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Development of a flexible pavement condition index for urban road network

Desenvolvimento de um índice de condição de pavimento flexível para rede de via urbana

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Recebido:
11 de fevereiro de 2021
Aceito para publicação:
26 de maio de 2021
Publicado:
19 de julho de 2022
Editor de área:
Jorge Barbosa Soares

Keywords:
Urban pavement condition index.
Distresses.
Serviceability.

Palavras-chave:
Índice de condição de pavimentos urbanos.
Defeitos.
Serventia.

DOI:10.14295/transportes.v30i2.2553

ABSTRACT
In the urban pavement management, it is essential to develop urban pavement condition indexes to support Municipal Secretariat for Infrastructure on decisions making in relation to maintenance and rehabilitation (M&R). The aim was to develop an urban pavement condition index (UPCI) for flexible pavements and perform a comparative analysis with some pavement condition indexes (PCI). The work method followed such steps: definition of sampling size; formation of rating panel and training; data collection about present serviceability rating (PSR) and flexible pavement distress; development of an UPCI; and, comparative analysis with some PCI. Multilinear regression modeling based on distresses and PSR carried out the UPCI, in accordance with some statistical assumptions such as homoscedasticity, serial correlation, multicollinearity and normality tests. The PCI chosen carried out variability between them and the PSR, which was statistically analyzed by errors and correlation tests. Lastly, the proposition of an urban pavement condition index for flexible pavement allows a better M&R planning, budget distribution and benefits to the population, because well-kept pavements promote comfort, travel time reduction and safety to the users.

RESUMO
Na gerência de pavimentos urbanos é primordial desenvolver índices de condição de pavimentos para dar suporte à Secretaria Municipal de Infraestrutura durante às tomadas de decisão sobre manutenção e reabilitação (M&R). O objetivo foi desenvolver um índice de condição de pavimentos urbanos (ICPU) para pavimentos flexíveis e realizar uma análise comparativa com vários índices de condição de pavimentos (ICP). O método de trabalho consistiu em: definição do tamanho da amostra; criação de um grupo para avaliação e treinamento; coleta dados sobre o Valor de Serventia Atual (VSA) e defeitos dos pavimentos flexíveis; desenvolvimento de um ICPU; e, análise comparativa com vários ICP. O ICPU foi obtido por regressão linear múltipla com os defeitos e o VSA, em conformidade com várias análises estatísticas (testes de homoscedasticdade, correlação serial, multicolinearidade e normalidade). Os ICPs escolhidos resultaram em variabialidade entre eles e o VSA, que foi estatisticamente analisada por testes de erros e de correlação. Por fim, o ICPU proposto pode permitir melhor planejamento de M&R, distribuição de recursos e pavimentos bem mantidos, com conforto, redução do tempo de viagem e segurança.

1. INTRODUCTION

One of the main components in urban infrastructure is the road network, since it provides economic development, increases life quality and urban mobility. Despite its importance, public administrators are still careless in carrying out suitable preventive maintenance and lifespan rehabilitation to the urban roads, through an urban pavement management system (UPMS).

Municipal Secretariat for Infrastructure manages UPMS utilizing pavements evaluation and intervention prioritization, taking account local conditions and available resources. Pavement management makes possible to plan maintenance and rehabilitation (M&R), in which the performance of road network covers not only repair of its immediate pathological manifestation, but also a prevention work to extend its lifespan and ensures quality, comfort and safety standards at the lowest possible cost.

The pavement condition indexes analyze condition of pavement layers and support decision making for segment prioritization and M&R interventions. Some indexes developed for interurban or rural or urban networks may be cited, such as Present Serviceability Index, Pavement Condition Index, Global Severity Index, Pavement Quality Index, Urban Pavement Condition Index and Overall Pavement Condition Index (Carey and Irick, 1960; Picado *et al.*, 2004; ASTM D6433-18; Loprencipe and Pantuso, 2017; Fuentes *et al.*, 2021; DNIT-PRO 006/2003a; Reza, Boriboonsomsin and Bazlamit, 2006; Osorio *et al.*, 2014; Sadeghi, Najafabadi and Kaboli, 2017; Arevalo *et al.*, 2017; Shah *et al.*, 2013). Urban network index can be more complex, because in the cities there are some factors such as water and sanitation systems, bus stops and others that may favor emergence of pavement distresses. Thus, it is useful to create a methodology to develop a urban pavement condition index, which obeys the local condition for each city.

