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Procedia - Social and Behavioral Sciences 104 (2013) 332 – 341
Procedia
Social and Behavioral Sciences

2nd Conference of Transportation Research Group of India (2nd CTRG)

Development of Overall Pavement Condition Index for Urban Road Network

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Abstract

Pavements are major assets of highway infrastructure. Maintenance and rehabilitation of these pavements to the desired level of serviceability is one of the challenging problems faced by pavement engineers and administration in the highway sector. The evaluation of pavement performance using pavement condition indicators is a basic component of any Pavement Management System. Various indicators like Pavement Condition Index (PCI), Present Serviceability Rating (PSR), Roughness Index (RI), etc. have been commonly used to assign a maintenance strategy for the existing pavements. The present paper is an effort in the similar direction, to develop a combined Overall Pavement Condition Index (OPCI) for the selected network of Noida urban roads.

The study area consists of 10 urban road sections constituting 29.92 km of Noida city. The methodology includes identification of urban road sections, pavement distress data collection, development of individual distress index and finally developing a combined OPCI for the network. The four performance indices viz. Pavement Condition Distress Index ($PCI_{Distress}$), Pavement Condition Roughness Index ($PCI_{Roughness}$), Pavement Condition Structural Capacity Index ($PCI_{Structure}$) and Pavement Condition Skid Resistance Index (PCI_{Skid}) are developed individually. Then all these indices are combined together to form an OPCI giving importance of each indicator. The proposed index is expected to be a good indicative of pavement condition and performance. The developed OPCI was used to select the maintenance strategy for the pavement section.

Keywords: Pavement condition distress index; pavement condition roughness index; pavement condition structural capacity index and pavement condition skid resistance index.

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Selection and peer-review under responsibility of International Scientific Committee.
doi:10.1016/j.sbspro.2013.11.126

1. Introduction

Pavement condition evaluation which includes evaluation of distress, roughness, friction and structure is one of the important components of pavement design, rehabilitation and management. Most of the cost effective maintenance and rehabilitation (M&R) strategies developed using Pavement Management System (PMS) is due to accurate pavement evaluation (Huang, 1993).

This paper presents the pavement performance evaluation for ten selected urban road sections of Noida city, near New Delhi, capital of India. The condition indicator used to represent the pavement condition of selected urban road sections is, combined Overall Pavement Condition Index (OPCI). The developed index is based on four performance indices viz. Pavement Condition Distress Index ($PCI_{Distress}$), Pavement Condition Roughness Index ($PCI_{Roughness}$), Pavement Condition Structural Capacity Index ($PCI_{Structure}$) and Pavement Condition Skid Resistance Index (PCI_{Skid}). These indices were developed individually and were then combined together to form an OPCI giving importance of each indicator. The pavement condition data was collected in the year 2012, which included measurements of longitudinal and transverse cracking, alligator cracking, potholes, rut depth, patching, raveling, roughness, structural deflection and skid resistance for all the selected ten urban road sections. All the individual condition indices and the combined index ranged from the value 0 to 100. The pavement condition was rated based these values as 0-10: Failed; 10-25: Very Poor; 25-40: Poor; 40-55: Fair; 55-70: Good; 70-85: Very Good; 85-100: Excellent.

2. Literature Survey

Some of the past studies related to pavement performance evaluation using condition indicators are presented. AASHO had undertaken pavement performance study for 123 test sections (74 flexible and 49 rigid pavement sections) to develop Present Serviceability Index (PSI) model based on subjective rating Present Serviceability Rating (PSR) and objective ground measurements. Through multiple regression analysis a mathematical index was derived and validated through which pavement ratings can be satisfactorily estimated from objective measurements taken on the pavements (Cary 1960). The pavement condition index (PCI) has been developed by the U.S. Army Corps of Engineers (1982). The PCI value is decreased by a cumulative deduct value score based upon the type, quantity, and severity level of distress and type of pavement. Karan et al., 1983 gave an approach of pavement quality index (PQI) for statistically capturing information from an expert panel. It was developed from an analysis of 40 sections rated for riding comfort index (RCI), structural adequacy index (SAI), and surface distress index (SDI), each on a scale 0 to 10. FHWA, 1990 described an index representing an overall aggregation of the different measures of pavement condition.

