ZULFAQAR Journal of
Defence Science, Engineering & Technology
Journal homepage: zulfaqar.upnm.edu.my

DEVELOPMENT OF A COMPOSITE PAVEMENT PERFORMANCE INDEX TO MONITOR THE PAVEMENT CONDITION IN UPNM

Muhammad Nur Arsyad Azman[a], Choy Peng Ng[b,*], Faridah Hanim Khairuddin[b], Neza Ismail[b], Wan Mohamed Syafuan Wan Sabri[b]

[a] *Student, Faculty of Civil Engineering, Universiti Pertahanan Nasional Malaysia, 57000 Kuala Lumpur*
[b] *Lecturer, Faculty of Civil Engineering, Universiti Pertahanan Nasional Malaysia, 57000 Kuala Lumpur*

*Corresponding author: *cpng@upnm.edu.my*

ARTICLE INFO

Article history:
Received
06-12-2019
Received in revised
16-12-2019
Accepted
18-12-2019
Available online
30-06-2020

Keywords:
Composite Pavement Performance Index, pavement assessment, pavement distress, pavement deterioration

e-ISSN: 2773-5281
Type: Article

ABSTRACT

Road surface condition of a pavement is one of the most important features as it affect driving comfort and safety. A good road surface condition could reduce the risk of traffic accidents and injuries. Pavement Condition Index (PCI) is one of the important tools to measure the pavement performance. By conducting pavement evaluation, civil engineers could prioritize the maintenance and rehabilitation which usually incurred a huge cost. In University Pertahanan Nasional Malaysia (UPNM), there was no proper maintenance and rehabilitation scheduled for the roads as no performance evaluation tool available to measure the pavement condition. Thus, the objective of this study was to develop a Composite Pavement Performance Index (CPPI) to monitor the pavement condition and to rank the roads in UPNM. To develop the CPPI, road defects data were collected from 6 internal roads in UPNM. From the data collected, 4 major distresses were identified: longitudinal cracking, crocodile cracking, potholes and ravelling were found more likely to affect the pavement's condition in UPNM. By measuring the growth of the distresses over a period of 6 months, modelling was conducted using simple linear regression. The growth of the distresses were compared, and odds ratios were computed to calculate the weightage of each distress for the determination of the CPPI value. The CPPI value developed could be used to rank the roads in UPNM. This study demonstrated that the road connecting to the library building in UPNM experienced the worst pavement deterioration with a PCI of 24 or a CPPI value of 1.1915. The level of severity was classified as "SERIOUS" in accordance to ASTM D6433. This road was recommended for reconstruction to increase the comfort and safety for road users.

Introduction

Road surface condition or the pavement condition, is one of the most important pavements features as it effects the dynamic load of vehicles travelling on it, the quality of travel and the vehicle operating costs. Dynamic load of vehicle travelling on pavement surface will accumulate when it is open to traffic. It is essential to consider the pavement defects under different vehicle loading and weather conditions. Road damage also can happen due to compressive strength loss attributed to poor compaction process during the construction phase.

Generally, pavement distresses are classified into two different categories. The first category is known as functional failure. In this case, the pavement does not carry out its intended function without either causing discomfort to passengers or high stresses to vehicles. The second category, known as structural failure, includes a collapse of pavement structure or the breakdown of one or more components of the pavement with such magnitude that the pavement becomes incapable of sustaining the loads imposed upon its surface (Smith et al., 1979). Functional failure of pavements depends primarily on the degree of surface roughness while structural failure in pavement may be attributed as a results of fatigue, consolidation or shear developing in the subgrade, subbase, base course or surface (Yoder and Witzak, 1975).

Road pavements require continuous maintenance and rehabilitation works to prevent defects and deterioration caused by repetitive traffic loadings and environmental factors such as weathering. However, with the limited fund allocated for pavement works, there is a need to use the available funds as effectively as possible in pavement preservations. To accomplish this, a systematic procedure for scheduling maintenance and rehabilitation works to optimize the benefits to road users and to minimize the costs to the agency responsible for pavement management is recognized as a useful measure. Pavement Management System (PMS), is a system that would allow administrators and engineers to allocate funds, personnel, resources and etc. most effectively (Hajj et al., 2011). The Pavement Condition Index (PCI) is one of the useful tool under the PMS where pavement performance evaluation is normally conducted annually in order to evaluate the changes that occurred in the road network system especially measuring the pavement performance, for example, the distresses develop in the pavements, pavement's defects and deteriorations.

