A Review of Pavement Condition Rating Models for Flexible Pavements

Madhavendra Sharma[1], Pradeep Kumar[2], Sanjeev Kumar Suman[3]

[1]*M. Tech Research Scholar, Civil Engineering Department, National Institute of Technology Patna*
[2]*Principal Scientist and Head, Pavement Evaluation Division, CSIR – Central Road Research Institute, New Delhi*
[3]*Assistant Professor, Civil Engineering Department, National Institute of Technology Patna*

---***---

Abstract – *All Civil Engineering structures deteriorate with time and pavements being no exception undergo deterioration with time. The various factors that influence the deterioration process of pavements include traffic loading, climatic conditions and quality control during construction among others. An efficient Pavement Management System (PMS) is the need of the hour for maintenance of huge and rapidly growing road network of India. One of the major components of an efficient PMS is the Pavement Condition Rating (PCR) model. PCR quantifies the present pavement condition of a pavement into numeric form on the basis of functional and structural parameters that affect the pavement health. This study presents a concise review of various PCI models followed by different pavement agencies at global level to quantify the present condition of pavements along with the factors considered by agencies. This will help in evaluating the usefulness of the various models. The study will also help in refinement and development of national and state guidelines for determining PCI for a pavement section. A discussion comparing various models is also presented in this study.*

Key Words: *Pavement Management System, Pavement Health, Pavement Condition Models*

1. INTRODUCTION

With the growth of pavement infrastructure in India the need of an efficient Pavement Management System (PMS) is also increasing at a higher pace. One of the major features of a PMS is to perform pavement condition analysis and determine the present condition of road in terms of a quantifiable value. To quantify the condition of pavement reliably, an objective, repeatable rating system for identifying the pavement's condition must be used [1].

A pavement rating system tries to capture the observed distresses and deterioration of a pavement segment. The causes of pavement distresses and deterioration are environmental and structural. Environmental induced distresses are due to weathering, moisture, and aging. Loading causes structural induced distresses. Pavement deterioration usually occurs from both loading and weathering[2].

Present pavement condition is quantified in terms of either single parameter based index or composite indices. Composite indices or combined measures include the aggregation of individual measures. The most widely used indices by the highway agencies across the globe include Present Serviceability Index (PSI), International Roughness Index (IRI), Riding Comfort Index (RCI), Pavement Condition Index (PCI) and Pavement Quality Index (PQI) [3]. Apart from indices used by agencies there are others developed by researchers as per the requirement and observed deterioration pattern of flexible pavements, which in recent times includes Unified Pavement Distress Index (UPDI) [4], Overall Pavement Condition Index (OPCI) [5], Pavement Performance Index (PPI) for Indian Rural Roads [6], A fuzzy logic based methodology proposed by Singh et al. (2018) for assessment of pavement condition.

The objective of the present work is to study the existing pavement condition rating models used by various highway agencies and present a concise review of these models and systems. The study also presents a comparison of these models.

2. OVERVIEW OF EXISTING PAVEMENT CONDITION RATING SYSTEMS

Pavement Condition Indices typically provide aggregated measures of several related pavement features. Typical indices assign a rating of 100 to pavements having no discernable distress [8]. While a composite or combined index can be extremely useful at the strategic or network levels, at the project level particular information can be masked in the aggregation [3]

Existing pavement indices are based on either one of (a) Direct Panel Rating, (b) Utility Functions or (c) Deduct Values and Weighting Factors [9].

2.1. Indices determined based on Direct Panel Rating

A) Present Serviceability Index (PSI) and Present Serviceability Rating (PSR)

One of the earliest developments in composite indices is the concept of Present Serviceability Index (PSI) based on the results of AASHO road test conducted during 1950-59. Carey

Jr and Irick, (1960) developed the condition rating system for flexible and rigid pavements. The parameters considered in development of aforementioned model are slope variance (SV), Rut Depth (RD), cracking and patching. Equation (1) shows the developed relationship for flexible pavements.

$$PSI = 5.03 - 1.91\log(1 + \overline{SV}) - 1.38\overline{RD}^2 - 0.01\sqrt{C + P} \quad (1)$$

where, PSI = the present serviceability index

SV = slope variance over section (Slope Variance was an early roughness measurement)

RD = mean rut depth (in.)

C = cracking (ft2/1000ft2)

P = patching (ft2/1000ft2)

The PSR is a rating scale varying in the range of 0 to 5 with verbal rating and description as shown in table 1. PSI is a statistical estimate of the panel's mean rating i.e. PSR for a given section [10].