In this perspective, this research had the goal to develop a calibrated and validated urban pavement condition index for flexible pavements to support the development of an urban pavement management system for João Pessoa, Brazil. In addition, some pavement condition indexes were used to compare and evaluate their efficiency to analyze urban pavement condition.

2. BACKGROUND

Pavement layer condition is one of the main inputs of the UPMS, so it is necessary to use efficient and effective methods to evaluate pavement conditions. The municipal governments must be aware that data survey of pavement condition is an important and expensive process to UPMS (Bektas, Smadi and Nlenanya, 2015). Therefore, efficient approach and techniques of data collection are necessary, that are adaptable to their goals and financial resources.

To deal with this challenge, several pavement condition manuals and evaluation methods, including manual and automatic data collection were developed: Distress Identification Manual for the Long-Term Pavement Performance Program (FHWA, 2003), International Standard Practices for Roads and Parking Lots Pavement Condition Index Surveys (ASTM, 2018).

Evaluation of pavement condition is performed by subjective or objective ways. On subjective evaluation, a group of experts (or trained users) evaluates roughness and comfort of pavement segments, according to an appropriate scale stated by Carey and Irick (1960). Objective evaluation provides the pavement condition based on type, severity and density of pavement distress.

There are vast majority of researches about pavement condition indexes, they were performed for interurban and rural road networks, for example, Present Serviceability Index (Carey and Irick, 1960), Global Gravity Index (DNIT-PRO 006/2003a), Pavement Condition

Rating (ODOT, 2006), Pavement Quality Index (Reza, Boriboonsomsin and Bazlamit, 2006) and Pavement Condition Index (ASTM D6433-18). However, the concepts of interurban and rural pavement management can be applied to urban pavement management; though they contain different specifications that should be considered, such as breaking points for speed bumps, reduced traffic, accentuated slopes, maintenance of electrical networks and basic sanitation (Picado *et al.*, 2004; Shah *et al.*, 2013 and Osorio *et al.*, 2014).

In general, the application of those indexes is not representative to rank the pavements condition in urban roads, because they were elaborated for rural roads, which material features, pavement design, maintenance and rehabilitation activities are different in relation to urban roads (Osorio *et al.*, 2014; FHWA, 2017). However, those condition pavement indexes need to be adjusted for local condition as an index for urban pavements. Furthermore, the climate is a fundamental parameter that should be considered on pavement designs, because it influences the appearance of type, severity and density of distress (Kim *et al.*, 2011; Schwartz *et al.*, 2013; Ceylan *et al.*, 2013). Thus, it is essential that those indexes must be calibrated and validated themselves according to climate, construction process, materials, types of maintenance and rehabilitation.

Currently, the utilization of a learning machine system for pavement data processing has been studied. The pavement diagnosis has been made by data collected by smartphone accelerometers and satellite photographs. These techniques of artificial intelligence contribute for faster pavement diagnosis, providing reduced human labor, as well as decreasing M&R costs and maximizing financial resources. For other hand, these techniques can contribute to reduction of traffic accidents with the evaluators and inconvenience of vehicle waiting time by interrupted road during data collection (Wang *et al.*, 2019; Magalhães *et al.*, 2020; Majidifard *et al.*, 2020).

Some indexes were developed to improve the evaluation of asphalt pavement condition in urban and interurban areas. In our research, some indexes were chosen quoting the Distress Manifestation Index Network Level (Chamorro *et al.*, 2010), Pavement Condition Index (ASTM D6433-18), and Urban Pavement Condition Indexes (Osorio *et al.*, 2014; Arevalo *et al.*, 2017).

The Distress Manifestation Index Network Level (DMINL) was developed and validated to be used in the road network of Ontario. The collection of pavement distresses were accomplished with laser profilometer and digital images, which are widely used in network levels, because its time of collection is shorter than manual methods (Chamorro *et al.*, 2010). The index is calculated through equation 1:

$$DMINL = 10 - 0.117FC - 0.133R - 0.157LWP - 0.035LNWP - 0.01T \quad (1)$$

where FC: fatigue cracking (%);

R: rutting (mm);

LWP: longitudinal cracking inside of wheel track (%);

$LNWP$: longitudinal cracking outside of wheel track (%);

T: transverse cracking (%).;

The Pavement Condition Index (PCI) was chosen because it is a distress index well recognized worldwide to classify pavement condition and indicate maintenance and rehabilitation alternatives. The PCI was developed for airports pavements, after that adapted to roads and parking lots. This index is based on a distress survey realized to a sample of pavements, according to type, severity level and density of distress. PCI ranks pavements in a condition scale from up 0 (failed) to 100 (good), portrays present pavement condition, according to surface layer evaluations as structural integrity, roughness and safety (ASTM D6433-18). PCI is calculated by equations 2 and 3.