The literature on PCI demonstrated that most of the PCI were determine following the procedures of American Society for Testing and Materials (ASTM) D6433 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys (Shahin, 1997; Sunitha et al., 2012; Shah et al., 2013; Setyawan et al., 2015; Kelly et al., 2016). However, various studies also demonstrated that modified or self-developed PCI were also reliable and able to predict the PCI as accurate as specified by the ASTM D6433 (Saranya et al., 2013; Tawalare and Raju, 2016; Pinatt et al., 2020; Majidifard et al., 2020). Since there was no proper PMS available in UPNM, this study objective was to develop a Composite Pavement Performance Index (CPPI) to monitor the pavement performance within the campus. A general search on the records of maintenance and rehabilitation for roads in UPNM revealed that there was no scheduled routine or periodic maintenance works for the roads. Most of the maintenance and rehabilitation works were carried out due to events (such as the convocations) or after receiving emergency and complaints from the top management.

A reconnaissance survey around UPNM was conducted in early September 2018 and it was observed that most of the roads, especially those minor roads with less traffic volumes in UPNM has minor to major distresses, defects and deteriorations. Thus, the development of a CPPI would be useful to help the UPNM's Development and Maintenance Department to carry out the assessment for the roads annually in order to schedule a routine or periodic maintenance for the pavements. This is very important to preserve the serviceability of the pavement and to ensure the pavement would last until the end of its service life. Due to limited funding is available for pavement maintenance and rehabilitation, prioritizing the roads would help the UPNM to plan and to schedule a routine or periodic maintenance for the pavements.

Methodology

Several stages must be accomplished to achieve the objectives of this study. Figure 1 shows the flow chart of the research methodology employed for this study. These include literature review, site reconnaissance survey, data collection and analysis, the development of CPPI, verification and validation of CPPI and finally pavement ranking using the developed CPPI.

A literature review provides useful information on the methodology adopted in previous studies to develop a CPPI. After literature review, a site reconnaissance survey was conducted to identify the type of pavement distresses that commonly occur in UPNM's pavements. Next, a schedule was planned to measure the growth of the distresses over the time. The pavement distresses were marked, measured, and recorded at a weekly or bi-weekly basis from October 2018 to April 2019 for a period of 6 months.

The data obtained from measuring the growth of the pavement's distresses were then used to model the growth of the distresses. This was accomplished by using Simple Linear Regression analysis in SPSS. Using the model developed, the odds ratio measuring the growths of the pavement distresses were computed. The odd ratios computed served as a guideline to calculate the weightage for each type of distresses in developing the CPPI. The CPPI developed in this study was based on the common type of pavement distresses found in UPNM's road. The developed CPPI was then verified and validated by comparing the PCI and ranking computed using ASTM D6433.

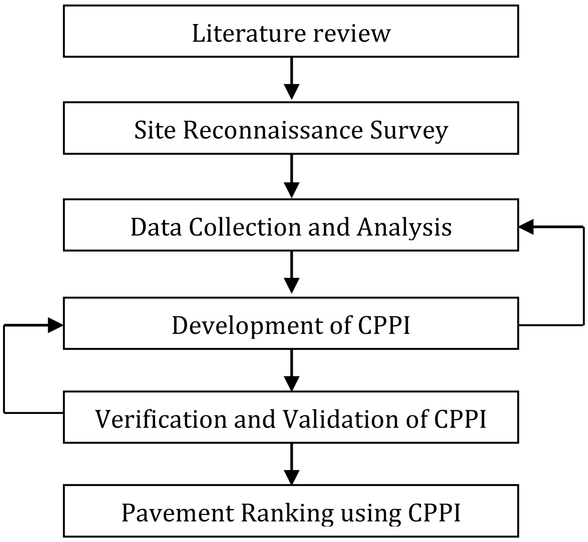


Figure 1. Flow chart of the Research Methodology

Site Reconnaissance Survey and Data Collection

During the site reconnaissance survey, 6 roads in UPNM that satisfied the site selection criteria were included in the study. The pavement distresses, such as cracking, potholes and ravelling with low to high severity were found at these locations. Figure 2 shows the layout plan of the study location.

