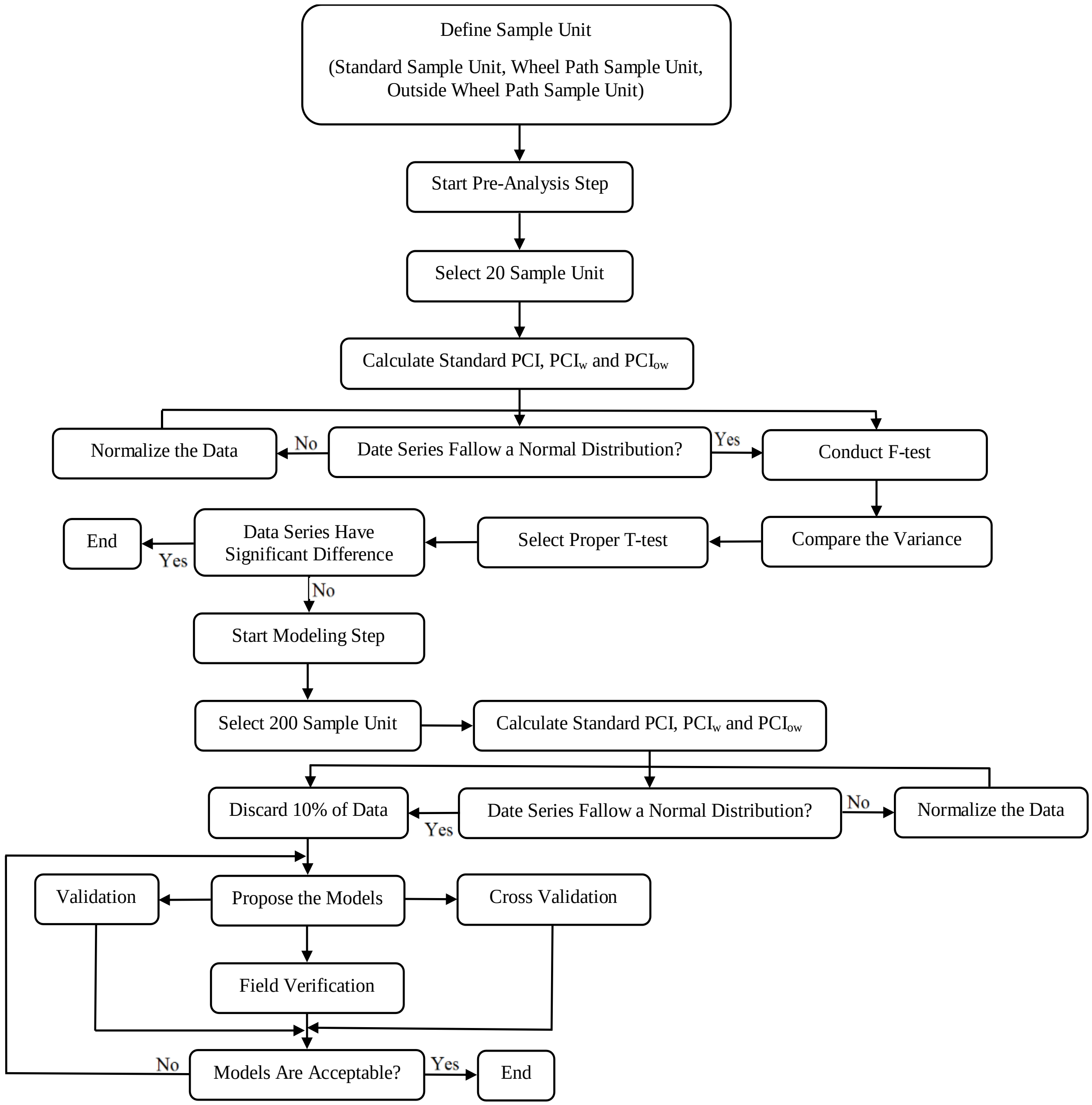
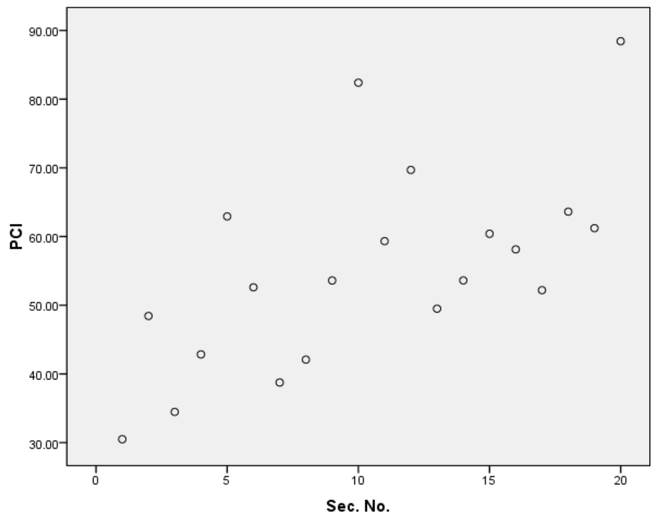