Juang and Amirkhanian (1992) documented the development of unified pavement distress index (UPDI) using the theory of fuzzy sets. Zhang (1993) developed a comprehensive ranking index for flexible pavements called the overall acceptability index (OAI) based on fuzzy set theory. Four parameters viz. roughness, surface distress, structural capacity and skid resistance were considered for OAL. Shoukry et al. (1997) adopted a fuzzy logic approach to derive a universal pavement distress evaluator defined as Fuzzy Distress Index (FDI) and based on this pavement sections were ranked for maintenance needs. Thube et al. (2007) developed a PSI and PCI based composite pavement deterioration models for low volume roads of India. Gharaibeh et al. (2010) compared the pavement condition indexes from five DOTs in United States, and the results showed significant differences among seemingly similar pavement condition indexes, which may be due to different distress types considered, weighting factors and the mathematical forms of the indexes, as concluded by the author.

3. Methodology and Field Data Collection

NOIDA (New Okhla Industrial Development Authority) is considered to be one of the modern cities of Uttar Pradesh state of India, about 20-kilometre southeast of New Delhi, and is the selected study area. The study area consists for a major 10 arterial/sub-arterial road sections of Noida having 29.92 km (59.84 km both sides) of total road length with four & six lanes divided carriageway. The details of the 10 road sections are given in Table 1. Various data collected for analysis are discussed in the following sections. The detailed methodology adopted for the study is presented in Fig. 1.

Table 1. Details of selected urban roads

Sr. No.	Name of the Road	Section ID	Length (km)	Number of Lanes
1	Jamnalal Bajaj Marg (MP Road No 1)	UR 01	3.5	6
2	Maharaja Agrasen Marg & Ashok Marg (MP Road No 2)	UR 02	6.0	6
3	Amrapali Marg & Golf Marg (MP Road No 3)	UR 03	7.5	6
4	Udhyog Marg	UR 04	3.2	6
5	Vindayachal Marg & Shivalik Marg	UR 05	2.2	6
6	Nithari Road	UR 06	2.4	6
7	Kamal Marg	UR 07	3.0	6
8	Amity University Road (Bet. Sec. 125 & 126)	UR 08	0.7	4
9	Lotus Valley School Road (Between Sector 126 &127)	UR 09	0.7	4
10	Road between Sector 7 & 8 (Near Vasundhara Enclave)	UR 10	0.7	4

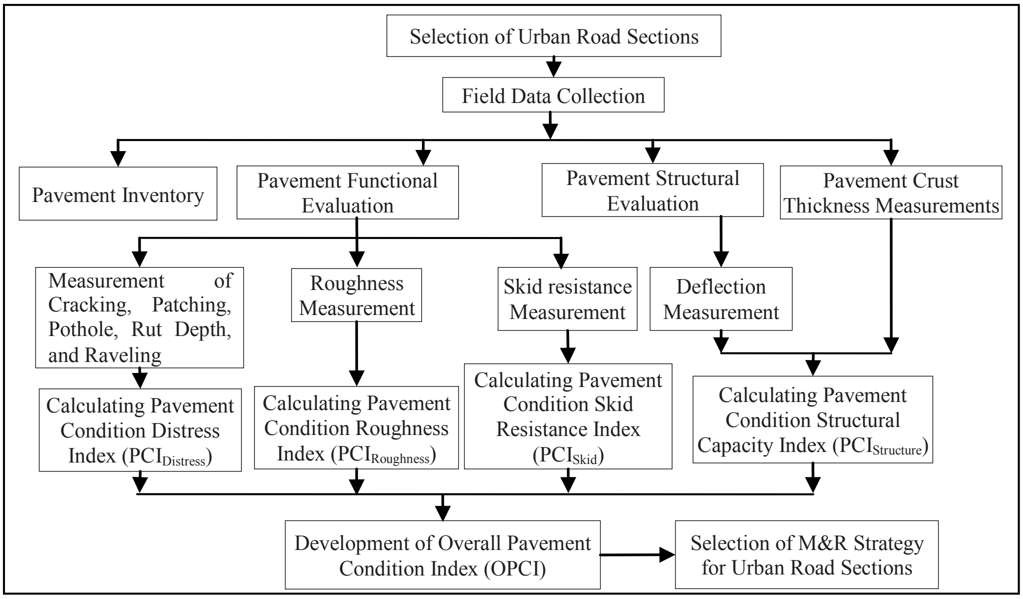

Fig. 1. Methodology for development of OCPI

3.1. Pavement inventory details

The inventory data includes the following details about selected pavement sections: Name of Road, category of road, carriageway width road geometrics, surface type, details regarding the history of maintenance and construction of these roads, etc. The same was collected from visual inspection of pavement sections and measurements, as well as from the construction and maintenance records of the highway division's in-charge of the maintenance. The objective rating of urban roadway drainage conditions have been done in four categories: excellent, good, fair, poor and very poor based on visual inspection. The rating criteria's included availability and functionality of side drains, storm water drainage system, inlets & culverts, drainage related pavement damage and adequate crown on the pavement carriage.