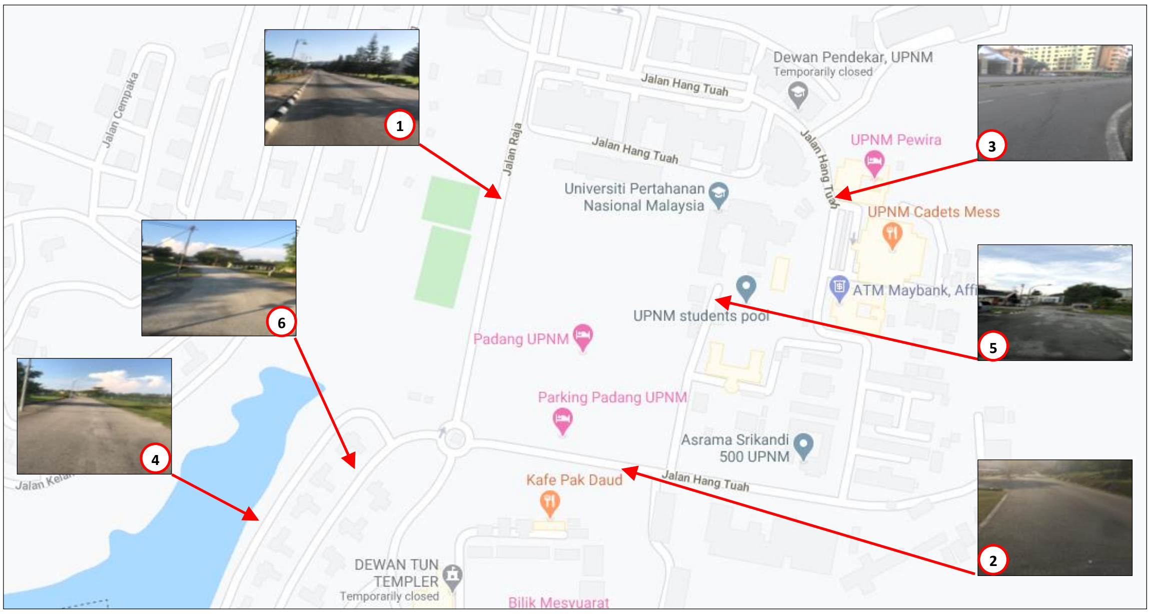


Figure 2. Layout Plan of the Study Location

The information for each road, such as the length and the width of the road were measured with measuring tape and walking measures. Table 1 showed the details of the roads. The area of the pavement was computed as this information was required to calculate the density of the pavement distress. The density of the pavement distress was computed by dividing the area of the distress by the area of the pavement and multiplied by 100 percent.

The severity level of various pavement distresses was important when interpreting the condition of the roads as different severity of pavement distress may require different rehabilitation and maintenance method and incurred different costs. The pavement distress rating criteria was as shown in Table 2. This rating criteria was adopted from Mustafa (1992) and was used as the basis for calculating the CPPI. The level of severity, i.e. low, moderate and high severity was rated as 1, 2, 3, respectively when computing the CPPI.

Table 1. Study Location

No.	Road's Name	Length (m)	Width (m)	Area (m²)
1	Main Road	330.0	8.0	2640.00
2	Lembah	157.7	9.0	1419.30
3	Wisma Pegawai Kadet	112.6	5.7	641.80
4	Marine Centre	360.0	4.6	1656.00
5	Library	179.9	7.2	1295.28
6	Officer's House	406.0	3.6	1461.60

Table 2. Pavement Distress Rating Criteria
(Source: Mustafa, 1992)

Rating Criteria	Severity of Distress		
	Low	Moderate	High
	1	2	3
Longitudinal cracking (m)	< 3	3 - 15	> 15
Crocodile Cracking (m²)	< 1	1- 3	>3
Ravelling (m²)	< 1	1- 3	>3
Pothole (m²)	< 0.3	0.3 - 0.9	> 0.9

The Growth of The Pavement Distresses

The growth of various pavement distresses, i.e. longitudinal cracking, crocodile cracking, potholes and ravelling were measured for a period of 6 months. Tables 3-6 shows the results of the growth of the distresses versus time. The growth of the distresses was modelled with linear regressions without constant. The independent variables used to measure growth were the changes in length (ΔL), changes in width (ΔW) and changes in area (ΔA) of the distresses while the dependent variable for time used in the regression was the "number of day".

Table 3. Growth Prediction Models for Longitudinal Cracking

IV: Days (d)	Model A Δ Length (ΔL)	Model B Δ Width (ΔW)
Regression	$\Delta L = 0.0484\ d$	$\Delta W = 0.0008\ d$
R-squared	0.7546	0.1325*

* Not significant, $p > 0.05$

Table 4. Growth Prediction Models for Crocodile Cracking

IV: Days (d)	Model A Δ Length (ΔL)	Model B Δ Width (ΔW)	Model C Δ Area (ΔA)
Regression	$\Delta L = 0.0491\ d$	$\Delta W = 0.0396\ d$	$\Delta A = 17.0200\ d$
R-squared	0.7595	0.8040	0.8110