Fig. 3. Research study framework

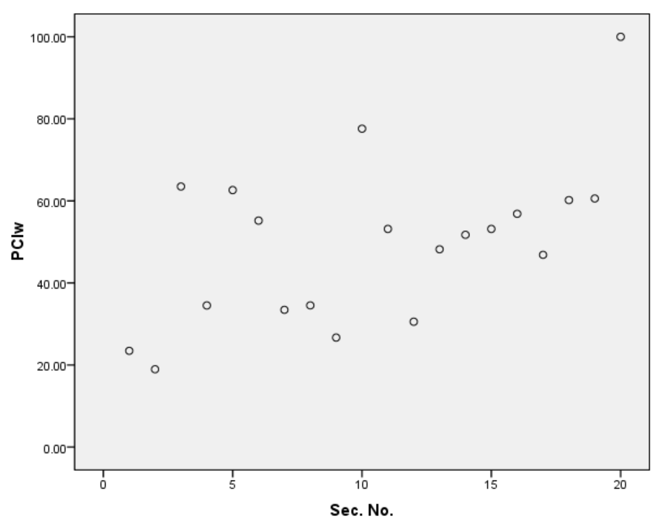
Data Collection

The ASTM-D6433-07 standard was adopted for the data collection process. Based on ASTM-D6433-07, 19 types of distress in three levels of low, medium, and high should be surveyed (ASTM D6433-07, 2007). On surveyed sections, pavement distresses included alligator cracking, bleeding, block cracking, bumps and sags, edge cracking, shoulder drop off, long and trans cracking, patching, polished aggregate, potholes, rutting, and weathering.

The values of PCI, PCI_w, and PCI_{ow} for the purpose of pre-analysis and modelling are demonstrated in Figures 4 and 5, respectively. The same procedure used in PCI data collection was applied to gather the PCI_w and PCI_{ow} data.



(a)



