

Index for assessing the condition of flexible urban pavements based on a constructivist multicriteria analysis

Índice para evaluar el estado de los pavimentos urbanos flexibles basado en un análisis multicriterio constructivista

Vitor Hugo Salviatto ^{1*} <http://orcid.org/0000-0003-4320-2254>,
Heliana Barbosa Fontenele * <http://orcid.org/0000-0003-2046-0568>

* Londrina State University – Londrina, BRAZIL

Fecha de Recepción: 23/06/2020
Fecha de Aceptación: 15/12/2020
PAG 107-116

Abstract

The main methods for assessing pavement condition do not consider the factors involved in pavement deterioration. Thus, the objective of this research was to develop a current pavement condition index that took into account the factors that lead to deterioration. The index included an assessment of riding comfort, existing distresses, longitudinal slope, drainage aspects and bus traffic volume. The criteria and performance levels were weighed by means of a method known as Measuring Attractiveness by a Categorical Based Evaluation Technique. To be tested and validated, the index developed was applied to 13 Sample Units, and a correlation analysis based on the Fixed-Value Matrix method was performed. In said analysis, a correlation of 0.12 was obtained when all units were considered, and 0.48 when the units with high traffic volume were removed. It was concluded that the proposed method presents a more rigorous assessment of pavement condition, mainly when it comes to distresses and bus traffic.

Keywords: Pavement management system, traffic volume, MCDA-C, MACBETH correlation

Resumen

Los principales métodos de evaluación del estado de los pavimentos, no toman en cuenta los factores que intervienen en su deterioro. Por lo tanto, el objetivo de esta investigación era desarrollar un índice de condición actual de pavimentos que tuviera en cuenta los factores que conducen al deterioro. El índice incluía una evaluación del confort de conducción, los deterioros existentes, la pendiente longitudinal, los aspectos de drenaje y el volumen de tráfico de autobuses. Los criterios y niveles de rendimiento se ponderaron mediante un método conocido como Medición del atractivo mediante una técnica de evaluación basada en categorías. Para su comprobación y validación, el índice desarrollado se aplicó a 13 unidades de muestra y se realizó un análisis de correlación basado en el método de la matriz de valores fijos. En dicho análisis, se obtuvo una correlación de 0,12 cuando se consideraron todas las unidades, y de 0,48 cuando se eliminaron las unidades con alto volumen de tráfico. Se concluyó que el método propuesto presenta una evaluación más rigurosa del estado del pavimento, principalmente cuando se trata del deterioro y del tráfico de autobuses.

Palabras clave: Sistema de gestión de pavimentos, volumen de tráfico, MCDA-C, correlación MACBETH

1. Introduction

The maintenance of paved road networks is not always performed with proper planning, which renders it ineffective and expensive. This makes the adoption of Urban Pavement Management Systems (UPMSs) fundamental in obtaining pavements in better conditions using fewer resources (Pereira et al., 2019).

One of the bases to decision-making concerning a UPMS is related to information on the state of pavements collected in the field through evaluations. However, data collection and index calculation methods are not always easy and fast. According to Cafiso (Cafiso et al., 2019), the data collection phase is the one that demands the most time and resources in a UPMS.

In addition, many of them assess pavement conditions only from existing distresses, disregarding other characteristics in the road that are responsible for deteriorating the pavement.

An analysis tool that considers the road characteristics that contribute to pavement deterioration and that provides a simple data collection procedure can help pavement managers determine pavement conditions and maintenance priority in a faster, reliable and less costly manner. Therefore, the present study aims to develop a condition index that assesses the surface conditions of urban flexible pavements in a simple way, by analyzing road distresses and characteristics.

¹ **Corresponding author:**

Londrina State University – Londrina, BRAZIL
E-mail: vitor.salviatto@uel.br



2. Urban Pavement Management System

An Urban Pavement Management System (UPMS) aims to efficiently utilize the limited resources allocated to road infrastructure administration, by means of strategies that ensure that the pavement remains in good condition for a longer time. A UPMS helps pavement managers make decisions about the best maintenance and rehabilitation (M&R) activities to be applied, besides how they should be carried out, the places that require greater attention and when to act.

Some authors, in an attempt to show the effectiveness of using a UPMS, have conducted investigations on the subject. Hosten (Hosten et al., 2013) concluded, in their research, that the implementation of a UPMS in the city of Christiansburg, Virginia, USA, can help engineers plan long-term maintenance activities, and that the costs involved can be reduced with the adoption of preventive maintenance activities. Zanchetta (Zanchetta, 2017) sought to contribute to the implementation of a UPMS in Brazil. In his study, the author concluded that the methods currently adopted by pavement managers, such as pothole filling and resurfacing operations, are twice as expensive and keep the pavement in worse condition compared to the techniques used by a UPMS.

