**A SMART BI-PARAMETRIC APPROACH FOR HOMOGENEOUS DELINEATION OF RURAL ROADS**

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**Abstract:** *In order to accord maintenance and rehabilitation strategies, it is important to segment pavements that possess similar performance characteristics through the process of homogeneous sectioning. Literature revealed that the existing delineating methods help segment the pavements using individual parameters such as International Roughness Index, rutting, deflection, and skid resistance. However, the resulting segments may have similar performance within the one parameter of interest, but may be different in the case of other parameters. Hence, there is a need to define a bi-parametric based sectioning process for pavements in order to arrive at a rational maintenance treatment. Thus, the objective of this study was to define a bi-parametric approach for delineation, in which the road roughness characteristics and rutting potential were considered for defining a dimensionless parameter called “spurn” for segmentation. The dataset comprising of 561 data points was collected from Andhra Pradesh Road Development Corporation (APRDC), India. Furthermore, quality control charts were established on the spurn values to delineate the pavements as homogeneous sections having similar spurn magnitudes. A pavement treatment classification scale was also defined based on spurn for suggesting maintenance treatment for the delineated segments. It was found that the spurn-based sectioning was quite efficient to suggest appropriate maintenance strategies to the homogeneous sections compared to the existing approaches in the literature. The rational sectioning method could be applied globally for sectioning as well as treatment selection for rural roads specifically where budget constraints are prevalent. Further, the suggested maintenance strategies would reduce wastage of material and emissions, hence conserve the natural of villages creating an ambience to establish smart villages within a larger community conglomerate.*

**Keywords:** Homogeneous Sectioning, Roughness, Rutting, Pavement Asset Management System, Spurn, C-Charts

## Introduction

Of late, the development and maintenance of rural road infrastructure has become the focal point in the emerging economies, mainly to augment exchange of goods and services (World Highways 2020). Further, the economic growth is being matched with the number of rural road kilometers per capita of population. In general, road infrastructure deteriorates over time due to increased traffic loads as well as seasonal and climatic variations, which is characteristic of rural roads as well. Pavement asset management system (PAMS) is a tool used to aid in the pavement management decisions that helps reduce the deterioration rate while also enhancing the overall performance of roadway infrastructure. Based on the fundamental philosophy of PAMS, it is far less expensive to keep a pavement in good condition than to repair, if it has deteriorated. Therefore, PAMS focuses on suggesting optimum maintenance strategies to the pavement segments, especially with similar conditions (Haas et al. 2015). In the context of rural roads, scientific and innovative maintenance methods would improve the quality-of-life of smart cities and villages.

Nowadays, several agencies have started to use automated condition data collection vehicles (DCV) to map functional condition and pavement profiles as part of PAMS database creation. In the process, International Roughness Index (IRI), rutting, and texture are collected by the embedded sensors mounted within the DCVs, whereas the other distresses are retrieved from pavement videos (Bennett et al. 2006; Bogus et al. 2010; Haas et al. 2015; Ong et al. 2010; Peraka and Biligiri 2020). In order to suggest a maintenance strategy, pavement should be delineated having similar condition characteristics, called *homogeneous sections*.

In principle, segmenting the pavements into homogeneous sections is significantly affected by two factors: cost and time. As the data gets collected for long pavement stretches, a single type of treatment to the whole pavement section would result in high cost (Haas et al. 2015). Even though the agency is ready to bear the economic losses, it would not result in an efficient output. Consequentially, it will not improve the long-term performance of the pavement system (Thomas 2003, 2004). Therefore, the road section is segmented into homogeneous subsections, which will have consistent statistical properties and the information stored for each segment could be summarized without losing any significant information within each segment. The ability to delineate the general boundary locations of these segments in an effective manner is very important for maintenance and rehabilitation keeping the investment needs as top priority.

Several research studies pertinent to homogeneous sectioning of pavements have been performed having similar performance characteristic using cumulative difference approach (CDA), absolute difference approach (ADA), cumulative sum (CUSUM) method, classification and regression trees (CART) approach, and quality control charts (Cafiso and Di Graziano 2012; Donev and Hoffmann 2018; El Gendy, Amin, Shalaby 2008; Peraka and Biligiri 2020; Thomas 2003, 2004). Segmentation techniques have two main objects: (a) to identify change points where a structural modification is observed in the mean or variance of a dataset, and (b) to define indicators that characterize homogeneous sections in terms of mean and/or variance of data segments between the change points.