B) Asphalt Institute Method (Minnesota Asphalt Pavement Association)

Minnesota Asphalt Pavement Association (MAPA) devised a rating system based on subjective rating by the experts. Rating was done in a scale of zero (0) to five (5) for less serious observations while more serious observations were rated on a scale of zero (0) to ten (10). A rating of zero (0) was designated for a pavement that is free from distress [11]. Score provided for individual distresses is summed and subtracted from 100 to get overall condition rating. Defects considered in condition rating form includes Transverse Cracks (TC), Longitudinal Cracks (LC) , Alligator Cracks (AC), Shrinkage Cracks (SC), Rutting, Corrugations, Raveling, Shoving or Pushing, Pot Holes, Excess Asphalt, Polished Aggregate and Drainage Deficiency.

Table -1: PSR RANGES FROM 0 TO 5 BASED ON DESCRIPTION OF RIDE ABILITY AND PHYSICAL DISTRESS [12].

PSR	Verbal Rating	Description
4.0 – 5.0	Very Good	Only new, superior pavements that are likely to be smooth enough and distress free
3.0 – 4.0	Good	Pavements in this category, although not as smooth as above but give first class ride. Flexible pavements may be beginning to show evidence of rutting and fine cracks
2.0 – 3.0	Fair	The riding qualities of pavements in this category are noticeably inferior to those of new pavements and may be barely tolerable for high speed traffic
1.0 – 2.0	Poor	Pavements in this category have deteriorated to such an extent that they affect the speed of free-flow traffic
0.0 – 1.0	Very Poor	Pavements in this category are in an extremely deteriorated condition

2.2. Indices determined based on Utility Functions

A) Texas Department of Transportation (Tx DOT) Method

TxDOT uses the concept of Distress Score (DS) and Condition Score (CS) as discussed subsequently in (2) and (3). Defects considered under TxDOT pavement rating system are Rutting, Patching, Block Cracking (BC),AC, LC, TC and Ravelling for asphalt pavements [13].

$$DS = 100 \times \prod_{i=1}^{n} U_i \quad (2)$$

$$CS = U_{Ride} \times DS \quad (3)$$

Where Ui= utility value for distress type i and is computed as

$$U_i = \begin{cases} 1.0, & \text{when } L_i = 0 \\ 1 - \alpha e^{-\left(\rho/L_i\right)^{\beta}}, & \text{when } L_i > 0 \end{cases} \quad (4)$$

Ui ranges between 0 and 1, 1 indicates that distress type i is not present; Li represents the density of the distress in the pavement section. α (maximum loss factor), β (slope factor) and ρ (prolongation factor) control the location of the utility curve's inflection point and slope of the curve at that point as illustrated in fig. 1 [9].

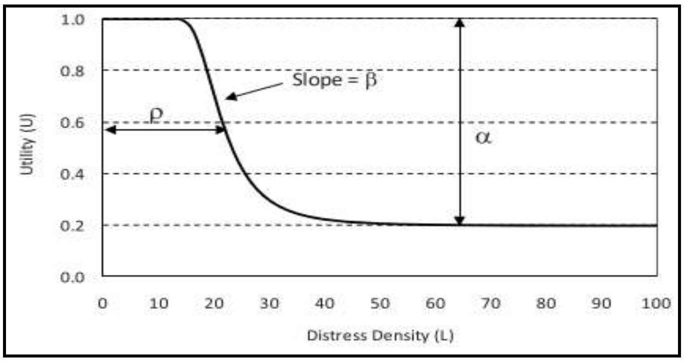

Fig- 1: General shape of utility curves used for computing Tx DOT's DS and CS (Gharaibeh et al., 2010)

2.3. Indices Determined based on Deduct Values and Weightage Factors

A) Pavement Condition Index (PCI)

PCI was modeled and documented by U.S. Army Corps of Engineers in 1976. PCI is a numerical index, ranging from 0 to 100, where 0 denotes a failed pavement while 100 denotes a pavement in perfect condition. The degree of pavement deterioration is a function of distress type, distress severity and amount or density of distress. To incorporate all these parameters in one index deduct values were introduced as a type of weighing factors [14]. PCI model can be expressed as shown in (5), fig 2 shows the scale used for PCI. The procedure was later adopted in ASTM D6433 standard

$$PCI = 100 - \sum_{i=1}^{p}\sum_{j=1}^{m_i} a(T_i, S_j, D_{ij})F(t, d) \quad (5)$$

Where PCI = Pavement Condition Index; a( ) = deduct value depending on distress type Ti, level of severity Sj and Density of Distress Dij; p = total no. of distress types; F(t,d) = an adjustment function for multiple distresses that vary with total summed deduct value (t) and number of deducts (d)