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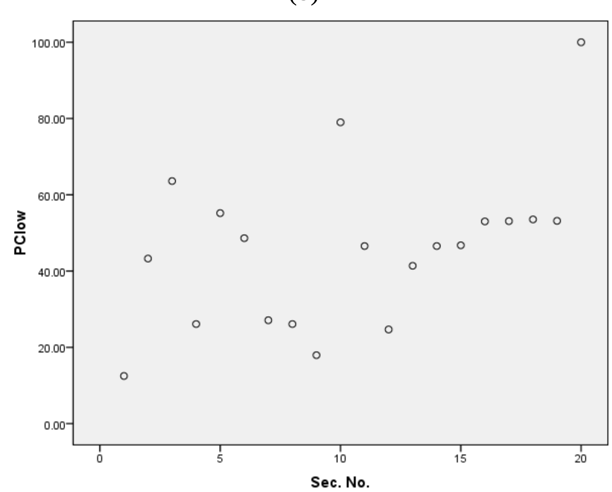
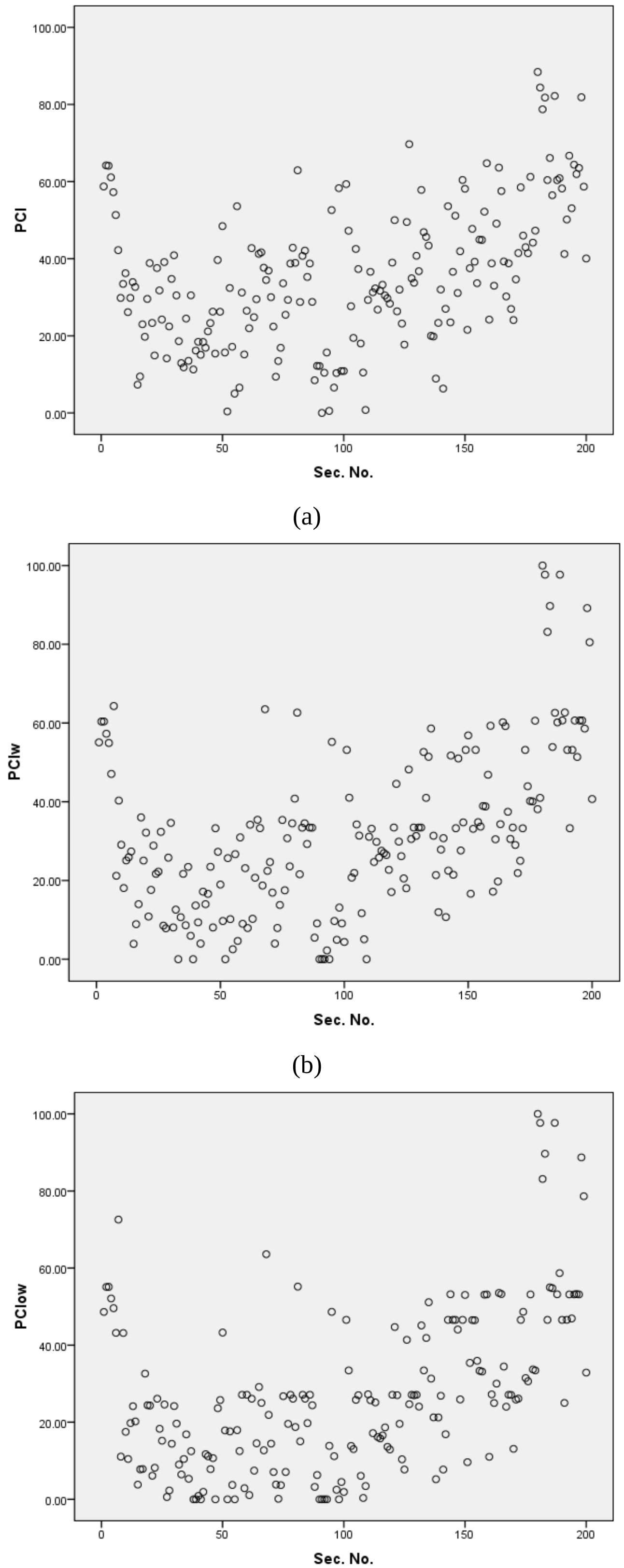


(c)

Fig. 4. Value of: a) PCI, b) PCI_w, and c) PCI_{ow} (comparison)



(a)

(b)