$$PCI = 100 - \sum_{i=1}^{p}\sum_{j=1}^{m_i} a(T_j, S_i, D_{ij})F(t,q) \quad (2)$$

$$PCI = 100 - CDV \quad (3)$$

where $a(\,)$: deduct value depending on distress type Tj, level of severity S_i; density of distress D_{ij};

i: counter for distress types;

j: counter for severity levels;

p: total number of distress types for pavement type under consideration;

m_i: number of severity levels for the ith type of distress;

$F(t,q)$: an adjustment function for multiple distresses that vary with total summed deduct value (t) and number of deducts (q);

CDV: Corrected deduction value.

The Urban Pavement Condition Index (UPCI) is used on pavement management systems in Santiago, Chile. Equation 4 presents calculations to rank the condition of flexible pavements (Osorio *et al.*, 2014):

$$UPCI = 10 - 0.038FC - 0.0049TRC - 0.046DP - 0.059R - 0.237P \quad (4)$$

where FC: fatigue cracking (%);

TRC: sum of transverse and reflection crackings (%);

DP: deterioration of the patching (%);

R: rutting (mm);

P: potholes (%).

In Brazil, Arevalo *et al.* (2017) developed an urban pavement condition index (UPCI) to the Federal District. The calculation of the UPCI is made by equation 5.

$$UPCI = 100 - \sum_{i}(WD_i \cdot WS_i \cdot WE_i) \quad (5)$$

where WD_i: weigh factor per distress type;

WS_i: weight factor for distress severity;

WE_i: weight factor for distress size.

The most principal difference for distress indexes cited above is that PCI (ASTM D6433-18) takes account 20 distresses for flexible pavement, while DMINL (Chamorro *et al.*, 2010) and UPCI (Osorio *et al.*, 2014) take into account 5 distresses (fatigue, transverse and longitudinal cracks, rutting, deterioration of patching and potholes). Although UPCI (Arevalo *et al.*, 2017) were carried out from 15 distresses, 96.57% of occurrences on pavements studied by them are represented by fatigue cracks, rutting, and deterioration of patching, potholes and raveling.

The expression to calculate PCI (ASTM D6433-18) considers deduct value curves for distress in function of type, density and severity. No doubt, PCI is very robust, complete distress index and well recognized worldwide for evaluation pavement condition on roads and parking lots.

In spite that, some wear and tear could not be usual on urban roads, so pavement condition index that consider less quantity of distress, but with more frequency and significance could simplify steps of pavement evaluation, decreasing time of data collection and costs, and minimizing solutions for maintenance and rehabilitation activities on them (Chamorro *et al.*, 2010;Sahah *et al.* 2013, Osorio *et al.*, 2014; Arevalo *et al.*, 2017). In addition, the PCI demands more time to collect distress and achieve results, becoming more expensive, and difficult to implement that indicator to support pavement management systems in municipalities (Elhadidy *et al.*, 2021).

3. WORK METHOD

The work method steps to create an urban pavement condition index consisted of: *1*) literature review; *2*) description of the study area; *3*) definition of sampling size; *4*) definition of evaluation guidelines; *5*) formation of evaluation groups and training; *6*) data survey; *7*) data processing; *8*) development of urban pavement condition index; and, *9*) comparative analysis between some pavement condition indexes.

3.1. Characterization of study area

The area of João Pessoa city is about 211.5 Km², divided into four areas: North, South, East and West. Three functional road classes (arterial, collector and local ways) and some types of pavements compose the road network. The types of pavements include flexible pavement, paving stone, interlocking blocks, partial paving or no paving, whose the total length is about 2,045 Km. Flexible pavement represents about 571 Km or 27.9% of total pavement length. The structures of flexible pavement are composed by asphalt surface course and base course of granular materials or of paving stone.

3.2. Definition and dimension of sampling

For this study, the sample of flexible pavements were chosen. After that, a sampling unit was defined as a street or an avenue segment for a specific area (length x width), which the pavement inspection was performed. To elaborate an urban pavement condition index, it was necessary to define dimension and quantity of samples, for evaluation purposes of pavement condition. The segment length was 50 m and width of lane up 6 to 12 meters; these dimensions were adopted in accordance with an area around 225 ± 90 m^2 suggested by ASTM D6433-18.