3.2. Pavement functional evaluation

Functional evaluation of pavements consisted of collection of road data related to severity and extent of surface distresses (cracking area and pattern, raveling area, pothole area), rut depth, skid resistance and surface roughness of selected in-service urban road sections.

The detailed description of various types of distresses considered with their level of severity is given in Table 2. The distress index was calculated using the principle of Maximum Allowable Extents (MAE). The maximum allowable extent (MAE) for low, medium and high severity level for each type of distress which is used to calculate the $PCI_{Distress}$ has also been given in Table 2.

Table 2. Description of severity levels for distresses

Sl. No	Distress Type	Severity Level	Description	MAE
1	Longitudinal and Transverse Cracking	Low	Crack with mean width < 6 mm	25
		Medium	Crack with mean width > 6 mm and < 19 mm	20
		High	Crack with mean width > 19 mm	10
2	Alligator Cracking	Low	An area of cracks with no or only a few connecting cracks; cracks are not spalled or sealed; pumping is not evident	50
		Medium	An area of interconnected cracks forming a complete pattern; cracks may be slightly spalled; cracks may be sealed; pumping is not evident.	25
		High	An area of moderately or severely spalled interconnected cracks forming a complete pattern; pieces may move when subjected to traffic; cracks may be sealed; pumping may be evident	15
3	Patching	Low	Patch has, at most, low severity distress of any type; Ride quality is affected minimally	50
		Medium	Patch has moderate severity distress of any type; ride quality is noticeably affected	15
		High	Patch has high severity distress of any type; ride quality is rough over patching	10
4	Ravelling		Not Applicable	70
5	Rutting	Low	Ruts with a measured depth ≥ 6 mm to ≤ 12 mm	80
		Medium	Ruts with a measured depth > 12 mm to ≤ 25 mm	60
		High	Ruts with a measured depth > 25 mm	30

6	Potholes	Low	< 25 mm depth	1.0
		Medium	25 -50 mm depth	1.0
		High	> 50 mm depth	0.5

- Ride quality survey: The pavement riding quality survey was conducted on the selected 10 urban road sections to develop pavement roughness based index ($PCI_{Roughness}$). The riding quality of the pavement depends on the road roughness and vehicle speed. A team of experts travelled over the selected urban road sections at design speed in a passenger car and were asked to assess the riding condition of pavement sections on a scale of 0 to 100 defined as ride quality rating (RQR).

3.3. Pavement structural evaluation

Structural evaluation of the material properties of in-service pavements is a key activity for both the project and network level pavement management systems. Benkelman Beam was used to measure the deflection as per the procedure described in IRC-81:1997. Test points were taken at a distance of 1.5 m from the edge of a pavement. A standard axle load of 8162 kg on the rear axle of the loaded truck, and a tyre pressure of 5.6 kg/cm^2 were maintained throughout. Since the deflections measured by the Benkelman Beam are influenced by the pavement temperature and seasonal variations in climate, therefore pavement temperature, and soil subgrade details were also collected at all observation points for making subsequent corrections to the deflection values.

3.4. Pavement crust thickness measurements & Material properties

The crust compositions of the existing pavement structure for all 10 selected roads were taken by digging the test pits measuring 60cm x 60cm in size. The thicknesses of different pavement layers were noted down and visual observations were taken. The properties of pavement materials were also evaluated in laboratory by collecting the samples.

4. Development of Pavement Condition Indices

4.1. Development of pavement condition distress index ($PCI_{Distress}$)

Distress Index has been calculated using following equations, for each distress to calculate the combined pavement condition index. For all distresses the threshold index value has been taken 60 to indicate that the pavement is in need of repair.