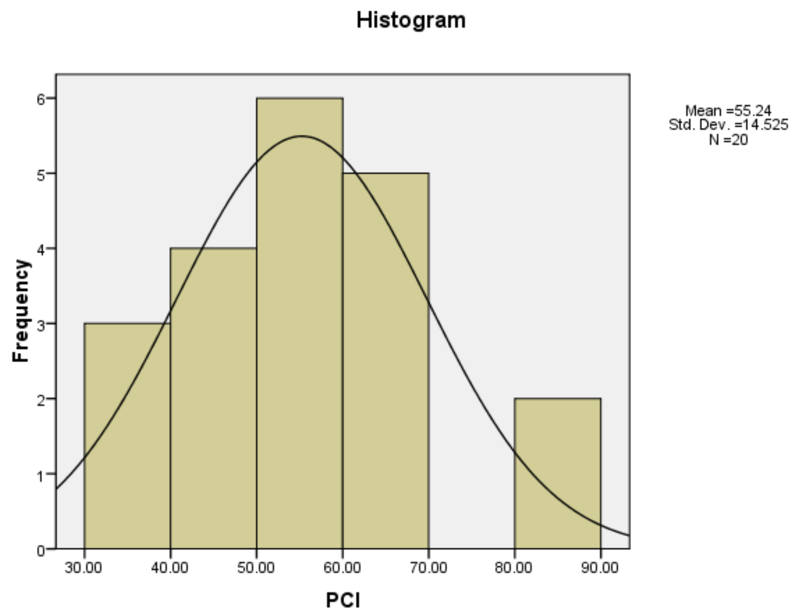
(c)

Fig. 5. Value of: a) PCI, b) PCI_w, and c) PCI_{ow} (modelling)

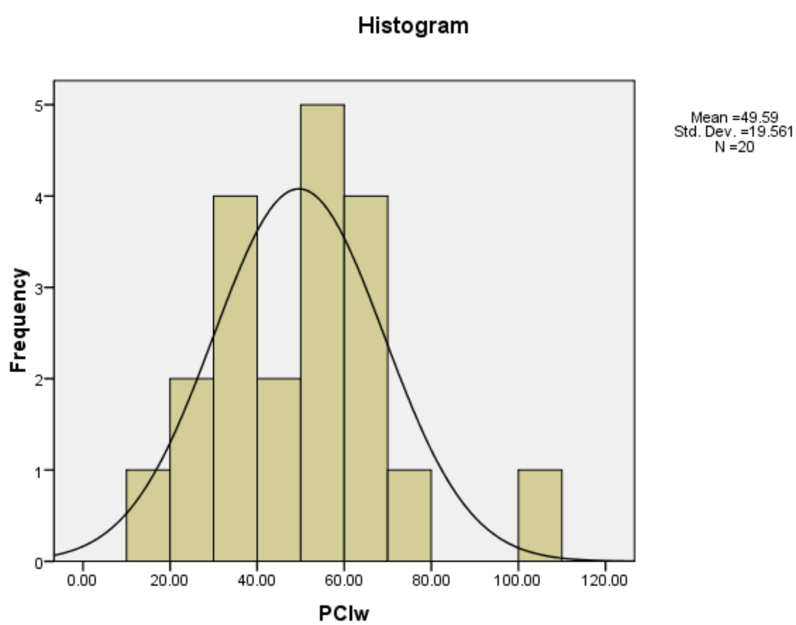
RESULTS AND DISCUSSION

Pre-Analysis

Before modelling, the PCI data were statistically compared with PCI_w and PCI_{ow} data. This comparison showed the ability of PCI_w/PCI_{ow} in predicting PCI. As shown on Figure 6, the distribution of data was normal. According to Table 2 (F > F Critical One-Tail), the variances of data sets were unequal. Thus, a t-teat assuming unequal variances was run to examine the difference among data series. Based on the results of t-test illustrated in Table 3, there was no significant difference among data series. Therefore, PCI_w/PCI_{ow} has sufficient capability to be representative of the standard PCI.