3.3. Samples quantity estimation

The quantity of data samples were obtained from an expression that estimates finite sample number, according to equation 6 (Vallejo, 2012).

$$n = \frac{Z_{\alpha/2}^2 \cdot p \cdot q \cdot N}{e^2(N-1) + Z_{\alpha/2}^2 \cdot p \cdot q} \tag{6}$$

where
- n: Sample quantity;
- N: Population size;
- $p \times q$: Population variation in dichotomous items;
- Z: Confidence interval;
- e : Margin of error.

The size, number and frequency of samples required a statistical analysis to ensure representative statistics of collected data. Thus, it is limited to a 10% maximum error and 95% confidence level, whose probability of uncertainty is 5% to determine a confidence interval, in which should be the true value parameter (Chou and Zou, 2002; Osório, 2014). The population size was obtained for division of asphalt pavement extension (570,970.38 m) by segment length (50 m) and 0.25 population variance. Thus, n could be calculated by equation 6, whose value was of 96 samples.

However, during the statistical analysis the normal distribution curve of pavement condition evaluation tended to be classified from regular to very good. Thus, it was necessary to increase the sample size to 113, with the pavement condition from very poor to regular.

To understand randomness criterion during collection of data, the city was divided according to areas defined by the Municipal Infrastructure Secretary. In each area was collected a number of samples which was proportional to asphalt pavement length. The areas, length and percentage of studied segments for asphalt pavement are in Table 1.

3.4. Evaluation Guidelines

Firstly, there were researched manuals and standards for distresses of asphalt pavements. The Distress Identification Manual for the Long-Term Pavement Performance Program (FHWA, 2003) and ASTM D6433-18 were chosen to standardize the collection of pavement distress data.

Table 1 – Quantity of evaluated segment by city area

Area	Length (m)	Percentage (%)	Segments
North	126,619.91	22.2	25
South	174,841.24	30.6	34
East	159,886.85	28.0	32
West	109,622.38	19.2	22
TOTAL	570,970.38	100.0	113

3.5. Data Survey

To start, the rating panel with five members were trained. The aim was to train them for collection of pavement distresses and to capacitate them about subjective evaluation. In addition, the training aimed to obtain homogeneity among the assigned scores during the subjective evaluation and to acquire a low coefficient of variation between them (DNIT–PRO 009/2003b; FHWA, 2003).

After that, the data survey was done on three phases:

- Elaboration of road network inventory containing street name, width, length, geographic location, number of lanes, road direction and hierarchical class;
- Collection of surface pavement distresses by walking and visual inspection;
- Subjective evaluation, that is, assigned scores for comfort and smoothness condition of roads attributed by panel's members.

For data survey, the equipment used were a pick-up truck, X safety vests, wheel measuring tape, measuring tape, aluminum ruler, truss for measuring of rutting, clipboards, hazard warning traffic tape and signaling cones. Data collections of pavement distresses were made by walking and visual inspection, during the day and with good weather conditions.

Concomitantly, the five members performed subjective evaluations according to procedures described in DNIT-PRO 009/2003b Brazilian standard.

3.6. Data processing

First, the homogeneity of the assigned scores for each sample unit was analyzed through the coefficient of variation and the mean of assigned scores. After these analyzes, the choice of dependent and independent variables that could compose the model was started. The dependent variable was defined as the mean of assigned scores, and the independent variables were defined as pavement distresses, they were obtained by statistical tests and multiple regression. Details are described on the following topics.

3.7. Development of the urban pavement condition index

After analyzing the homogeneity of assigned scores, it could be calculated the present serviceability rating (PSR), which is the average of five assigned scores. In the equation, PSR is the dependent variable and the independent variables are the pavement distresses. In order to develop the urban pavement condition index (UPCI), PSR was matched with UPCI to obtain distresses weight factors which were carried out by multiple linear regression based on equations 7 and 8 (Albuquerque, 2017).

$$UPCI = 5 - \sum_{i=1}^{n} (\alpha_i) \cdot \left(Distress\%_{i,j}\right) = PSR \quad (7)$$

$$Distress\%_{i,j} = \sum_{i,j=1}^{j=3} \left(DistressExtension\%_{i,j}\right) \cdot (SeverityFactor_j) \quad (8)$$

where $UPCI$: Urban Pavement Condition Index;

α_i: distress weight;

$Distress\ \%_{i,j}$: density for each type of distress (%);

$DistressExtension(\%)_{i,j}$: length or area percentage of distress in the sample;

$SeverityFactor_j$: severity type (low, moderate or high).