Despite its countless advantages, (Farashah and Tighe, 2014) argue that, due to lack of resources or experience, a UPMS may not be profitable. Thus, the activities adopted in pavement management must render UPMSs simple and effective.

A UPMS must be constantly supplied with data relating to pavement conditions. (Pereira et al., 2019) highlight the importance of data and pavement condition assessments, as they allow establishing goals and strategies towards solving problems.

3. Pavement Condition Indexes

Data sourced from pavement assessments can be organized as indexes. Pavement Condition Indexes (PCIs) allow learning about the state of roads and classifying them by order of priority. Most PCIs associate the type, severity and extent of distresses and are, in many UPMSs, the main instrument to assist in decision making.

Among the traditional methods for evaluating road pavement condition, the Pavement Condition Index (PCI) stands out, being regarded by many authors as one of the most comprehensive methods. The PCI classifies the condition of pavements on a scale from 0 (Failed) to 100 (Good) by identifying the severity and extent of existing distresses; the standard of the American Society for Testing and Materials (ASTM, 2018) describes 20 types of distresses to be analyzed. Each distress is assigned abacuses with deduction values to be used for finding the PCI on the assessed pavement. The number of distresses to be analyzed makes data collection through the PCI method a time-consuming process.

Some studies propose simpler assessment methods compared to traditional ones. (Zanchetta, 2017) developed a method for evaluating pavements, called Fixed-Value Matrix (FVM). The method assesses only the five distresses that are, according to the author, the most frequent in urban roads: fatigue cracking, pothole, patching, rutting and raveling. For each combination of distress severity and extent, the author defined fixed values to be summed; afterwards, this sum is subtracted from 100 and results in the Pavement Condition Index (PCI). Scores close to 100 represent pavements in better conditions, while scores close to 0 represent those in worse conditions. (Albuquerque, 2017), on the other hand, considered six types of distress in the Urban Pavement Condition Index of João Pessoa (UPCIJP): fatigue cracking, patching, pothole, rutting, raveling and polished aggregate. Using data collected from 113 samples, linear regression analyses were run to obtain the UPCIJP. Although they present solutions to simplify the data collection process, the studies by (Zanchetta, 2017) and (Albuquerque, 2017) consider only distresses in the road as a means of assessment.

However, characterization based only on the distresses found, which is the most common type of analysis in urban areas, may not provide enough information for pavement condition predictions. An integrated analysis of the various factors involved in pavement deterioration must be performed in order to verify the degree of vulnerability of the road and thus support decision making as to the M&R activities necessary to keep the pavement in good condition for a longer period of time.

Thus, some authors have developed indexes that consider factors other than distresses in the pavement. (Abu-Samra et al., 2017) considered factors such as pavement age, surface layer depth, temperature and traffic volume to develop, based on the Multi-Attribute Utility Theory (MAUT), the Condition-Rating (CR), which classifies the condition of flexible pavements. The authors statistically compared the results obtained from the application of the index with other condition indexes, such as the PCI, the Present Serviceability Rating (Highway Research Board (HRB, 1962), and the Pavement Quality Index (Reza et al., 2005). Since the CR classified the condition of the evaluated pavements similarly to the PCI, it was concluded that the proposed index was valid to assess pavement condition.



In Brazil, an initial study conducted by (Salviatto et al., 2019) proposed the Surface Condition Index for Flexible Pavements, developed from the Analytic Hierarchy Process method, the SCI-FP. The criteria that compose the index by (Salviatto et al., 2019) were obtained through brainstorming with the participation of 7 graduate civil engineering students. The criteria are:

- *Present Serviceability*: Related to the level of riding comfort and smoothness offered by the pavement, according to subjective evaluation.
- *Pavement Distresses*: Pavements found with the five most common types of distresses in urban roads: Pothole, Patching, Fatigue Cracking, Wheel Track Rutting, and Raveling.
- *Longitudinal Slope*: Related to the longitudinal slope of the assessed stretch; the greater the slope the greater the pressure that vehicles must apply on the pavement to perform braking and acceleration movements.
- *Drainage*: Related to longitudinal and cross slopes in the road; slopes are linked to better or worse water runoff.
- *Bus Traffic Volume*: It determines the volume of buses that travel along the stretch at peak hour, bearing in mind that they are the heavy vehicles with the greatest presence in the urban environment.