Longitudinal cracking index (LCI): LCI=100-40 [(%LOW/25)+(%MED/20)+(%HI/10)] (1)

Transverse cracking index (TC): TCI=100-40 [(%LOW/25)+(%MED/20)+(%HI/10)] (2)

Alligator cracking index (ACI): ACI=100-40 [(%LOW/50)+(%MED/25)+(%HI/15)] (3)

Patching index (PI): PI=100-40 [(%LOW/50)+(%MED/15)+(%HI/10)] (4)

Raveling index (RAI): RAI=100 - 40 (%RAVEL/70) (5)

Rut index (RI): RI=100-40 [(%LOW/30)+(%MED/15)+(%HI/10)] (6)

Percent of rut measurements within each severity = (Number of ruts within each severity/10)*100

$$\text{Pothole index (PHI): PHI}=100-40\ [(\%LOW/50)+(\%MED/30)+(\%HI/10)] \quad (7)$$

In all Eqn. (1 to 7), %LOW, %MED and %HI are the percentage of the observed pavement that contains a particular distress within the respective severities. The denominators values are the MAE for each severity indicating the percentage up to which a severity level of any particular distress is acceptable.

- Combined $PCI_{Distress}$

After evaluating the individual distress index, the combined $PCI_{Distress}$ was calculated using following Eqn (8). Since the influence of all distresses is not equal; to take into account their individual effect, different weights were assigned to distress based on expert's opinion from persons such as academicians and field engineers (Shah, Y. et al, 2012).

$$PCI_{Distress}=100\times[1-\{1-LCI/100\}\times0.355]\times[1-\{1-TCI/100\}\times0.355]\times[1-\{1-ACI/100\}\times0.355]\times[1-\{1-PI/100\}\times0.08]\times[1-\{1-RAI/100\}\times0.183]\times[1-\{1-RI/100\}\times0.12]\times[1-\{1-PHI/100\}\times0.262] \quad (8)$$

The results of combined $PCI_{Distress}$ as obtained for all 10 urban road sections in both directions are presented in Fig. 2. It can be observed that about 3 sections UR 01, UR 03, & UR 05 have 'good' pavement condition with PCI between 55-70 and remaining 7 sections are with 'very good' pavement condition with PCI between 70-85.

4.2. Development of pavement condition roughness index ($PCI_{Roughness}$)

The correlation was developed between the IRI (International Roughness Index, m/km) measured using ROMDAS and the ride quality rating (RQR) using regression analysis. The polynomial Eqn. (9) was found to be best fit and was used to calculate $PCI_{Roughness}$.

$$PCI_{roughness}= RQR = 1.227\times IRI^2-17.73\times IRI+100 \quad (9)$$

The $PCI_{Roughness}$ as calculated for all 10 sections in both directions is as shown in Fig. 3. As per the roughness criteria 3 sections UR 01, UR 03, & UR 08 fall under 'fair' pavement condition with PCI between 40-55 and remaining 7 sections fall under 'good' pavement condition with PCI between 55-70.

4.3. Development of pavement condition structural capacity index ($PCI_{Structure}$)

Structural Number is an index that quantifies the strength of the total pavement structure. For the determination of the structural capacity of the existing pavements, various methods are available among which the Non-destructive testing (deflection) is the most credited and inexpensive. $PCI_{Structure}$ has been calculated using following Eqn. (10).

$$PCI_{Structure} = 100-\left(1-(SN_{eff}/SN_o)\right)\times100 \quad (10)$$

Where, $PCI_{Structure}$ = effective structural capacity index (0-100), SN_{eff} = effective pavement structure number, SN_o = original pavement structural number.

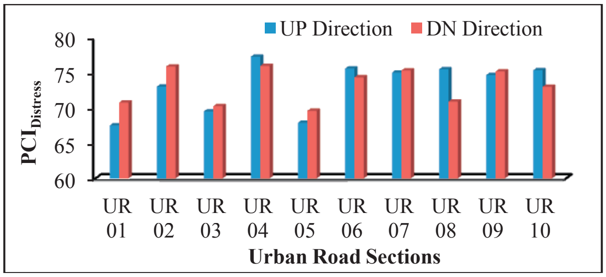

Fig. 2. Variation of combined $PCI_{Distress}$

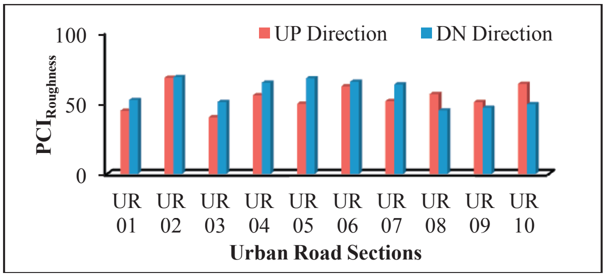

Fig.3. Variation of $PCI_{Roughness}$

The effective pavement structural number and original structural number has been calculated by the following Eqn. (11 & 12) respectively (Reddy, 1996).