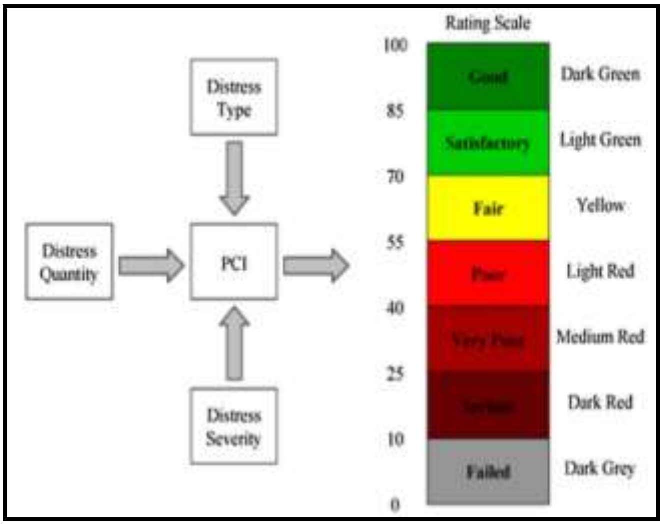

Fig-1: Procedure for calculation of PCI and Standard PCI Scale [15], [16]

B) FHWA Distress Identification Manual for NPS

Federal Highway Administration (FHWA) provides guidelines for the condition rating of pavements, park ways and parking lots in National Parks (NPS) of USA. The distresses considered in the development of guidelines for calculation of an Overall Pavement Condition Rating (OPCR) were Transverse Crack (TC), Alligator Crack (AC), Longitudinal Crack (LC), Patching / Potholes, Rutting and Roughness. The manual considers cracking as a major defect in pavements of NPS [17]. The manual suggests relationships for calculation of individual indices and then aggregating them into one single combined index. The procedure is listed in brief here.

$$AC_{INDEX} = 100 - 40 * \left[\left(\frac{\%LOW}{70}\right) + \left(\frac{\%MED}{30}\right) + \left(\frac{\%HI}{10}\right)\right] \quad (6)$$

$$LC_{INDEX} = 100 - 40 * \left[\left(\frac{\%LOW}{350}\right) + \left(\frac{\%MED}{200}\right) + \left(\frac{\%HI}{75}\right)\right] \quad (7)$$

$$TC_{INDEX} = 100 - \left\{\left[20 * \left(\frac{\%LOW}{350}\right) + \left(\frac{\%MED}{200}\right)\right] + \left[40 * \left(\frac{\%HI}{75}\right)\right]\right\} \quad (8)$$

$$PATCH_{INDEX} = 100 - 40 * \left(\frac{\%PATCHING}{80}\right) \quad (9)$$

$$RUT_{INDEX} = 100 - 40 * \left[\left(\frac{\%LOW}{160}\right) + \left(\frac{\%MED}{80}\right) + \left(\frac{\%HI}{40}\right)\right] \quad (10)$$

$$RCI = 32 * [5 * (2.718282^{-0.0041 * AVGIRI})] \quad (11)$$

$$SCR = 100 - [(100 - AC_{INDEX}) + (100 - LC_{INDEX}) + (100 - TC_{INDEX}) + (100 - PATCH_{INDEX}) + (100 - RUT_{INDEX})] \quad (12)$$

$$OPCR = (0.60 * SCR) + (0.40 * RCI) \quad (13)$$

Where LOW = Low range of severity; MED = Medium range of severity; HI = High range of severity RCI = Roughness Condition Index; SCR = Surface Condition Rating. The pavement is rated on the basis of OPCR values as POOR (OPCR<=60), FAIR (OPCR = 61-84), GOOD (OPCR = 85 – 94), EXCELLENT (OPCR =95-100) [17].

Table 1 Bituminous Pavement SR Weighting Factors [18]

Distress Type	Severity	Weighting Factor
Transverse Cracking	Low	0.01
	Medium	0.10
	High	0.20
Longitudinal Cracking	Low	0.02
	Medium	0.03
	High	0.04
Longitudinal Joint Deterioration	Low	0.02
	Medium	0.03
	High	0.04
Multiple (block) cracking	-	0.15
Alligator Cracking	-	0.35
Rutting	-	0.15
Ravelling & Weathering	-	0.02
Patching	-	0.04