(a)



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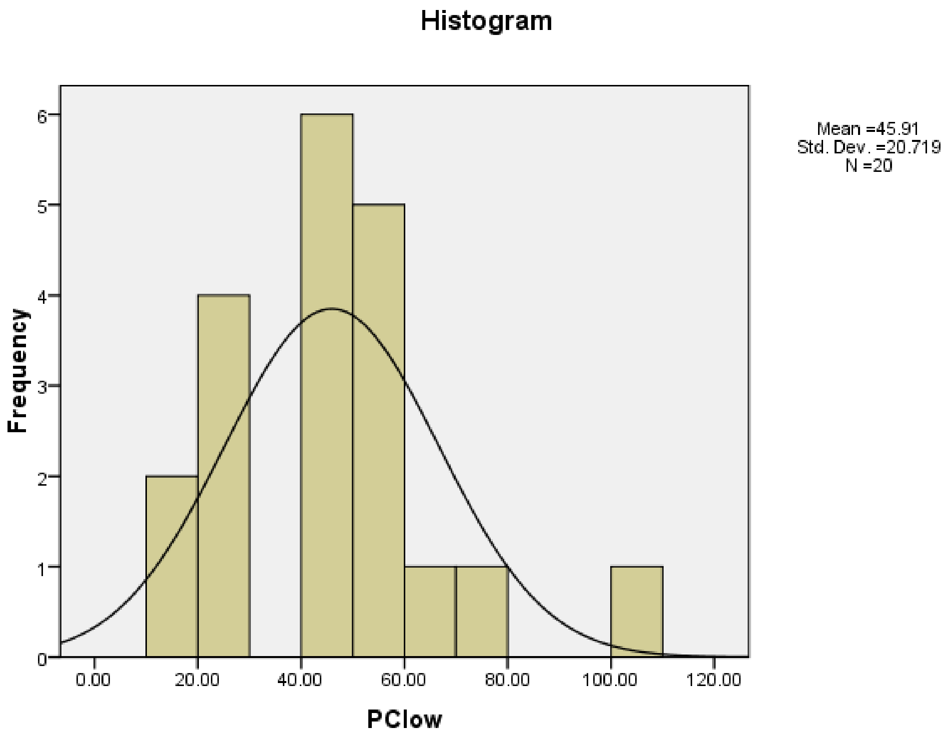


(c)

Fig. 6. Histogram of distribution of: a) PCI, b) PCI_w, and c) PCI_{ow}

Table 2. Results of F-test

F- test	PCI and PCI_w	PCI and PCI_{ow}
Observations	20	20
d_f	19	19
F	0.5513675	0.491441724
P(F <= f) one-tail	0.101785624	0.065182853
F Critical one-tail	0.461201089	0.461201089

Table 3. Results of t-test

t- test	PCI and PCI_w	PCI and PCI_{ow}
Observations	20	20
Hypothesized mean difference	0	0
df	35	34
t stat	1.036445308	1.648284216
P(T ≤ t) one-tail	0.153551258	0.054253058
t critical one-tail	1.689572458	1.690924255
P(T ≤ f) two-tail	0.307102516	0.108506116
t critical two-tail	2.030107928	2.032244509

Modelling

For modelling purpose, it is essential to know whether the data are following a normal distribution. Thus, the distribution of the dependent variable was checked in the form of histograms (Figure 7). It is clear that the distribution of data sufficiently followed the normal distribution. Also, according to Figure 7, the standard deviation was very close to the unit and the mean value was approximately negligible as the main characteristics of a normal distribution.

One-hundred eighty ordered pairs of collected data (PCI_w, PCI) were employed to regression. The remaining 20 pairs were used to validate the derived equation. Although different types of regression were applied to derive the model, the linear regression with $R^2 = 0.929$ was selected. The linear regression is presented in Eq. (1) and the fitness of the model to the data is shown in Figure 8.

$$PCI = 7.609 + 0.878 \times PCI_w\,, \quad 0 \le PCI \le 100, 0 \le PCI_w \le 100 \tag{1}$$

A similar process was followed to derive the linear regression of PCI and PCI_{ow} with $R^2 = 0.874$ as Eq. (2).

$$PCI = 13.186 + 0.829 \times PCI_{ow}\,, \quad 0 \le PCI \le 100, 0 \le PCI_{ow} \le 100 \tag{2}$$