Equation 1 presents the weights of the SCI-FP criteria, and Equations 2 and 3 bring the weights of the PD and DNG subcriteria, respectively.

$$SCI - FP = 0.34 PD + 0.26 PS + 0.20 BTV + 0.10 LS + 0.10 DNG \quad (1)$$

$$PD = 0.37 POT + 0.24 FC + 0.15 RUT + 0.14 RAV + 0.10 PAT \quad (2)$$

$$DNG = 0.51 CS + 0.49 DLS \quad (3)$$

Also, for each criterion, performance levels and their respective scores were adopted, which could range from 0 to 100 points. The results for the application of the SCI-FP to 13 Sample Units (SUs) were correlated with data obtained from the application of the Pavement Condition Index based on the Fixed-Value Matrix method proposed by (Zanchetta, 2017), the PCI_{FVM} , which provided a correlation of 0.19 between the indexes when all SUs were analyzed, and 0.58 when the SUs with high bus flow were removed from the analysis. The authors reported the need to improve the index for it to be able to indicate the pavement condition of roads with any traffic level.

4. Multicriteria Analysis

Situations that involve decision making can be complex, especially when the analysis encompasses several factors. In this context, multicriteria analysis tools can be very useful to assist the decision maker.

Current multicriteria analysis methods include the Decision Support Model (DSM) and the Multicriteria Decision Analysis Constructivist Model (MCDA-C). The MCDA aims to aggregate all data relating to a problem in order to obtain synthesized information; it comprises the problem formulation and evaluation stages, with the goal of selecting the best alternative. Examples of this methodology are the AHP and the MAUT methods (Machado et al., 2015). The MCDA-C, according to Ensslin, Giffhorn, Ensslin, Petri and Vianna (2010), emerged as a branch of the MCDA to support complex, conflicting and uncertain decision making. It is structured to develop the decision maker's knowledge on the best option and on the consequences of their choice.

The MCDA-C consists of these phases: structuring, evaluation and recommendations. In the structuring phase, all elements deemed important by the decision maker are organized following an order. During evaluation, elements are compared, and cardinal scales representing local and global preferences are created. Finally, the recommendations phase aims to analyze the consequences of decisions made (Machado et al., 2015).

Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) is an example of an MCDA-C-based method. According to Bana and Costa, Ângulo-Meza and Oliveira (2013), MACBETH weighs the criteria and assesses the options based on a qualitative judgment of differences in attractiveness.

M-MACBETH is a software that runs the method. Judgments are entered in it, and the program itself assesses their consistency, suggesting their revision when necessary (Villela, 2009).



Bana and (Costa et al., 2013) mention that the MACBETH method has been applied in several areas of knowledge. (Machado et al., 2015) also report that it is the most widely used method due to its theoretical foundation, representativeness and practical recognition. Therefore, MACBETH was the multicriteria analysis method chosen in this research for the development of the current pavement condition index, the ICAP.

5. Materials and Method

This item will present the materials and method used for developing the proposed index. The development of the ICAP was based on the criteria and performance levels adopted by (Salviatto et al., 2019) when creating the SCI-FP; the type of multicriteria analysis method for the weighting was therefore changed. Thus, in accordance with the MCDA-C procedures, the structuring, evaluation and validation phases of the proposed index are addressed in this item.

5.1 Structuring

The structuring phase encompassed the construction of a decision tree, the creation of performance levels for each criterion, and the adoption of upper and lower references for the performance levels.

The M-MACBETH software was used for developing the index. The first step was to create the decision tree, made up of a root node (decision problem) and its branches (criteria and subcriteria). It should be noted that the M-MACBETH does not allow a joint analysis of criteria and subcriteria. For this reason, the criteria that had subcriteria were analyzed in separate files.

The next step was to create the performance levels (PLs) for each criterion. The same PLs used in the SCI-FP were adopted; in the latter, the authors defined, based on related studies, standards and manuals, possible scenarios to be found in the field. Thus, quantitative and qualitative PLs that represented the same intervals considered in the SCI-FP were created on M-MACBETH.

Finally, the last structuring phase consisted of defining the upper and lower references of the PLs. The upper reference (good level) is defined as the level at which performance is considered satisfactory (100 score), while the lower reference (neutral level) is defined as the level at which performance shows the minimum acceptable value (0 score). In this research, the worst possible scenarios in each criterion were adopted as neutral level, and the best scenarios, as good level.