Table 5. Growth Prediction Models for Pothole

IV: Days (d)	Model A Δ Length (ΔL)	Model B Δ Width (ΔW)	Model C Δ Area (ΔA)
Regression	$\Delta L = 0.0901\ d$	$\Delta W = 0.0763\ d$	$\Delta A = 16.3270\ d$
R-squared	0.8326	0.8364	0.7260

Table 6. Growth Prediction Models for Ravelling

IV: Days (d)	Model A Δ Length (ΔL)	Model B Δ Width (ΔW)	Model C Δ Area (ΔA)
Regression	$\Delta L = 0.0445\ d$	$\Delta W = 0.0245\ d$	$\Delta A = 8.6589\ d$
R-squared	0.9323	0.7692	0.8230

All models were statistically significant with the coefficient of the independent variable having a p-value of less than 0.05 and the R-squared value greater than 0.7 except for the regression model explaining the growth in the width for the longitudinal cracking. The coefficient for the independent variable was not significant with a p-value greater than 0.05 and a very low R-squared value for the model.

The Computation of Odds Ratio for Calculating the Weightage for CPPI

The odds ratio was computed to compare the relative damages of various distress to the pavement. During the computation of odds ratio, the odds ratio from the longitudinal cracking was omitted due to this distress has very minor impact on pavement performance when compared to other distresses, such as crocodile cracking, potholes and ravelling. The crocodile cracking, potholes and ravelling generally has larger effect on pavement performance as the damages cause by these distresses were classified as structural failure. They were very visible and affect the driving comfort and safety.

The odd ratios described the relative damages of these distresses to the pavement. Models C for crocodile cracking, potholes and ravelling were used to compute the weightage. The odds ratio computed between 'potholes and crocodile cracking' and 'ravelling and crocodile cracking' were 0.959 and 0.509, respectively as indicated in Equations 1 and 2.

$$\frac{\Delta A_p}{\Delta A_{cc}} = \frac{16.3270}{17.0200} = 0.959 \qquad \text{Eqn. 1}$$

$$\frac{\Delta A_r}{\Delta A_{cc}} = \frac{8.6589}{17.0200} = 0.509 \qquad \text{Eqn. 2}$$

Using the odds ratio computed, the weightage of the damages for crocodile cracking, potholes and ravelling were determine as 0.405, 0.389 and 0.206, respectively. These weightages were used to calculate the CPPI.

The CPPI and PCI Score Rating

Three different aspects were used in the calculation of CPPI: the weightage, the density and the rating of the deterioration. The developed formula used to evaluate the CPPI was taken as,

$$CPPI = \sum_{i=1}^{n} (W_i \times D_i \times R_i) \qquad \text{Eqn. 3}$$

where CPPI = Composite Pavement Performance Index; W_i = weightage of each deteriorating parameter (obtained from the odds ratio calculation); D_i = density of each deteriorating parameter and R_i = rating of each deteriorating parameter modified from Mustafa (1992).

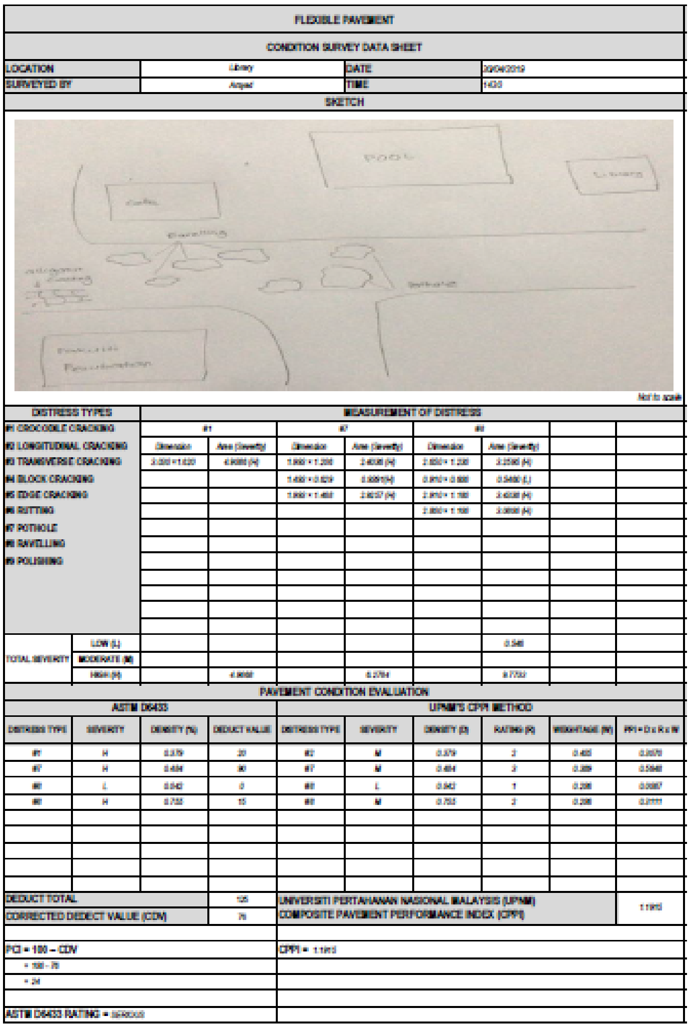
The CPPI model was modified from Tawalare and Raju (2016). The value of CPPI represents the pavement condition index, where a larger value represents larger pavement deterioration. To verify and validate the CPPI, the computation of the CPPI value and the ranking of the pavement were compared with the PCI value and ranking calculated based on ASTM D6433. A good pavement evaluation tools shall be able to rank the pavement and produce the same results as ASTM D6433. The CPPI value provide a general idea of the pavement condition and the magnitude of work that will be required to maintain or rehabilitate the pavement.