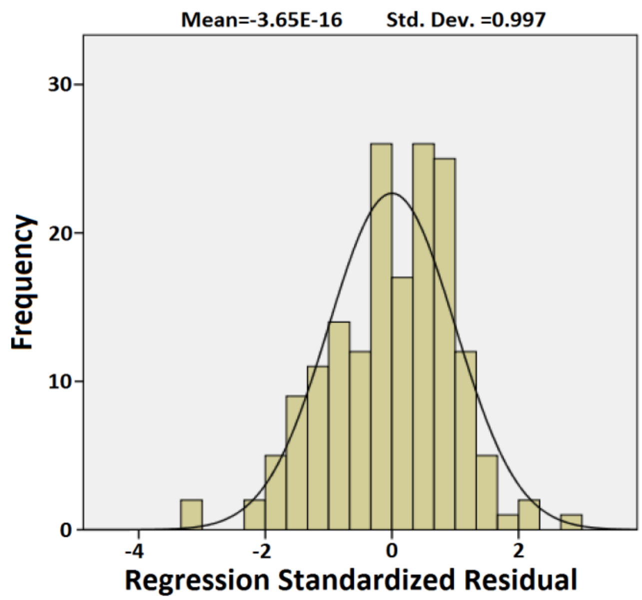


Fig. 7. Histogram of distribution of the dependent variable (PCI)

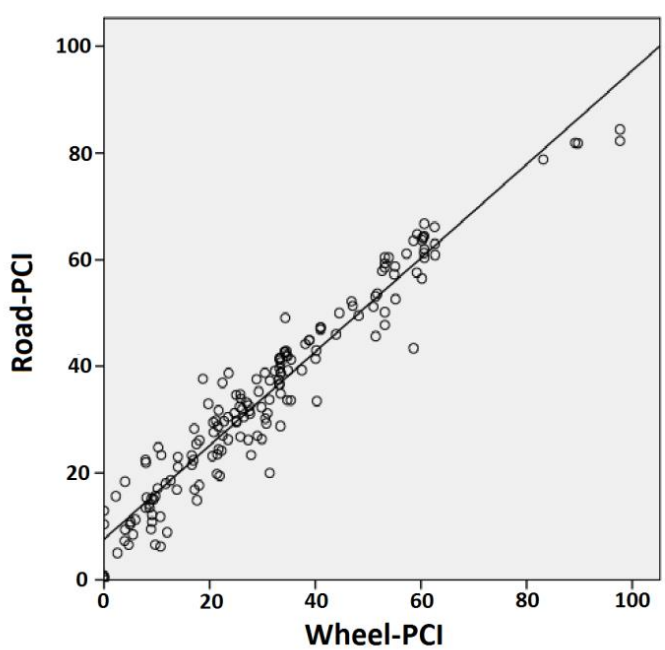


Fig. 8. Linear regression of PCI and PCI_w

Validation

In order to validate the equations, the Durbin-Watson test has been employed and 1.420 and 1.417 were obtained for the derived regression between (PCI, PCI_w) and (PCI, PCI_{ow}), respectively, which were in the standard band of 1.5 to 2.5. Therefore, the residuals of the regression were independent. Also, another statistical value was applied for the evaluation of regressions as shown in Tables 4 and 5, respectively.

Furthermore, cross-validation was employed to validate Equation 1. Therefore, the 20 pairs of (PCI, PCI_w) data which were discard in model predication process were utilized. The result of cross-validation in Figure 9 shows the value of R^2 = 0.969 between the real and formula PCI.

Field Verification

To verify Eq. (1) on other roads, the distress was surveyed on three roads (with different class, traffic, pavement condition, etc.) for 60 sections. Afterwards, the standard PCI and PCI_w were calculated. The information on the new surveyed roads are given in Table 6. Then, standard PCI was calculated by Eq. (1) for the considered sections. Finally, the real and formula PCI were compared (Figures 10-A to 10-D). The R^2 value for Figures 10-A to 10-D are presented in Table 6. These results verify the sufficiency of the correlated equation.