5.2 Evaluation

In this phase, attractiveness was judged by means of judgment matrices in which the criteria were subjected to a pairwise comparison (Figure 1). First, the criteria were ordered on the matrix by level of attractiveness: the most attractive criterion was placed in the first column of the matrix, and the least attractive, in the last column. This sorting was established according to the final weights obtained in the SCI-FP: the criterion with the greatest weight was considered the most attractive, and so on for the other criteria. In the evaluation of the PLs, the latter were ordered according to the score assigned to each one in the SCI-FP: the level with 100 score was considered the most attractive, and so on for the other levels of each criterion.


	[Criterion 1]	[Criterion 2]	[Criterion "n"]
[Criterion 1]	no	?	?
[Criterion 2]	?	no	?
[Criterion "n"]	?	?	no

Figure 1. M-MACBETH judgment matrix

The judgment process was carried out by six graduate students from the transportation field. Among them, four participated in the SCI-FP criteria judgment. With all students together, the following question was asked for the



evaluation: “Given that level A is more attractive than level B, what difference in attractiveness do you see between level A and B: very weak, weak, moderate, strong, too strong or extreme? In other words, what is the impact of moving from level B to level A?”. The options that the evaluators should adopt for the difference in attractiveness were: null, very weak, weak, moderate, strong, very strong or extreme. The matrix was filled out based on a consensus on the difference in attractiveness between the assessed options. The same procedure was performed for the PLs of the criteria. The levels were inserted in order of attractiveness in the matrices and then compared pair by pair.

After the judgment, the judgments had to be subjected to a consistency test, which is carried out on the software itself. In the cases in which the program found inconsistency, the judges discussed the differences in attractiveness adopted, and new concepts were given, until reaching a matrix with consistent judgments.

At the end of the judgments, the weights of each criterion and the MACBETH Value Functions (MVs) were generated. The MVs determine the score of intermediate performance levels in relation to the levels defined as good (100 score) and neutral (0 score).

The additive aggregation model was used for representing the ICAP. This model transforms a multi-factor model into a single-factor model. Equation 4 represents the additive aggregation model, with p representing the weights of the factors, and v , the score for the performance obtained in a given factor.

$$ICAP = \sum_{i=1}^n p_1 v_1 + p_2 v_2 + \dots + p_n v_n \quad (4)$$

5.3 Validation

The ICAP was validated using data from the 13 Sample Units (SUs) evaluated in urban stretches by (Salviatto et al., 2019), as shown in Table 1. The stretches were one-road-block long, included lanes only and presented constant longitudinal slope and width.

Table 1. Identification of the assessed roads and blocks

Road	SU	Road	SU
Benjamin Constant Street	1	Elias Daniel Hati Street	8
	2		9
	3		10
Brasil Street	4	Jorge Velho Street	
	5		11
	6		12
	7		13

Note. Taken from “Condition Assessment Index for Urban Flexible Pavements” by Salviatto et. al, 2019

The ICAP was compared with the SCI-FP and with the index based on the Fixed-Value Matrix (PCI_{FVM}) method. The analysis was run by means of correlation and equivalence tests with results obtained by (Salviatto et al., 2019). The correlation test was performed in two ways: the first considered all evaluated SUs, while the second disregarded the SUs with high bus traffic volume.

6. Results and Discussion

The criteria selected to compose the ICAP were: Present Serviceability (PS), Pavement Distresses (PD), Longitudinal Slope (LS), Drainage (DNG) and Bus Traffic Volume (BTM). The PD criterion has five subcriteria: Pothole (POT), Patching (PAT), Fatigue Cracking (FC), Rutting (RUT) and Raveling (RAV). The DNG criterion has two subcriteria: Drainage-Related Longitudinal Slope (DLS) and Cross Slope (CS).



(Table 2) displays possible scenarios for each criterion, and the levels selected as good (green) and neutral (blue) for the PS, LS and BTV criteria. (Table 3) shows the scenarios, as well as the good and neutral levels for the PD and DNG subcriteria.

Table 2. Scenarios and good and neutral levels for the PS, LS and BTV criteria

Criteria	Scenarios							
	Best scenario						Worst scenario	
PS (score)	100	85	70	55	40	25	10	0
LS (%)	0		3	6	9			12 or +
BTV (Bus/peak hour)	0			25				30 or +

Table 3. Scenarios and good and neutral levels for the DNG and PD subcriteria

Criterion – subcriterion	Scenarios					
	Best scenario				Worst scenario	
DNG – DLS (%)	2					0
DNG – CS (%)	2	2.5	1.5	3.0	1.0	0
PD – POT, PAT, FC, RUT, RAV	Has no distress					Has distress

Based on the judgments made by raters, MVFs were obtained for each one of the criterion. Each line slope is represented by an Equation that defines the criterion score (y axis) as a function of the observed scenario (x axis). Figure 2 shows value functions for PS, BTV, LS and subcriterion CS (DNG criterion).