$$SN_{eff} = 3.2(Def) -0.63 \quad (11)$$

$$SN_o = 0.0394 \sum_i^{nlayer} aihidi + SNSG \quad (12)$$

$$\text{Where, } SNSG = 3.5\log_{10}CBR - 0.85(\log_{10}CBR)^2 - 1.43, \text{ for } CBR \geq 3$$
$$= 0, \text{ for } CBR \leq 3 \quad (13)$$

Where, Def = deflection measured by Benkelman beam in mm, SN_o = original pavement structural number, CBR = California bearing ratio (%), SNSG = sub- grade strength contribution, a_i = strength coefficient of the i^{th} layer, hi = thickness of the i^{th} layer, d_i = drainage coefficient of the i^{th} layer.

The $PCI_{Structure}$ as calculated for selected 10 urban road sections in both directions are shown in Fig. 4. As per the structural evaluation, the pavement condition of UR 05 is found 'Excellent' (PCI: 85-100); UR 08 is 'Fair' (PCI: 40-55); UR 03, 08, 09, 10 is 'Good' (PCI: 55-70) and remaining sections is 'Very good' (PCI: 70-85).

4.4. Development of pavement condition skid resistance index (PCI_{Skid})

Surface characteristics based on the micro-texture and macro-texture properties can be manifested through this parameter. This index is incorporated into the performance to reflect the surface skidding impact. Skid resistance was measured directly from field on a scale of 0 to 100. Hence, the value as measured from portable skid resistance tester was directly considered as PCI_{Skid}. The skid resistance index for all 10 sections in both directions is as shown in Fig.5. The pavement section UR 10 was found 'fair' (PCI: 40-55); UR 09 was 'very good' (PCI: 70-85) and remaining 8 urban sections were 'good' (PCI: 55-70) with respect to skid resistance.

4.5. Development of combined overall pavement condition index (OPCI)

Once the individual pavement condition indices were calculated, all the above indices were combined together to form an combined overall pavement condition index (OPCI) which describes the pavement structural and functional capacities of the road section taking into consideration all data collected for the surface condition. Substituting each of the developed condition indicator, OPCI was calculated using following Eqn.(14). The weight for roughness, structure capacity and skid resistance were taken as 0.5, 0.75 and 0.25 respectively which were less than the distress weight (i.e. 1). Since the roughness is because of various distresses its weight is reduced a bit to avoid the doubling effect of such distresses. The weight taken for structural capacity is more than that assigned for both roughness and skid resistance as the structural characteristics have a detrimental effect on the overall pavement condition.