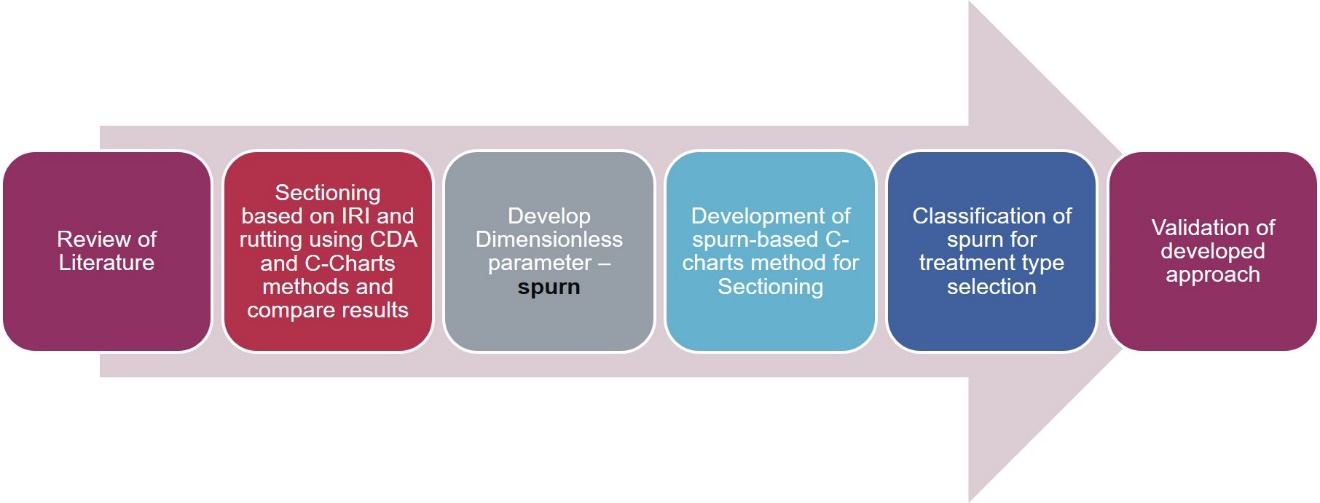
A detailed review of the segmentation methods is presented in Table 1. Importantly, homogeneous pavement sections have similar characteristics so a uniform maintenance strategy must be applied at an appropriate time. However, the existing methods / approaches delineate the pavement sections based on only one performance metric. Thus, there is a need to devise an approach to utilize more than one performance metric in the pavement delineation process in order to accord the best possible maintenance strategy, while also accounting for more than just one distress. Therefore, the objective of this study was to develop an approach to delineate pavement segments using multiple performance characteristics. It is envisioned that the novel delineation approach presented in this study will help segment the rural roadway sections in an optimal manner, and additionally suggest prioritized maintenance interventions, specifically for rural roads that are in dire need of repair and rehabilitation in several regions of the world.

**Table 1: Existing methods used for pavement segmentation**

|  |  |  |
| --- | --- | --- |
| **Source** | **Method(s) used** | **Remarks** |
| Thomas 2003 | Bayesian approach (BA) | It is sensitive to closely spaced changes, also flexible enough to “react” to changes. |
| Thomas 2004 | CDA | Non-substantial changes in trend are very frequent in these series and should be ignored (loss of data). |
| ADA | Can be preferred for long distances, not preferable for short distances as the end portions (section borders) cannot be found. Smoothening is done to find and is expected to do more harm than good when sudden change has to be identified. |
| BA | Measurement series containing excessive outliers might not be handled well. Missing values are not allowed. |
| Misra and Das 2003 | CDA | Choice of minimum section length cannot be incorporated in CDA. |
| CART | Has a better flexibility in terms of adjustments, possible to specify minimum section length and the number of delineated sections desired. |
| Tejeda et al. (2009) | CUSUM | This method produces the highest possible number of segments and the lowest sum of squared error. |
| Gendy and Shalaby (2008) | Quality control Charts (C-charts) | A profile can be segmented successfully without target range when there is no information about the referenced data was present. |
| Cafiso and Graziano (2012) | Minimization of sum of squared error (MINSSE) | Compared the SSE of CDA and ADA approaches. The method with lowest SSE would be considered for segmentation. |
| Syed and Sudhir (2015) | Falling weight deflectometer (FWD) data | Detection of local variations using CDA, T-test by making the process an iterative one (peak deflections and nearby deflections can be predicted and rehabilitated accordingly). |