Severity factors were defined as 0.5 for low severity, 1.0 for moderate severity and 2.0 for high severity in accordance with Osório (2014). Thus, calculations for distress density were carried out to 113 samples of asphalt pavement segments. After that, a statistical analysis software was used to define the independent variables (distresses) in function of the dependent variable (PSR).

The least square method (LSM) was used in statistical software to estimate coefficients of independent variables with better fitting to obtain data, thus, to establish a function that minimized the residual sum of squares. This step was separated in three phases: 1) elimination of independent variables according to significance; 2) establishment of independent variables and UPCI function; 3) fitting of UPCI function by intercept to maximize UPCI value for 5.

In the phase 1, the stepwise multiple regression was utilized, which was characterized by adoption of mathematical criteria for input of explanatory variables. The criteria for adding or removing a variable in any stage was expressed in terms of partial F test. Thus, the independent variables that had carried out P value < 0.05 were maintained, the ones carried out P value up 0.05 to 0.10 were analyzed by partial F test, to verify the acceptability in the model. In the phase 2, the UPCI was established in function of more significant independent variables and in accord with the assumptions of multiple linear regression. In phase 3, the UPCI was adjusted to up zero to 5 scale. As the intercept was less than 5, all parameters were corrected, so the parameters were multiplied by a ratio of 5 divided by intercept.

4. RESULTS AND DISCUSSION

4.1. Subjective evaluation of pavements segments

The Table 2 presents the subjective evaluation according to scale ranking (Carey and Irick, 1960), quantity and percentage of evaluated pavements segments. The spatial distribution from subjective evaluation is shown at Figure 1.

Table 2 – Distribution of subjective evaluation to evaluated pavements segments

Pavement condition	Segments	Percentage (%)
Very poor	0	0
Poor	8	7
Regular	34	30
Good	44	39
Very good	27	24
TOTAL	113	100

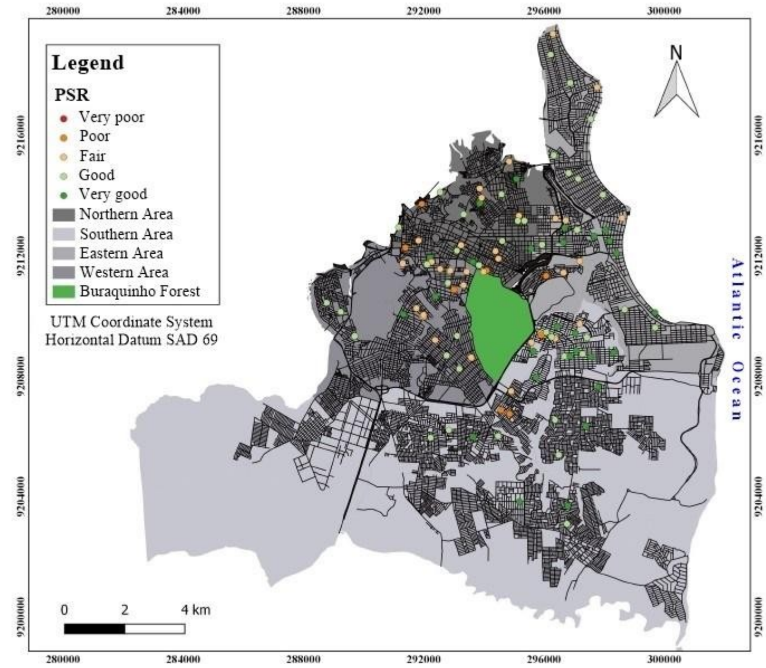

Figure 1. Present Serviceability Rating to pavement segments

According to Table 2 and Figure 1, it can be seen that only 7% of segments were classified on very poor or poor conditions. This one can be explained by the investments made in the last decade, by municipal and federal governments, to provide maintenance and asphalt pavement construction for main roads of the city, prioritizing public transport routes by bus.

4.2. Procedure for obtaining and validating the model

Stepwise Forward was the method chosen to build the model. The objective of the method is to determine, from a set of explanatory variables, those that have a reduced influence on the explained variable. Stepwise regression exists in two main forms: forward and backward. In its simplest form, a progressive regression selects a set of predictor variables determined by the data analyst, that predictor with the highest absolute correlation with Y; that is, | rYXj | (Darlington *et al.*, 2017). Direct selection starts with no variables in the equation and how to add one at a time based only on an input criterion F (Chernick *et al.*, 2003). That is, in this method, the explanatory variables are placed one by one and through a series of tests such as the F test and the t test, and those that have no significant influence are eliminated. The importance of the variable is defined in terms of a measure of statistical significance of the coefficient associated with the variable for the model. The procedure is finished when the last variable that inserted in the equation has an insignificant regression coefficient or all variables are included in the equation (Chatterjee *et al.*, 2012).