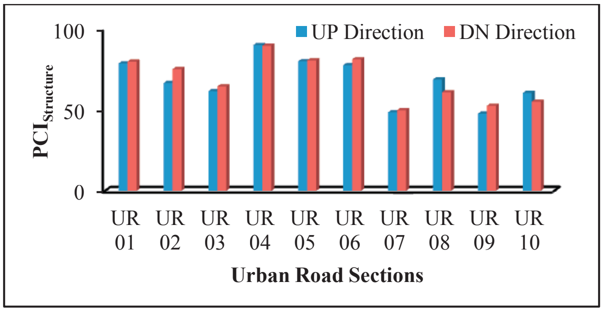

Fig.4. Variation of $PCI_{Structure}$

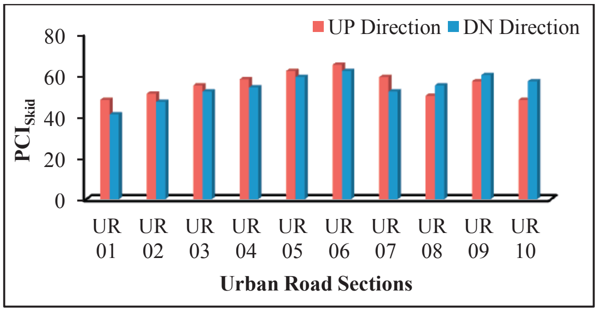

Fig.5. Variation of PCI_{Skid}

$$OPCI = f[PCI_{Distress}][PCI_{Roughness}][PCI_{structure}][PCI_{skid}]$$

$$OPCI = 100 \times [\{1-(1-LCI/100)\times 0.355\} \times \{1-(1-TCI/100)\times 0.355\} \times \{1-(1-ACI/100)\times$$
$$0.355 \times 1-1-PI100 \times 0.08 \times 1-1-RAI100 \times 0.183 \times 1-1-RI100 \times 0.12 \times 1-1-PHI100 \times 0.262 \times 1-1-PCIRou$$
$$ghness100 \times 0.5 \times 1-1-PCIstructure100 \times 0.75 \times 1-1-PCIskid100 \times 0.25 \quad (14)$$

Where, OPCI = overall pavement condition index, LCI = longitudinal cracking index, TCI = transverse cracking index, ACI = alligator cracking index, PI = patching index, RAI = raveling index, RI = rutting index, PHI = pothole index, $PCI_{Roughness}$ = pavement condition roughness index, $PCI_{Structure}$ = pavement condition structural capacity index, and PCI_{Skid} = pavement condition skid resistance index.

The results of OPCI as calculated by above equation are presented in Fig.6. The pavement condition based on individual condition indicator and combined index for all selected 10 urban road sections is shown in Fig. 7. It can be observed from figure that inclusion of a condition indicator to the previous PCI for each road degrades the pavement condition. This shows that the estimated OPCI gives a real indication of pavement condition inclusive of all functional and structural defects.

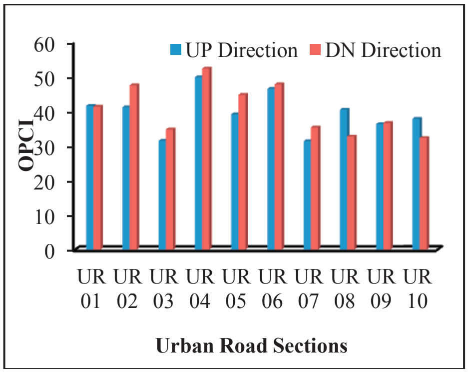

Fig.6. Variation of OPCI

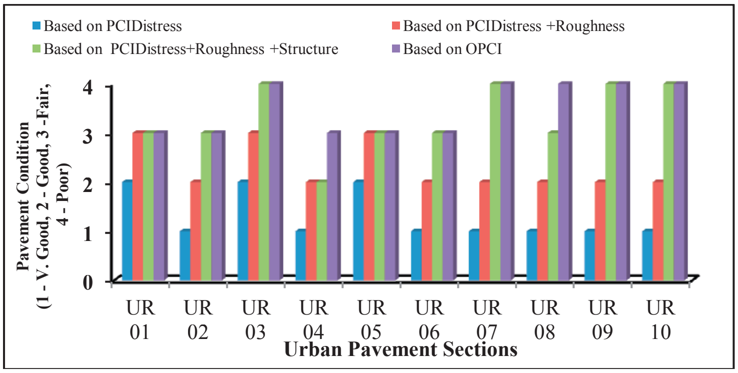

Fig.7. Pavement condition of selected urban sections

5. Selection of M&R Strategies based on OPCI

The determination of the required treatment depends on factors such as road class, surface type, pavement condition index, etc. The M&R strategies needed to be adopted based on OPCI are given in Table 3.

Table 3. M&R Strategies based on OPCI

OPCI Value	Pavement Condition Rating	M&R Strategy	Suggested Maintenance Alternatives
85-100	Excellent	Routine Maintenance	Patching, Pothole filling, Crack sealing
70-85	Very good	Preventive Maintenance	Chip Seal, Micro-Surfacing, Thin Overlays, Fog Seal
55-70	Good	Rehabilitation	Thick overlays, Mill & Overlays, Full depth patching, Premix Carpet
40-55	Fair		
25-40	Poor		
10-25	Very Poor	Reconstruction	Cold in-place recycling, Full depth reconstruction, Full depth reclamation
0-10	Failed		

Fig. 8 shows the distribution of the maintenance alternative for the selected urban road sections based on the introduction of the condition indicators one each time for the roads investigated in the study area. It was observed that 70% of pavement sections were in need for 'premix carpeting' while 30% were in need for 'thick overlay' based on $PCI_{Distress}$. While in case of $PCI_{Distress+Roughness}$, 10% pavement sections were in need for 'premix carpeting', 50% were in need for 'thick overlay' and 40% were in need for 'mill & overlay'. The distribution of maintenance alternatives based on $PCI_{Distress+Roughness+Structure}$ was 50% of pavement sections required 'thick overlay' and 50% were in need for 'mill & overlay'. There was no change observed in maintenance alternative distribution on inclusion of skid resistance values, as the selected road sections were good in skid resistance. This comparison showed that pavement structural strength has considerable impact on condition rating and consequently in the selection of optimum M&R alternatives.