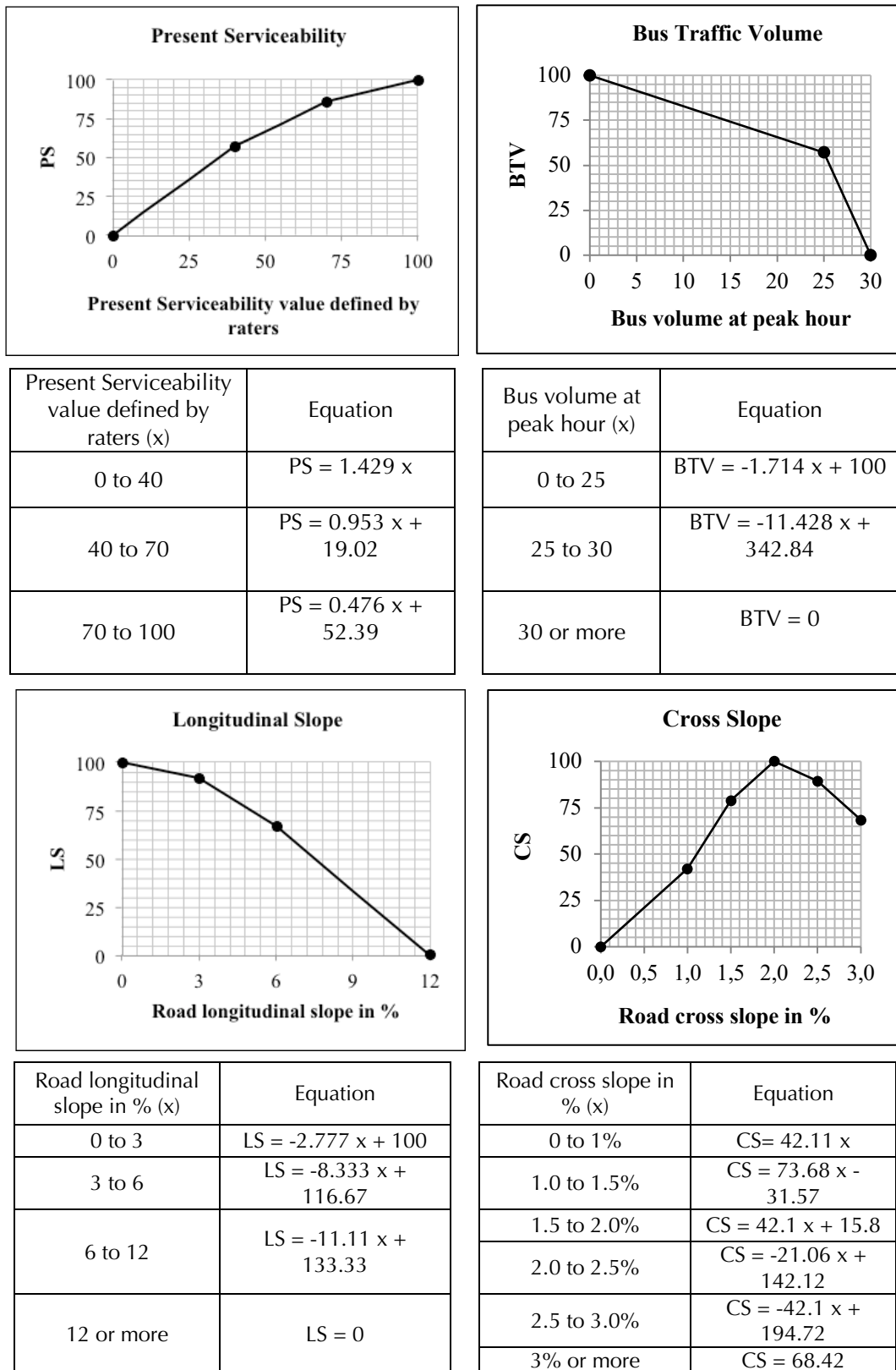


Figure 2. Value function for the PS, BTV, LS and CS criteria



The score of the PD subcriteria is obtained from the existence or absence of distress in the SU: if there is no distress, the SU receives the maximum score (one hundred); otherwise, it receives the minimum score (zero). Finally, the DLS score is obtained from the longitudinal slope of the road: for a slope greater than or equal to 2%, the SU receives the maximum score (one hundred); for a slope of up to 2%, the SU score is obtained by multiplying the slope (in percentage) by 50.