Referring to the ASTM D6433 PCI score rating, the values varies from 0 to 100, with a higher score indicating that the pavement in good or excellent condition while a lower score representing pavement below expectation that it required certain maintenance and rehabilitation. Table 7 showed the PCI in accordance to ASTM D6433. Pavements at the upper end of the scale were more likely to be candidates for maintenance and minor rehabilitation, while those in the lower ranges were more likely to require structural rehabilitation or reconstruction

Table 7. CPPI Score Rating
(Adopted from ASTM D6433, 2007)

Score	Remarks	Colour Indication
0-10	Failed	
11-25	Serious	
26-40	Very Poor	
41-55	Poor	
56-70	Fair	
71-85	Satisfactory	
86-100	Good	

The final pavement performance evaluation was conducted on 30 April 2019 using the developed CPPI. Crocodile cracking, potholes and ravelling of low to high severity levels and longitudinal cracking of low to moderate severity levels were identified using visual inspection and calculation on each road sections. Figure 3 showed the sample of the visual inspection for the road to UPNM's library.


FLEXIBLE PAVEMENT

CONDITION SURVEY DATA SHEET

LOCATION	Library	DATE	[illegible]
SURVEYED BY	[illegible]	TIME	[illegible]

SKETCH

Not to scale

DISTRESS TYPES	MEASUREMENT OF DISTRESS					
#1 CROCODILE CRACKING	#1		#7		#8	
#2 LONGITUDINAL CRACKING	Dimension	Area (Severity)	Dimension	Area (Severity)	Dimension	Area (Severity)
#3 TRANSVERSE CRACKING	[illegible]	[illegible] (H)	[illegible]	[illegible] (H)	[illegible]	[illegible] (H)
#4 BLOCK CRACKING			[illegible]	[illegible] (H)	[illegible]	[illegible] (L)
#5 EDGE CRACKING			[illegible]	[illegible] (H)	[illegible]	[illegible] (H)
#6 RUTTING					[illegible]	[illegible] (H)
#7 POTHOLE						
#8 RAVELLING						
#9 POLISHING						
TOTAL SEVERITY LOW (L)						[illegible]
TOTAL SEVERITY MODERATE (M)						
TOTAL SEVERITY HIGH (H)		[illegible]		[illegible]		[illegible]

PAVEMENT CONDITION EVALUATION

ASTM D6433				UPNM'S CPPI METHOD					
DISTRESS TYPE	SEVERITY	DENSITY (%)	DEDUCT VALUE	DISTRESS TYPE	SEVERITY	DENSITY (D)	RATING (R)	WEIGHTAGE (W)	PPI = D x R x W
#1	H	[illegible]	[illegible]	#2	M	[illegible]	2	[illegible]	[illegible]
#7	H	[illegible]	[illegible]	#7	M	[illegible]	2	[illegible]	[illegible]
#8	L	[illegible]	[illegible]	#8	L	[illegible]	1	[illegible]	[illegible]
#8	H	[illegible]	[illegible]	#8	M	[illegible]	2	[illegible]	[illegible]

DEDUCT TOTAL	[illegible]	UNIVERSITI PERTAHANAN NASIONAL MALAYSIA (UPNM) COMPOSITE PAVEMENT PERFORMANCE INDEX (CPPI)	[illegible]
CORRECTED DEDUCT VALUE (CDV)	[illegible]		

PCI = 100 – CDV

CPPI = [illegible]

ASTM D6433 RATING = [illegible]

Figure 3. Pavement Inspection for the Road to UPNM's library

The computation of PCI using ASTM D6433 required the used of distress figures as indicated in Figures 4-8. The PCI was computed using the relation PCI = 100 – CDV where CDV is the corrected deduction value. The severity and density of each distress must be identified from Figures 4-7 to obtain a deduction value. The Total Deduction Value (TDV) was then computed by adding all the deduction value. Before computing the PCI, the CDV must be identified from Figure 8 using the TDV and the total number of distress present on each road.