Table 4. Model summary of regression between PCI and PCI_w

Model	**R**	**R^2**	**Adjusted R^2**	**Standard error**	**Durbin-Watson**
Value	0.964	0.929	0.928	4.938	1.420

Table 5. Model summary of regression between PCI and PCI_{ow}

Model	**R**	**R^2**	**Adjusted R^2**	**Standard error**	**Durbin-Watson**
Value	0.935	0.874	0.873	6.500	1.417

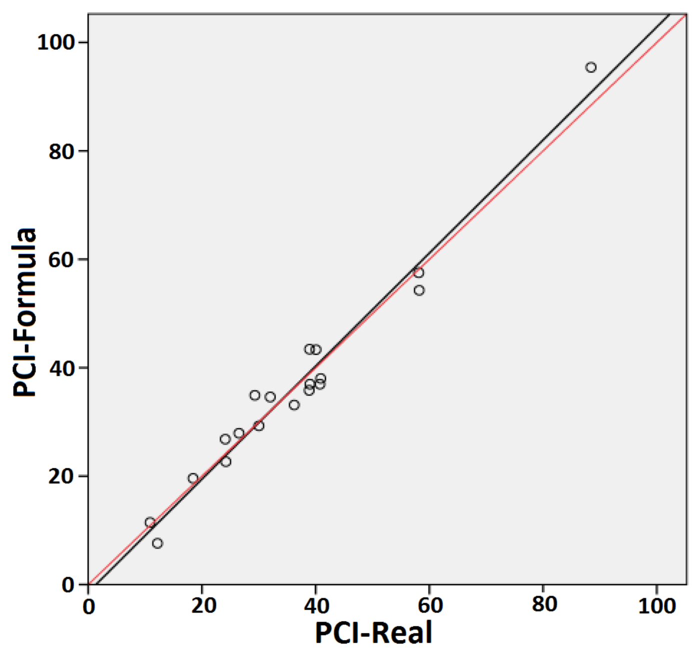
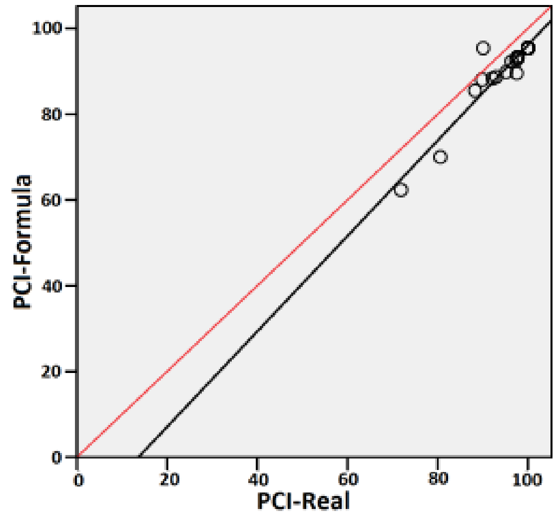
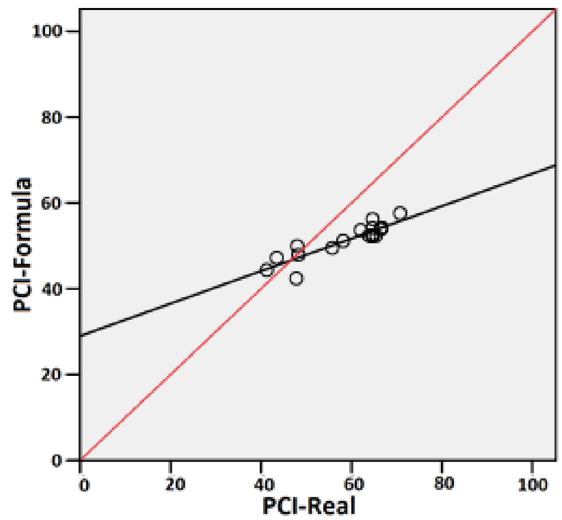


Fig. 9. Linear correlation of the PCI of 20 samples and their corresponding values calculated from Eq. (1); Red line: y = x, black line: correlation line