The existence of value functions for obtaining the score of criteria is one of the main differences between the adopted methodologies. In the SCI-FP, within each criterion, performance intervals and their respective scores were adopted. This way, different observed scenarios could have the same score within a criterion. For instance, a road with a 2% cross slope would score 100 points in the LS criterion of the SCI-FP; this same road, in the LS criterion of the ICAP, would score 94.45 points, according to the value function presented in (Figure 2).

Using the M-MACBETH software, the evaluators judged the criteria and subcriteria pair by pair, according to their level of attractiveness. (Equation 5) represents the ICAP.

$$ICAP = 0.35 PD + 0.29 PS + 0.21 BTV + 0.12 LS + 0.03 DNG \quad (5)$$

Because the criteria were sorted according to the weights obtained in the SCI-FP, the order of importance of the criteria within the index obtained by the MACBETH method remained the same, with only the weights being changed.

Since the PD and DNG criteria had subcriteria, their importance within their respective criteria was judged. (Equation 6) and (Equation 7) represent the weights of the PD and DNG subcriteria, respectively.

$$PD = 0.40 POT + 0.29 FC + 0.20 RUT + 0.08 RAV + 0.03 PAT \quad (6)$$

$$DNG = 0.50 CS + 0.50 DLS \quad (7)$$

Just as with the criteria, the order of importance of the subcriteria remained the same. It is worth noting that the weight of the PAT subcriterion dropped from 10% to 3%. By the MACBETH method, the DNG subcriteria had the same weight (50%), while, by the AHP method, the CS subcriterion had a weight of 51% against 49% for the DLS subcriterion.

The data collected from the 13 Sample Units (SUs) and used in the SCI-FP were applied to the ICAP. (Figure 3) presents the results found, as well as the results for the assessment of the pavement condition in the stretches by the PCI_{FVM} .