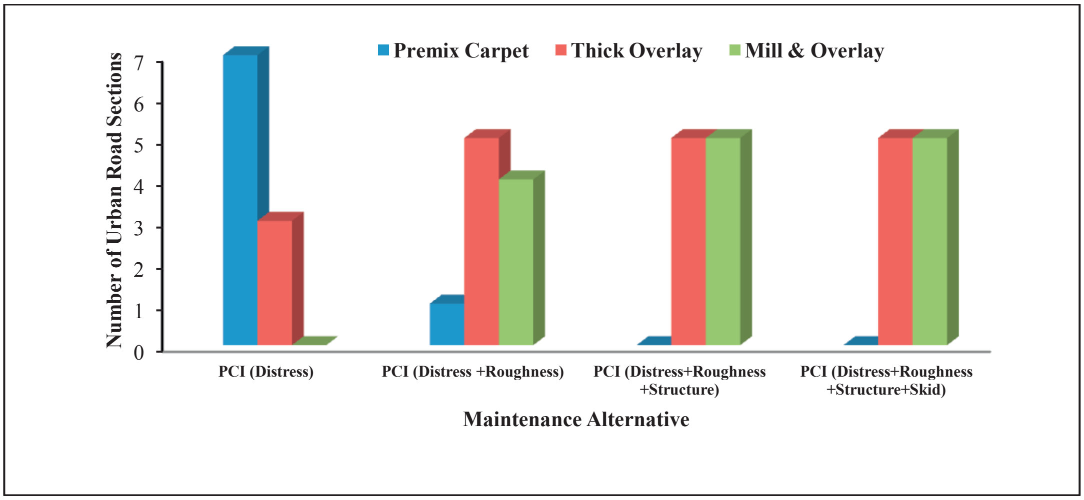

Fig.8. Distribution of maintenance alternative based on different condition indicators

6. Conclusions

The study was primarily aimed to use the outputs of different pavement condition indicators of flexible pavement in deciding the M&R requirements. The combined OPCI was evaluated by considering the effects of four main pavement performance indicators viz. distresses, roughness, structural capacity and skid resistance for selected urban road sections of Noida city. Following are the main conclusions drawn from the study.

- The minimum and maximum range of various pavement performance indicators observed on the study sections are: longitudinal cracking: 8.3% & 11.86%; transverse cracking: 2.23% & 6.61%; alligator cracking: 11.44% & 16.16%; patchng: 4378% & 12.0%, raveling: 9.58% & 29.24%; potholes: 1 & 6 nos.; IRI: 2.08 m/km & 5.41 m/km; deflection: 1 mm to 1.82 mm & SRV: 48 & 75 respectively.
- The average $PCI_{Distress}$, $PCI_{Distress+Roughness}$, $PCI_{Distress+Roughness+Structure}$ and OPCI values of selected urban road sections were found to be in a range of 69-77 (good to very good pavement condition), 51-63 (fair to good pavement condition), 37-57 (poor to good pavement condition) and 33-51 (poor to good pavement condition) respectively.
- Pavement structural strength was found to be a crucial pavement condition indicator for changing the pavement performance and deciding the M&R strategy for selected urban pavement sections.
- Structural capacity indicator is important from the fact that mostly the pavement are rehabilitated or reconstructed due to inherent structural weaknesses. Therefore, this indicator can be used to filter the pavement sections that should be selected to work on project level.
- Skid resistance index as a condition indicator is very important in the areas exposed to frequent rain and wet weather conditions. However it can be avoided, where the rain is very scarce.

It can be stated from the study that using multi-indices condition indicators is much more reliable and efficient in selecting the appropriate treatment to fully restore the riding quality and structural integrity. Further research is recommended to develop the predictive models considering the combined pavement condition indices.

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