The scope of the work included analyzing the characteristics of the known parameters using control charts and find a dimensionless parameter called *spurn* comprising of characteristics of IRI and rutting parameters, both measured using the automated condition survey. This was accomplished by creating a grading scale based on metrics of the known parameters, which resulted in optimum sectioning of pavement stretches using two parameters, i.e., based on bi-parametric sectioning approach. The chronology of the activities performed in this study is as follows (Figure 1):

* Review of the existing pavement delineation methods
* Sectioning of pavements using CDA and C-charts methods, and comparison of the results
* Establishment of a dimensionless quantity for the given dataset for two parameters, called spurn
* Use of C-charts method for sectioning of spurn values
* Comparison of the bi-parametric approach used in the study with the Indian Roads Congress (IRC) guidelines and check the defined scale compatibility, and
* Preparation of a new scale for the spurn value, which classifies a treatment utilizing both the parameters at individual levels.



**Figure 1: Study Methodology**

# Dataset and Comparison of Existing Methods

***2.1 Dataset***

The road maintenance division of Andhra Pradesh Road Development Corporation (APRDC), in the State of Andhra Pradesh, India collected condition data during 2015 and 2016, as part of annual maintenance activities. For this study, pavement condition data of fourteen road sections in the East Godavari district were used. These sections are major district roads (MDR) connecting the rural areas to the district headquarters and subsequently to the state highways. Poor maintenance of MDRs resulted in increased travel time and vehicle operating costs, thereby reducing the efficiency of the rural roadway infrastructure. Therefore, in this study, the maintenance of MDRs was given top priority and sectioning was performed to take appropriate decisions with respect to maintenance of rural roads and highways.

Amongst those, one road section data was used for development of the dimensionless metric spurn, and the others were used for testing the performance of the developed metric. The road section between Kakinada and Rajanagaram (56.09 km long) was used for defining spurn. The road section was an undivided sealed bituminous pavement. Rutting and IRI magnitudes were collected at every 100 m interval, which resulted in 561 data points for performing the parametric studies.

# *2.2 Comparison of Existing Methods*

In order to understand the gaps with the existing homogeneous pavement sectioning methods, delineation in this study was performed using CDA and C-chart approaches.

### **CDA Approach**

### The cumulative difference approach recommended by the American Association of State Highway and Transportation Officials ((AASHTO)-Guide (Thomas 2003)) deals with the cumulative difference of the zi values, as given in Equations (1) and (2).

(1)

Where (2)

Where, = cumulative difference of response to the mean, = response, = global mean of responses, and k = number of responses

The dataset was delineated based on the CDA method for both IRI and rutting individually. It was observed that a small change in response value resulted in a section border even though a significant change was not observed. The sectioning criteria in CDA were chosen according to the response values and a scaling was achieved, as given in Table 2 for IRI and Table 3 for rutting. A total of 24 homogeneous sections were observed when the segmentation was performed for IRI, whereas 11 sections were observed for rut depth. A schematic representation of homogeneous sectioning using CDA of chainage 20 to 40 km is given in Figure 2.