At the 5% significance level, the method tested a sample with 113 elements and sixteen independent variables, namely: TF (Fatigue cracking), TB (Block cracking), DB (Edge cracking), TR (Reflection cracking), TT (Transverse cracking), TLF (Non-wheel path longitudinal cracking away from wheel cracking), TLD (Wheel path longitudinal cracking), RM (Patching), PN (Pothole), Rutting DP (Shoving), EX (Bleeding), AP (Polished aggregates), DE (Raveling), BO (Water bleending and Pumping), DES (Lane-to-shoulder Dropoff). Table 3 presents the result of the process with the six variables that the method included in the model, the respective B coefficients and levels of significance. All variables, including the intercept, presented a significance level of 0%, thus meeting the formulation of the null hypothesis. The coefficients in Table 3 compose the UPCI equation (9).

$$UPCI = 4.385 - 0.014TF - 0.026RM - 0.233PN - 0.043DP - 0.018DE - 0.014AP \qquad (9)$$

Table 3 – Weighting Factors Generated For The Model

	Non-standardized coefficients		**Standardized coefficients**	**t**	**Significance level**
Model	B	Standard error	Beta		
Intercept	4.385	0.067		65.010	0.000
TF	-0.014	0.002	-0.221	-5.961	0.000
RM	-0.026	0.002	-0.583	-14.819	0.000
PN	-0.233	0.053	-0.160	-4.426	0.000
DP	-0.043	0.005	-0.329	-8.214	0.000
DE	-0.018	0.004	-0.162	-4.493	0.000
AP	-0.014	0.003	-0.159	-4.407	0.000
Dependent Variable – PSR					

Legend: TF (Fatigue Cracking); RM (Patching); PN (Pothole); DP (Rutting); DE (Raveling); AP (Polished Aggregates). The legend are the same described in Albuquerque (2007)'s dissertation.

For a multiple linear regression equation (RLM) to be valid and reliable, and to reflect the values of a population, the assumptions of homoscedasticity, serial correlation, multicollinearity, normality of errors must be satisfied (Mourad *et al.*, 2005; Hair *et al.*, 2009). All tests to verify whether these assumptions were violated were carried out with a significance level of 5% (α) and the results achieved are described below.

To verify homoscedasticity, the Pesarán-Pesarán test was performed and the result is shown in Table 4. In this table, it can be seen that the test's significance level was 0.580. Thus, at the significance level of 5% (0.05), the null hypothesis is accepted that the residual data are homoscedastic.

Table 4 – ANOVA - Pesarán-Pesarán Test

Model	Sum of Squares	Freedom degree	Average Squares	F	Significance level
Regression	0.646	1	0.646	0.309	0.580
Residual	232.259	111	2.092		
Total	232.905	112			

To verify the serial correlation, the Durbin-Watson test was performed, which presented a value of 2.203 (Table 5). For a sample with 113 elements and a level with a significance level of 5%, the Durbin-Watson table shows: dl = 1.60206 and du = 1.78644. With these values, the intervals are constructed: 4 – dl = 4 – 1.60206 → 2.3979; and 4 – du = 4 – 1.78644 → 2.2135

Table 5 – Durbin-Watson Test

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
	0.931	0.867	0.860	0.30748	2.203

Figure 2 shows that this value the Durbin-Watson statistic was in the zone of no correlation. Therefore, with a significance level of 5%, it do not reject H0 and claim that the residues are independent.

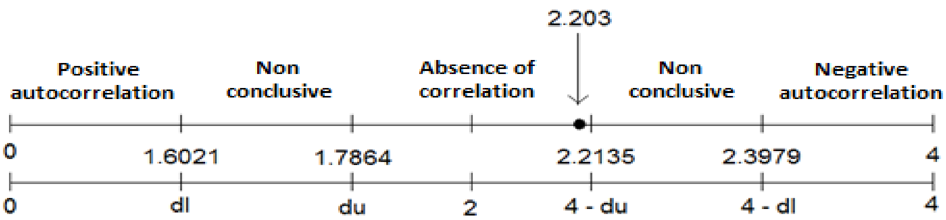

Figure 2. Durbin-Watson

To analyze multicollinearity, a test was carried out in which the VIF (variance inflation factor) of each independent variable was determined (Table 6). This table shows that the VIF values were close to one unit therefore multicollinearity is acceptable.