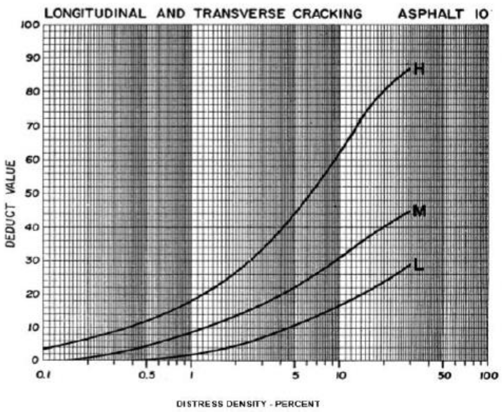


Fig 4. Flexible pavement deduction value for longitudinal cracking

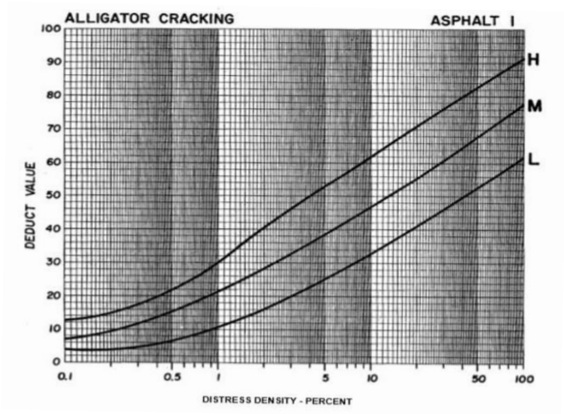


Fig 5. Flexible pavement deduction value for crocodile cracking

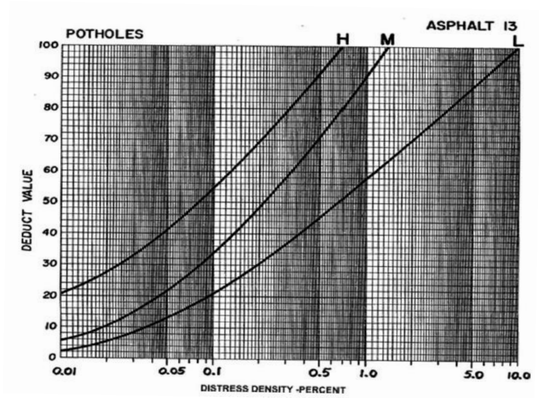


Fig 6. Flexible pavement deduction value for potholes

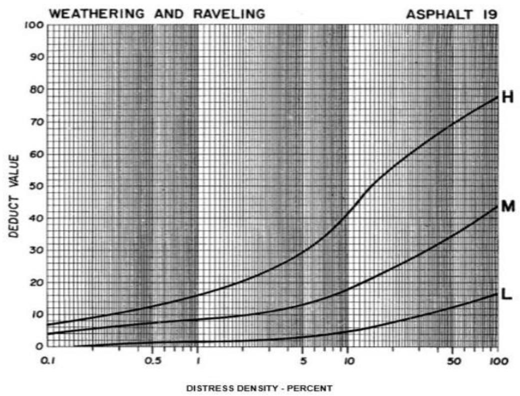


Fig 7. Flexible pavement deduction value for ravelling

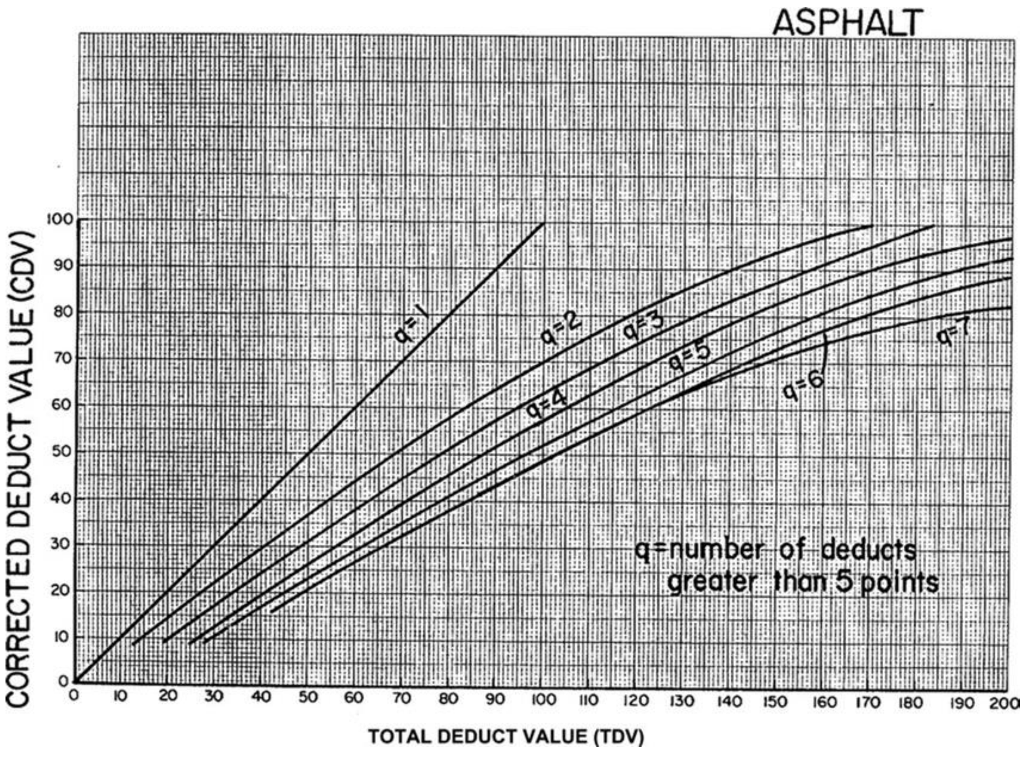


Fig 8: Corrected Deduct Value

The PCI and CPPI was computed from the visual inspections and the results were summarized as indicated in Table 8. The rankings of the PCI and the developed CPPI were found consistent, indicating that the developed CPPI was able to be used to evaluate pavement performance in UPNM accurately.

Table 8. The PCI and CPPI

No	Name of the road	ASTM D6433 Pavement Condition Index (PCI)			UPNM's Composite Pavement Performance Index (CPPI)	
		PCI	Rating	Ranking	CPPI	Ranking
1	Main Road	35	VERY POOR	2	0.0817	2
2	Lembah	76	SATISFACTORY	4	0.0451	4
3	Wisma Pegawai Kadet	77	SATISFACTORY	5	0.0132	6
4	Marine Centre	77	SATISFACTORY	5	0.0218	5
5	Library	24	SERIOUS	1	1.1915	1
6	Officer's House	67	FAIR	3	0.0762	3

Figure 9 showed the illustration of the PCI for the 6 roads in UPNM. Based on Table 8 and Figure 9, the road to UPNM's library experienced the worst condition, with a PCI of 24 and a CPPI value of 1.1915 indicating the level of deterioration was "SERIOUS". Based on the decision matrix of CPPI, this road was recommended for reconstruction. The main road condition was classified as "VERY POOR", rehabilitation works such as strengthening the base and subbase layer of the pavement and thin asphalt overlay could increase the pavement service life. Meanwhile, the road to Officer's house was classified as "FAIR", however, maintenance activities such as crack sealing and patching could preserve the pavement life. For the rest of the roads under "SATISFACTORY" rating, minimum maintenance such as crack sealing was recommended.