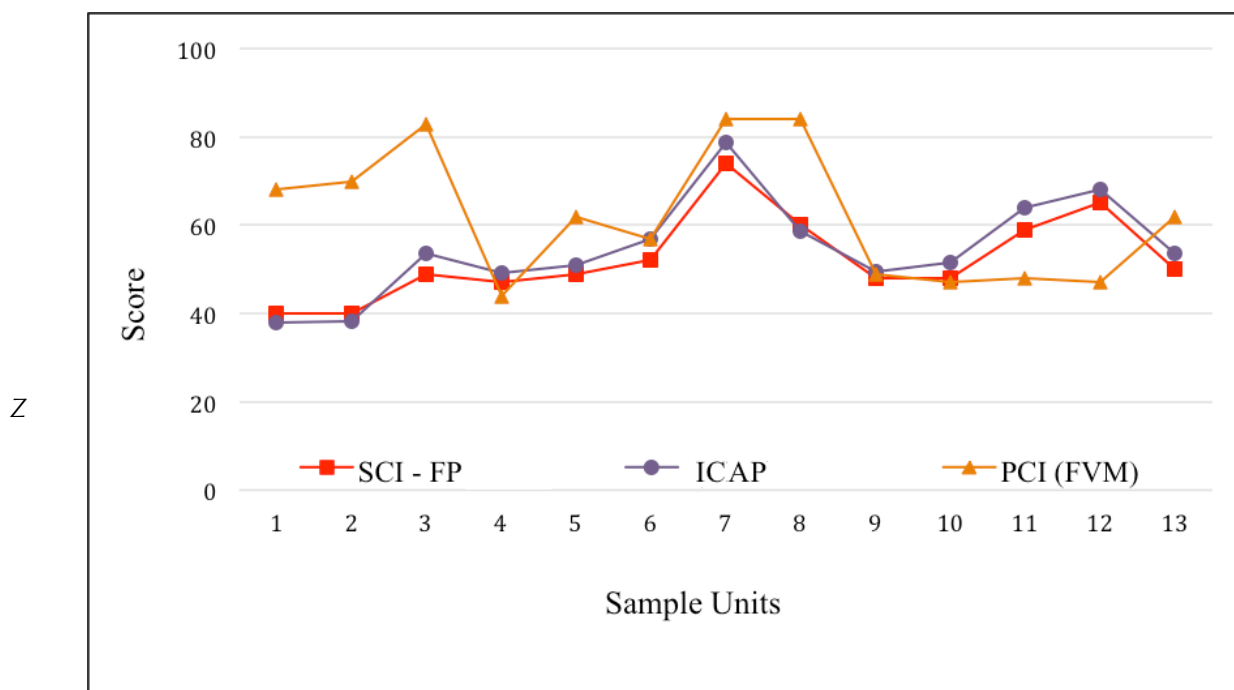


Figure 3. SCI-FP, ICAP and PCI_{FVM} of the Sample Units



The chart in (Figure 3) shows that the ICAP presents higher scores compared to the SCI-FP in 10 of the 13 evaluated stretches. Just as in the SCI-FP, the SUs with the greatest difference in values, comparing the ICAP with the PCI_{FVM} , were 1 to 3 (SUs with high bus traffic volume).

(Table 4) compares the score of the PD criterion in the ICAP and in the PCI_{FVM} (since the latter evaluates pavement condition based on distresses only).

Table 4. Comparison between the PD criterion and the PCI_{FVM}

SU	1	2	3	4	5	6	7	8	9	10	11	12	13
PD	8.57	8.57	40.00	0.00	0.00	20.00	68.57	11.43	0.00	0.00	60.00	60.00	20.00
PCI_{FVM}	68	70	83	44	62	57	84	84	49	47	48	47	62

It is possible to notice that the ICAP distress assessment method is more rigorous, since in 11 of the 13 SUs, the PD criterion scored lower in relation to the PCI_{FVM} . Because PD had the greatest weight among the factors, the ICAP evaluated the SUs with the lowest scores in relation to the PCI_{FVM} . Additionally, SUs 1-3 scored low on the BTV criterion, which made the ICAP even more rigorous. Because the other SUs scored high on the BTV criterion, the scores of the indexes had closer scores. In units 11 and 12, the PCI_{FVM} was more rigorous, since these units scored high on the PD and BTV criteria in the ICAP.

Moreover, correlation was found for each pair of indexes (ICAP versus PCI_{FVM} , and ICS-PF_{MACBETH} versus SCI-FP) by means of Pearson's correlation test. The *r* values found are shown in (Table 5), taking into account, first, all SUs, then disregarding the SUs for Benjamin Constant Street (high bus traffic volume).

Table 5. *R* values for the correlations between the condition indexes

	SCI-FP versus PCI_{FVM} (Salviatto et al., 2019)	ICAP versus PCI_{FVM}	ICAP versus SCI-FP
All SUs	0.19	0.12	0.98
Without the SUs of Benjamin Constant Street (1 to 3)	0.58	0.48	0.98

Table 5 shows that the *r* values had a reduction in the correlation between ICAP and the PCI_{FVM} compared to the correlation between the SCI-FP and the PCI_{FVM} . However, the value for the correlation between the SCI-FP and the ICAP of 0.98 reveals that there is no statistical difference between the indexes. Still from the correlation results, it is possible to observe that, just as the SCI-FP, the correlation index increased when the analysis was performed without the SUs with a high bus traffic volume.

7. Conclusions

In the structuring phase, no difference was detected when different decision-making methods were used. In both methods, it was necessary to define a main problem, as well as to determine the criteria and their respective performance levels. The construction of separate decision trees for the criteria that had subcriteria made the use of the MACBETH method more similar to that of the AHP, since in this method subcriteria are analyzed separately.



ENGLISH VERSION.....

However, it is worth noting in this study that the problem was structured in a way that enabled the use of data sourced from the investigation conducted by (Salviatto et al., 2019). Other structuring methods can be used.

Since 4 of the 6 ICAP evaluators participated in the SCI-FP criteria judgement as well, no significant changes were found in the weights of the criteria when the AHP and MACBETH methods were used, with the DNG criterion presenting the greatest change. The subcriteria, in their turn, suffered major changes with the application of different decision-making methods.

As for the application results, it can be concluded that different scores were obtained for the pavement condition of one same SU when different decision-making methods were adopted, but on a small scale, since the weights of the criteria did not undergo major changes when the two decision-making methods were applied.

The correlation test showed that the ICAP and SCI-FP indexes were strongly correlated. The greatest correlation with the PCI_{FVM} was obtained when the SUs with a high bus traffic volume were disregarded. In these SUs, the ICAP and the SCI-FP proved to be more rigorous than the PCI_{FVM} , mainly because they consider traffic in the assessment and are stricter when it comes to distress evaluation (comparing the PD criterion and the PCI_{FVM}). It should be noted that further studies will be carried out in order to enhance the index developed, so that it is capable of providing a more reliable assessment of roads with any traffic volume.