C) Mn/DOT Pavement Distress Rating System

MnDOT PQI system based on Surface Rating (SR) and Ride Quality Index (RQI). As per the procedure the Total Weighted Distress (TWD) is calculated by multiplication of percent distresses and weighing factors as shown in table 2. SR value is calculated from TWD using (9) [18].

$$SR = e^{(1.386-(0.045)(TWD))} \quad (14)$$

Roughness or Ride Quality is expressed in terms of RQI using PSR developed during AASHO Road test as depicted in table 1. RQI is measured on a scale of 0 to 5, SR in the range 0 to 4 and PQI is calculated as shown in (15) in the range of 0 to 4.5.

$$PQI = \sqrt{(RQI)(SR)} \quad (15)$$

D) South Dakota's DOT Surface Condition Index (SCI)

SDDOT's SCI is a 0-5 point scale index with 5 representing minimal distress and computed using (16) as follows [19]:

$$SCI = \mu - 1.25\sigma \quad (16)$$

Where μ = mean of all contributing individual distress indices; σ = standard deviation of these individual indices. The individual index for distress 'i' is computed as

$$INDEX_i = 5 - D_i \quad (17)$$

Where Di is the deduct value determined on the basis of extent and severity of distress 'i' from table 3.

E) IRC 82:2015

IRC: 82 – 2015, i.e. Code of Practice for Maintenance of Bituminous Road Surfaces, published by Indian Road Congress, provides guidelines for determining condition ratings on a scale of 0-3 for different classes of pavement. Table 4, 5 and 6 provides rating values for different classes of pavements. The ratings are combined using weightage factors as shown in table 5.

Table 2 SDDOT's Deduct Values [19]

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

Table 3 Pavement Distress Based Rating for Highways [20]

Defects (Type)	Range of Distress		
Cracking (%)	>10	5 to 10	<5
Ravelling (%)	>10	1 to 10	<1
Potholes (%)	>1	0.1 to 1	<0.1
Shoving (%)	>1	0.1 to 1	<0.1
Patching (%)	>10	1 to 10	<1
Settlement and Depression (%)	>5	1 to 5	<1
Rut Depth (mm)	>10	5 to 10	<5
Rating	1	1.1-2	2.1-3
Condition	Poor	Fair	Good

Table 4 Pavement Distress Based Rating for MDR, ODR and Village Roads [20]

Defects (Type)	Range of Distress		
Cracking (%)	>20	10-20	<10
Ravelling (%)	>20	10-20	<10
Potholes (%)	>1	0.5-1	<0.5
Patching (%)	>20	5-20	<5
Settlement and Depression (%)	>5	2-5	<2
Rating	1	1.1-2	2.1-3
Condition	Poor	Fair	Good

Table 5 Pavement Distress Based Rating for Urban Roads [20]

Defects (Type)	Range of Distress		
Cracking (%)	>15	5-15	<5
Ravelling (%)	>10	5-10	<5
Potholes (%)	>0.5	>0 and <0.5	NIL (0)
Settlement (%)	>5	1 - 5	<1
Rut Depth (mm)	>10	5 to 10	<5
Rating	1	1.1-2	2.1-3
Condition	Poor	Fair	Good

Table 6 Weightage Factors for parameters [20]

S. No	Parameter	Weightage (Multiplier Factor)
1	Cracking	1.00
2	Raveling	0.75
3	Potholes	0.50
4	Shoving	1.00
5	Patching	0.75
6	Settlement	0.75
7	Rut Depth	1.00

3. Discussion and Conclusions

The objective of the paper is to study and review the existing Pavement Rating Models used by various highway agencies to provide an acute overview of the practices and their feasible application with or without modification. Pavement

Condition Measures are aggregated measures of the structural and material integrity of pavements. The various PCR models studied and reviewed in the study were observed to have different approaches in rating the present condition of road viz. direct rating by expert panel, utility values and deduct value approach.

Direct rating by expert panel deemed to fit for agencies having low budgets and scarce resources for pavement evaluation. Although the models under the direct panel rating are easily applicable but they include subjectivity resulting from the difference in perception of different members in panel. A well-established pavement condition rating system must be repeatable which not the case with direct panel rating systems is as a new panel could provide a different rating for the same section having same conditions.

Model based on utility values as used by TxDOT provides a good objective system of quantifying the present condition of pavement but deals with only distress type and density of distress and doesn't consider the severity of the distress. Severity being an important parameter in distress classification can affect the condition rating value of pavement significantly.

The deduct value methods are most widely used and accepted. The procedure as depicted in ASTM – D 6433 works as standard method for determination of PCI. The method as described in ASTM – D 6433 has been modified further by the agencies as per the respective conditions and distresses prevalent.