Table 6 – Collinearity Test

Variables	Tolerance	VIF
TF	0.909	1.100
RM	0.811	1.233
PN	0.962	1.040
DP	0.782	1.279
DE	0.970	1.031
AP	0.958	1.043

To analyze the normality of the error, the Kolmogorov-Smirnov test was performed. This test assumes that the error variable should adjust to a normal distribution with zero mean and variance (Table 7). It can be seen that this test presented a significance of 0.917, that is, a significance value greater than 5% (0.05). Therefore, at the 5% significance level, the null hypothesis of residual normality was accepted.

Table 7 – Kolmogorov-Smirnov Normality Test

	Standardized residue
N	113
Kolmogorov-Smirnov Z	0.541
Asymptotic - Sig. (two-sided)	0.932
Exact - Sig. (two-sided)	0.917

Thus, from the results of the assumption tests, it can be seen that equation (9) developed for the urban pavement condition index (UPCI) was validated.

The UPCI has a maximum value equal to 5, when is a new surface course or pavement overlay, thus it is free from defects. That value is reached by the UPCI when the values of the distresses represented by independent variables are equal to is zero. It can be seen in equation 9 that the calculated intercept was equal to 4.385. Therefore, to fit the model's intercept to the maximum value all parameters were multiplied by the relation 5 / 4.385. After this multiplication, the UPCI equation was fitted (Eq. 10).

$$UPCI = 5 - 0.016TF - 0.030RM - 0.266PN - 0.049DP - 0.021DE - 0.16AP \quad (10)$$

where TF: Fatigue Cracking, %;

RM: Patching, %;

PN: Pothole, %;

DP: Rutting, mm;

DE: Raveling, %;

AP: Polished Aggregates, %.

The percentage of distresses must be calculated by equation 8. The severity factors for pavement distresses are low (0.5), medium (1.0) or high (2.0).

4.4. Comparative analysis with pavement condition indexes

In possession of results about distresses collections, some calculations with PCI, DMINL, UPCI (Osorio *et al.*, 2014), UPCI (Arevalo *et al.*, 2017) and UPCI (Albuquerque, 2017) were performed to rank pavement condition at 113 segments. In order to allow better visualization of results carried out, a chart (Figure 3) was drawn up to correlate present serviceability rating (PSR) and pavement condition indexes.

A statistical analysis was conducted to allow a better evaluation in terms of obtained differences between pavement conditions indexes related to present serviceability rating. Thus, the mean absolute relative error (MARE), mean square error (MSE), mean Absolute error (MAE) and coefficient of correlation (R) were calculated, as presented in Table 8.

In accordance with Figure 3 and Table 8, UPCI (Albuquerque, 2017) carried out the smallest MARE, MSE and MAE, and correlation coefficient of 0.98. These values were expected in the performance analysis of ranking for urban pavement condition, which is explained due to development of UPCI (Albuquerque, 2017) was correlated with attributed scores by members and distresses collected on pavements at João Pessoa.

As for the UPCI (Osorio *et al.*, 2014) contains transverse and reflection cracks, but these distresses were verified with low frequency in segments auscultated during development their project, that may have overestimated calculated values and increased discrepancy in relation to the PSR on our analyzes. Such differences between values calculated by UPCI (Osorio *et al.*, 2014) and PSR can be observed in Figure 3, and in light of errors contained in Table 8.

The UPCI (Arevalo *et al.*, 2017) carried out the third best mea absolute relative error (Table 7), so that closer approach of the results in relation to UPCI (Albuquerque, 2017) it may be due to similarity such as independent variables (distresses), construction methods same climate. Although there are differences on equations to calculate pavement condition index between them. From these results, it is verified that the differences between results can be associated with many factors, such as types of distresses, severity levels, weight factors, deductive values and equations, as highlighted by Gharaibeh et al (2010).