**Table 2: Sectioning criteria considered for IRI – CDA method**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Average IRI of each segment** | **Section No.** | **No. of segments in each section** | **Average IRI of each segment** | **Section No.** | **No. of segments in each section** |
| 2.0-2.2 | H1 | 1 | 4.6-4.8 | H14 | 3 |
| 2.2-2.4 | H2 | 5 | 4.8-5.0 | H15 | 5 |
| 2.4-2.6 | H3 | 8 | 5.0-5.2 | H16 | 2 |
| 2.6-2.8 | H4 | 14 | 5.2-5.4 | H17 | 4 |
| 2.8-3.0 | H5 | 11 | 5.4-5.6 | H18 | 1 |
| 3.0-3.2 | H6 | 23 | 5.6-5.8 | H19 | 1 |
| 3.2-3.4 | H7 | 21 | 5.8-6.0 | H20 | 1 |
| 3.4-3.6 | H8 | 16 | 6.0-6.2 | H21 | 2 |
| 3.6-3.8 | H9 | 16 | 6.2-6.4 | H22 | 3 |
| 3.8-4.0 | H10 | 11 | 6.4-6.6 | - | - |
| 4.0-4.2 | H11 | 9 | 6.6-6.8 | H23 | 1 |
| 4.2-4.4 | H12 | 9 | 8.2-8.4 | H24 | 1 |
| 4.4-4.6 | H13 | 3 |  |  |  |

**Table 3: Sectioning criteria considered for rut depth – CDA method**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Average of Rut depth of each segment** | **Section No.** | **No. of segments in each section** | **Average of Rut depth of each segment** | **Section No.** | **No. of segments in each section** |
| 0.0-1.0 | H1 | 1 | 6.0-7.0 | H7 | 3 |
| 1.0-2.0 | H2 | 10 | 7.0-8.0 | H8 | 2 |
| 2.0-3.0 | H3 | 54 | 8.0-9.0 | H9 | 1 |
| 3.0-4.0 | H4 | 42 | 9.0-10.0 | H10 | 1 |
| 4.0-5.0 | H5 | 22 | 10.0-11.0 | H11 | 1 |
| 5.0-6.0 | H6 | 12 |  |  |  |

### 

### **Figure 2: Homogeneous sectioning using CDA of chainage 20 to 40 km**

### **C-Charts Method**

C-charts method helps in treating the outlier data. The C-charts method was used to delineate the dataset for IRI and rutting individually. Variance, standard deviation, upper control limit (UCL), and lower control limit (LCL) are major parameters of the C-charts. The control limits were calculated for 95% confidence interval of over 560 data points. The control limits for IRI and rutting are given in Table 4. A total of 36 homogeneous sections were observed when the segmentation was performed for IRI, whereas 46 sections were observed for rut depth. Figures 3 through 5 show the outliers in IRI, rut depth, and a schematic representation of sectioning process, respectively.