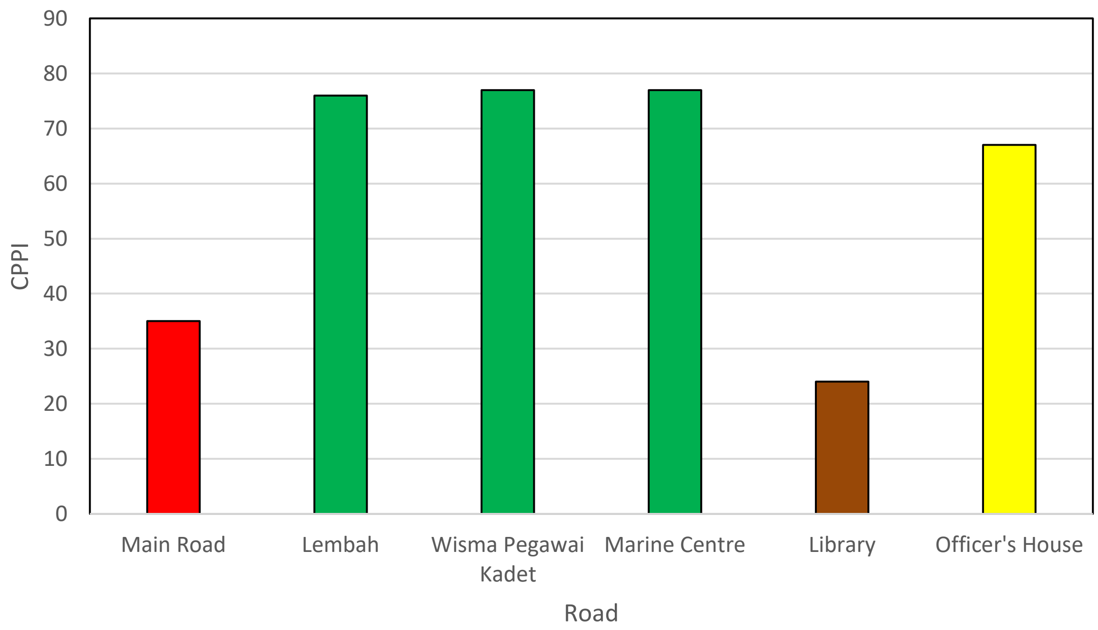


Fig 9. Pavement performance for 6 Roads in UPNM

Generally, the CPPI developed was suitable to be used as a tool to measure the pavement performance in UPNM. Using the developed CPPI, UPNM's Development and Maintenance Department could compute the pavement performance easily without having to refer to the charts from ASTM D6433. The calculation of CPPI value based on the developed CPPI could provide immediate information in the event of emergency or when immediate decision need to be made.

Conclusion

This study demonstrated that the developed CPPI could be used by the UPNM's Development and Maintenance Department to carry out the assessment for the roads annually to schedule a routine or periodic maintenance for the pavements.

Reference

ASTM D6433-07, 2007. Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys, ASTM International, West Conshohocken, PA, United States.

Hajj, E., Loria, L., Sebaaly, P., Borroel, C., & Leiva, P., 2011. Optimum Time for Application of Slurry Seal to Asphalt Concrete Pavements, Paper No. 11-4071, United States.

Kelly, G., Delaney, D. Chai, G. & Mohamed, S., 2016. Optimising Local Council's Return on Investment from Annual Pavement Rehabilitation Budgets through Targeting of the Average Pavement Condition Index. Journal of Traffic and Transportation Engineering, 3(5), 464-474.

Majidifard, H., Adu-Gyamfi, Y. & Buttlar, W.G.,2020. Deep Machine Learning Approach to Develop a New Asphalt Pavement Condition Index. Construction and Building Materials, 247, 118513.

Mustafa, M.S., 1992. A Guide to The Visual Assessment of Flexible Pavement Surface Condition. Public Works Department of Malaysia.

Pinatt, J.M., Chicati, M.L., Ildefonso, J.S. & Filetti, C.R.G.D., 2020. Evaluation of Pavement Condition Index by Different Methods: Case Study of Maringa, Brazil. Transportation Research Interdisciplinary Perspectives, 4, 100100.

Saranya, U., Sreedevi, B.G. & Sreelatha, T., 2013. Pavement Performance Modelling - A Case Study. International Journal of Innovative Technology and Exploring Engineering, 3(3), 166-170.

Setyawan, A., Nainggolan, J. & Budiarto, A., 2015. Predicting the Remaining Service Life of Road using Pavement Condition Index. Procedia Engineering, 125, 417-423.

Shah, Y.U., Jain, S.S., Devesh, T. & Jain, M.K. (2013). Development of Overall Pavement Condition Index for Urban Road Network. Procedia – Social and Behavioral Sciences, 104, 332-341.

Sunitha, V., Veeraragavan, A., Karthik, K.S. & Mathew, S., 2012. Cluster-Based Pavement Deterioration Models for Low-Volume Rural Roads. International Scholarly Research Notices, 12, 1-8.

Smith, R.E., Darter, M.I., & Herrin, S.M. 1979. Highway Pavement Distress Identification Manual. Federal Highway Administration, United States.

Shahin, M.Y., Darter, M.J., & Kohn, S.D., 1997. Development of a Pavement Maintenance Management System, Volume V, CEEDO-TR-77-44. Air Force Civil Engineering Centre, Tyndall Air Force Base, Florida, United States.

Tawalare, A. & Raju, K.V., 2016. Pavement Performance Index for Indian Rural Roads. Perspectives in Science, 8, 447-451.

Yoder, E. J. & Witzak, M.W., 1975. Principle of Pavement Design. John Wiley and Sons, United States.