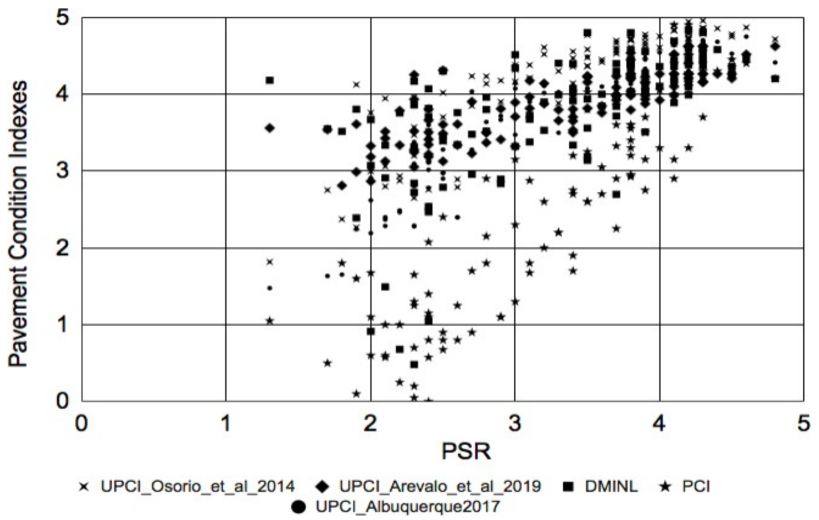

Figure 3. Dispersion of pavement condition indexes related to PSR

Table 8 – Errors and correlation calculations of pavement condition indexes related to PSR

Indexes	MARE (%)	MSE	MAE	R
UPCIAlbuquerque2017	7.1	0.23	0.18	0.98
UPCIOsorio_et_al2014	19.1	0.73	0.62	0.94
DMINLl	143.0	1.20	0.93	0.55
PCI	269.0	2.39	1.95	0.93
UPCIArevalo_et_al2019	24.9	1.03	0.18	0.87

The indexes DMINL and PCI carried out the biggest MARE, MSE and MAE values. DMINL represented a linear correlation equal to 0.55, considered moderate. Therefore, DMINL may not be representative to evaluate conditions of pavement segments between regular and very poor, because that index does not include distresses, such as patching and potholes, which usually appear on pavements in that condition.

In addition, the calculation method of PCI is stricter than other indexes, since a high deductive value is attributed in segments with presence of pothole, even in small areas and with low severity. Thus, for evaluated segments with presence of pothole, PCI values were less than other indexes and present serviceability rating. Among five indexes, the MARE, MSE and MAE of PCI were the highest; in contrast, it presented a strong linear correlation of 0.93. Thus, it can be concluded that using only linear correlation to evaluate efficiency in classification of pavement condition can be a mistaken action.

Stands out still, which these indexes were developed in other regions, whose materials, construction and maintenance processes, traffic and environmental conditions are different from Brazil. In addition, the climate conditions directly influence an appearance on pavement distresses (Kim *et al.*, 2011; Schwartz *et al.*, 2013; Ceylan *et al.*, 2013). So, it becomes essential that municipalities secretariats for infrastructure develop their own pavement condition indexes and distress manuals, or adjust existing distress index according to local conditions (Loprencipe and Pantuso, 2017). Thereby, DMINL and PCI cannot adequately represent the pavement condition of the road network at João Pessoa. However, in relation to the UPCI (Osorio *et al.*, 2014) and UPCI (Arevalo *et al.*, 2017) may present a perspective to pavement conditions at network level, but to support decision making in project level, these indexes may not be appropriate for local conditions.

5. CONCLUSIONS

This work enhanced the development of a distress index to represent conditions of urban flexible pavements, for supporting municipal secretariat for infrastructure during decisions making in relation to maintenance and rehabilitation activities. To achieve the research aim, the following steps were developed: *i*) definition of sampling size for urban road network; *ii*) formation of rating panel and training; *iii*) data collection about present serviceability rating (PSR) and pavement distress; *iv*) development of an UPCI; and, *v*) comparative analysis with some PCI.

The stepwise method provided an urban pavement condition index with six distresses (patching, rutting, fatigue cracking, abrasion, pothole and polished aggregates), which presented significance (p-value < 5%) explaining the independent variable, denominated present serviceability rating (PSR). The quantification of distresses can contribute to decrease time of data collection and provide greater efficiency in pavement analysis on network level.

The comparative analysis in terms of errors (MARE, MSE and MAE) and coefficient of correlation (R) carried out divergence of results between pavement conditions indexes and present serviceability rating. These analyses corroborate with the hypothesis that some distress indexes cannot be representative to evaluate pavement condition on specific highways, so it is necessary to fit it or elaborate a new pavement condition index.

Lastly, the proposal of urban pavement condition index allows a better M&R planning, budget distribution and benefits to the population, because well-kept pavements promote comfort, reduction of travel time and safety to the users.

ACKNOWLEDGEMENTS

We are thankful to the Coordination for the Improvement of Higher Education Personnel (CAPES) and National Research and Technological Development Scientific Council (CNPq) for the granting of the masters and undergraduate student scholarships. Furthermore, we thank the research collaborators who supported data collection.

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