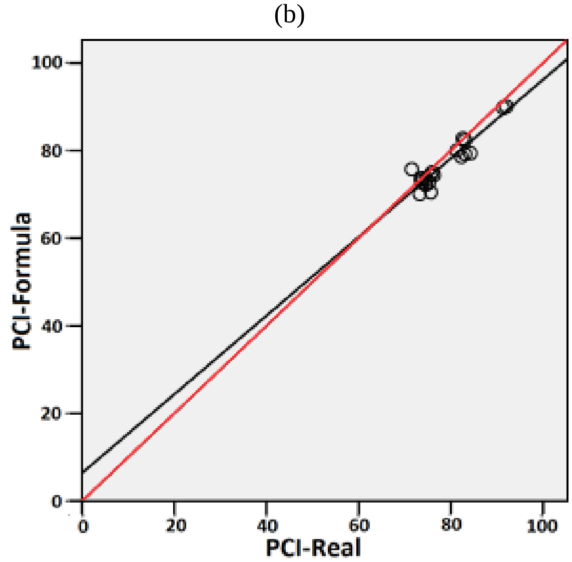
PCI-Formula
PCI-Real
0
20
40
60
80
100

(a)



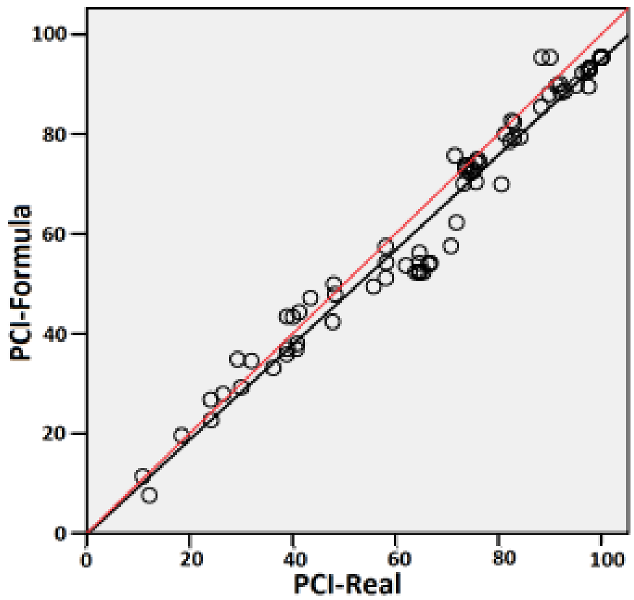
PCI-Formula
PCI-Real
0
20
40
60
80
100

(b)



PCI-Formula
PCI-Real
0
20
40
60
80
100

(c)



(d)

Fig. 10. Linear correlation of the PCI of 20 samples and their corresponding values calculated from Eq. (1); red line: y = x, black line: correlation line: a) Major road-a, b) Major road-b, c) Freeway, d) all roads

Table 6. Characteristics of the evaluated samples

No.	Highway classification	Sample width (m)	Number of sample	R^2 of linear regression (Figure 10)
A	Major road-a	7.1	20	0.882
B	Major road-b	8.1	20	0.799
C	Freeway	9.4	20	0.880
D	All of above classes	-	60	0.959

CONCLUSIONS

Based on the above discussion, the following concluding remarks can be inferred:

1. The results of pre-analysis showed that PCI_w and PCI_{ow} could be the representative of sample unit standard PCI.
2. The comparison of standard PCI with PCI_w and PCI_{ow} indicated two linear regression equations with $R^2 = 0.929$ and $R^2 = 0.874$, respectively.
3. It is clear that the proposed method highly saves energy and time in field.
4. By evaluating pavements using PCI_w and PCI_{ow}, the volume of required data is considerably reduced.
5. When data surveying is done manually in the proposed method, the safety of workers significantly increases.
6. At network-level PMS programs, PCI_w/PCI_{ow} is a more accessible index than the standard PCI.

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