There is a disagreement seen among the distresses considered in the rating models by different agencies. The inclusion of distress in the condition rating model can be attributed to the local practices within a highway agency. For example SDDOT's SCI considers only surface distresses with types of cracking and patching aggregating into the SCI while Mn/DOT also considers rutting and raveling in their system.

Another major observation that can be drawn from the above review is the use of Standard Deviation of the contributing individual distress indexes in SDDOT's SCI. With the use of standard deviation, larger deductions can result in case of higher variability among the contributing individual indices which makes the SCI more sensitive towards even smaller change in individual distresses.

The IRC method is used in India for performing condition rating along with direct panel rating i.e. PSR and roughness measurement. IRC 82 uses rating system as per the extent of a distress on pavement surface but lacks on inclusion of severity in the rating process. The rating points provided depends on the class of road which is due to the fact that different classes of roads have different traffic loadings which affect the occurrence of particular distress and deterioration pattern of pavement as whole.

Following from above discussion it can be concluded that PCR plays an important role in PMS, but the model used for performing condition rating is case specific and depends on the prevailing local conditions, budget constraints and agency's expertise in performing pavement evaluation. There exists a difference in all the models reviewed from each other in terms of distress type considered, weighing factors and the mathematical forms of aggregation.

REFERENCES

[1] Shahin, M. Y., Pavement Management for Airports, Roads and Parking Lots. Springer US, 2005.

[2] Lavin, P. G., Asphalt Pavements: A Practical Guide to Design, Production and Maintenance for Engineers and Architects (ISBN: 0203453298). 2003.

[3] Haas, R., Hudson, W. R., and Falls, L. C., Pavement Asset Management. 2015.

[4] Juang, C. H. and Amirkhanian, S. N., "Unified Pavement Distress Index for Managing Flexible Pavements," J. Transp. Eng., vol. 118, no. 5, pp. 686–699, 2007.

[5] Shah, Y. U., Jain, S. S., Tiwari, D., and Jain, M. K., "Development of Overall Pavement Condition Index for Urban Road Network," Procedia - Soc. Behav. Sci., vol. 104, pp. 332–341, 2013.

[6] Tawalare, A. and Vasudeva Raju, K., "Pavement Performance Index for Indian rural roads," Perspect. Sci., vol. 8, pp. 447–451, 2016.

[7] Singh, A. P., Sharma, A., Mishra, R., Wagle, M., and Sarkar, A. K., "Pavement condition assessment using soft computing techniques," Int. J. Pavement Res. Technol., vol. 11, no. 6, pp. 564–581, 2018.

[8] Mcghee, K. H., "Development and Implementation of Pavement Condition Indices for the Transportation Phase I," no. September, p. 44, 2002.

[9] Gharaibeh, N. G., Zou, Y., and Saliminejad, S., "Assessing the Agreement among Pavement Condition Indexes," J. Transp. Eng., vol. 136, no. 8, pp. 765–772, Aug. 2010.

[10] Carey Jr, W. N. and Irick, P. E., "The pavement serviceability performance concept," Highw. Res. Board Bull., no. 250, pp. 40–58, 1960.

[11] MAPA, "A pavement rating system for asphalt pavement," vol. 169, no. 1, pp. 1–8, 2012.

[12] Al-Omari, B. and Darter, M., "Relationships Between International Roughness Index and Present Serviceability Rating," Transp. Res. Rec. J. Transp. Res. Board, vol. 1435, no. 2, pp. 130–136, 1994.

[13] Scullion, T. and Smith, R., "TxDOT's Pavement Management Information System: Current Status and Future Directions," 1997.

[14] Shahin, M. Y., Darter, M. I., and Kohn, S. D., "Development of a Pavement Condition Index for Roads and Streets," 1978.

[15] ASTM D6433, "ASTM D 6433–07: Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys," 2015.

[16] Almuhanna, R. R. A., Ewadh, H. A., and Alasadi, S. J. M., "Using PAVER 6.5.7 and GIS program for pavement maintenance management for selected roads in Kerbala city," Case Stud. Constr. Mater., vol. 8, no. December 2017, pp. 323–332, 2018.

[17] FHWA, "Pavement distress identification manual for the NPS Road Inventory," 2009.

[18] Mn/DOT, "Mn/DOT Pavement Distress Identification Manual," no. July, 2011.

[19] SDDOT, "Connecting South Dakota and the Nation SDDOT ' S ENHANCED PAVEMENT," 2009.

[20] IRC:82-2015, "Code of Practice for Maintenance of Bituminous Road Surfaces," 2015.