8. References

- Abu-Samra, S.; Zayed, T.; Tabra, W. (2017).** Pavement condition rating using multiattribute utility theory. *Journal of Transportation Engineering Part B: Pavements*, 143(3), 1–15. doi: <https://doi.org/10.1061/JPEODX.0000011>.
- Albuquerque, T. P. e. (2017).** Índice de condição baseado em defeitos superficiais para gerência de pavimentos urbanos (Dissertação de Mestrado). Universidade Federal da Paraíba - UFPB, João Pessoa, PB, Brasil.
- ASTM D6433-18 (2018).** Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. American Society for Testing and Materials.
- Bana e Costa, C. A.; Angulo-Meza, L.; Oliveira M. D. (2013).** O método MACBETH e aplicação no Brasil. *ENGEVISTA*, 15(1), 3-27. Recuperado de <http://periodicos.uff.br/engevista/article/viewFile/8922/6392>. doi: 10.22409/engevista.v15i1.
- HRB 61E (1962).** The AASHO road test, Rep. 5: Pavement Research. Highway Research Board.
- Cafiso, S.; Di Graziano, A.; Goulías, D. G.; D'Agostino, C. (2019).** Distress and profile data analysis for condition assessment in pavement management systems. *International Journal of Pavement Research and Technology*, 12(5), 527-536. doi: <https://doi.org/10.1007/s42947-019-0063-7>.
- Ensslin, L.; Giffhorn, E.; Ensslin, S. D.; Petri, S. M.; Vianna, W. B. (2010).** Avaliação do desempenho de empresas terceirizadas com o uso da metodologia multicritério de apoio à decisão construtivista. *Pesquisa Operacional*, 30(1), 125-152. Recuperado de http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0101-74382010000100007. doi: 10.1590/s0101-74382010000100007.
- Farashah, M. K.; Tighe, S. L. (2014).** Development practices for Municipal Pavement Management Systems Application. 2014 Conference of the Transportation Association of Canada, Montreal, QC, Canada. Recuperado de <http://conf.tac-atc.ca/english/annualconference/tac2014/s-19/farashah.pdf>.
- Hosten, A. M.; Bryce, J.; Priddy, L. P.; Flitsch, G. W.; Izeppi, E. de L.; Nelson, W. O. (2013).** Improving Network Condition with Preventive Maintenance: A Pavement Management System Case Study in Christiansburg, Virginia. 92nd Annual Meeting of the Transportation Research Board. Washington, D.C., USA. Recuperado de <https://trid.trb.org/view/1241663>
- Machado, T. P. S. de O.; Ensslin, L.; Ensslin, S. R. (2015).** Desenvolvimento de produtos usando a abordagem MCDA-C. *Production*, 25(3), 542-559. Recuperado de http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-65132015000300542. doi: 10.1590/0103-6513.625ao.
- Pereira, L. A.; Silva Junior, C. A. P.; Fontenele, H. B. (2019).** Escala visual para avaliação de pavimentos urbanos. *Revista Ingeniería de Construcción*, 34(1), 45–54. doi: <http://dx.doi.org/10.4067/S0718-50732019000100045>.
- Bazlamit, S.M.; Reza, F.; Boriboonsomsin, K. (2006).** Development of a Pavement Quality Index for the State of Ohio. 85th Annual Meeting of the Transportation Research Board. Washington, D.C., USA. Recuperado de <https://escholarship.org/uc/item/3w68q7z6>
- Salviatto, V.H.; Louro, T.V.; Neri, T.B.; Wojahn, R.E.; Souza, B.Z.; Toma, W.; Merlo, P.; Fontenele, H.B. (2019).** Índice de condição baseado em defeitos e fatores de degradação de pavimentos flexíveis. 3º Congresso Nacional de Engenharia e Tecnologia – CONET, Ponta Grossa, PR, Brasil. Recuperado de https://aeapg.org.br/conet/2019/trabalhos_aprovados.
- Villela, F. R. (2009).** Análise Multicritério para a Definição do Índice de Qualidade de Fornecimento de Energia Elétrica por uma Distribuidora (Dissertação de Mestrado). Pontifícia Universidade Católica do Rio de Janeiro - PUC-Rio, Rio de Janeiro, RJ, Brasil.
- Zanchetta, F. (2017).** Sistema de gerência de pavimentos urbanos: avaliação de campo, modelo de desempenho e análise econômica (Tese de Doutorado). Escola de Engenharia de São Carlos – EESC da Universidade de São Paulo – USP, São Carlos, SP, Brasil.