**Table 4: Control limits for IRI**

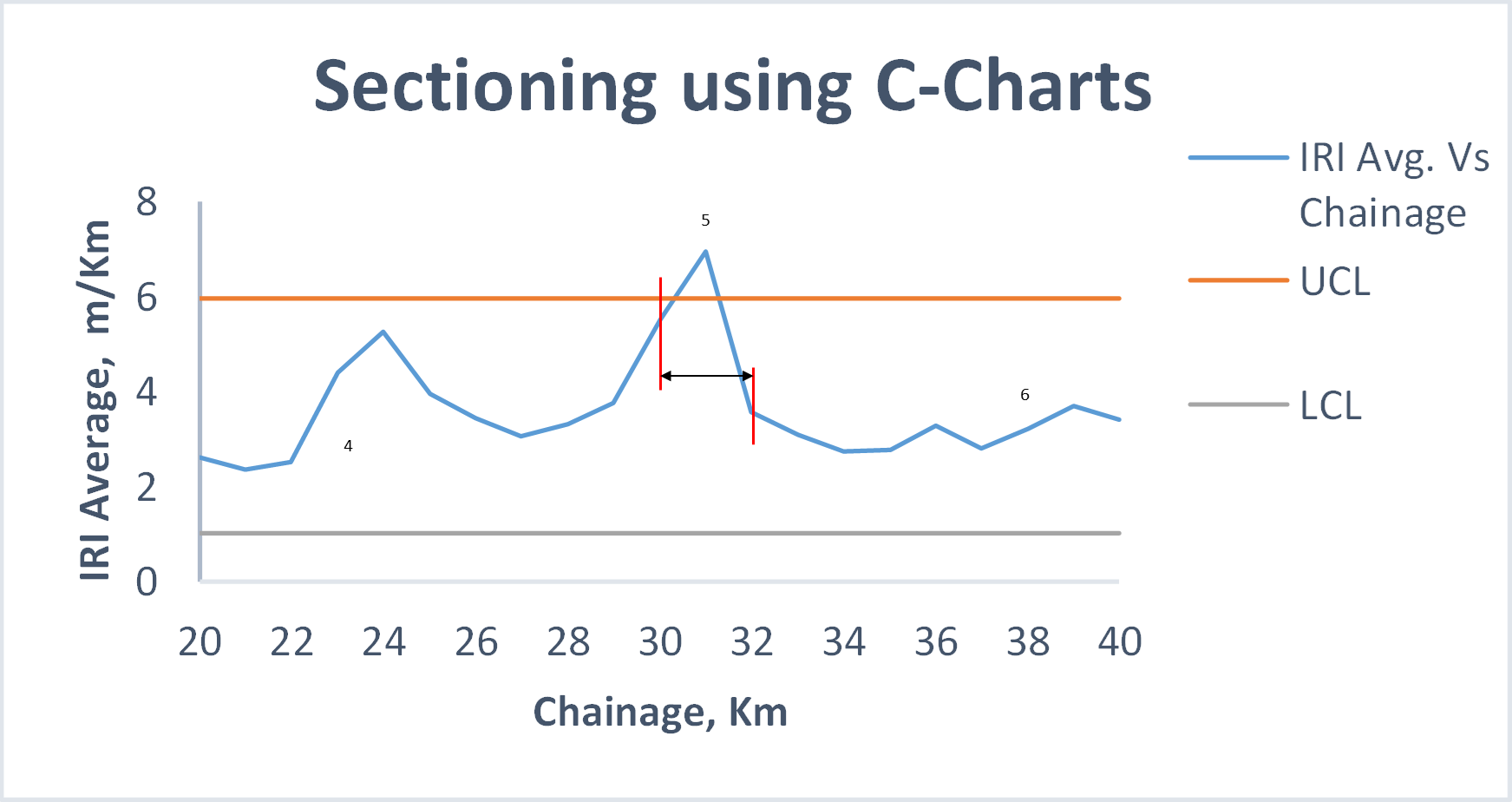
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Variance (σ 2)** | **Standard Deviation (σ)** | **UCL (μ+2σ)** | **LCL (μ-2σ)** |
| **IRI** | 1.593 | 1.263 | 6.0 | 0.95 |
| **Rutting** | 4.418 | 2.102 | 7.596 | 0 |



**Figure 3: IRI vs Chainage using C-charts**

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**Figure 4: Rut depth vs chainage using C-charts method**

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**Figure 5: Homogeneous sectioning using C-Charts approach of chainage 20 to 40 km**

The number of homogenous sections obtained in C-charts for IRI was greater than the CDA methods. This indicated that C-chart method identified sharp change in the readings, which resulted in a higher number of homogeneous sections. Similarly, C-chart method segmented higher homogenous sections for the rut depth criterion. As the chainage length was 100 m, it was essential to have higher number of homogeneous sections for rational treatment of the entire pavement stretch. Further, the C-charts method found the delineated sections with 95% confidence interval. Therefore, C-charts method was selected for the study for segmenting the other pavement sections in the dataset.

1. **Spurn – A Dimensionless Parameter for Homogeneous Sectioning**

# *3.1 Spurn*

From the previous exercise, it was observed that both IRI and rutting did not have equal number of homogeneous sections, which indicated that the effect of individual parameters was different and sectioning based on either of the parameters would not provide optimum sectioning method. Therefore, in this study, a dimensionless quantity called spurn was defined, the term which explains that the data will get rejected if it was below the requirement (decline and lower than the threshold).

Mathematically, spurn is the summation of ratio of response to the average responses of the two metrics, IRI and rutting. The mathematical expression is given in Equation (3).

, where, i = 1, 2, 3, …k (3)

Where, Spurn = dimensionless metric, xi(IRI) = IRI response, = mean of IRI responses, = rutting response, = mean of rutting responses, and k = number of datapoints in the measurement series.

Spurn was calculated for each data point, and sectioning was performed using C-charts method. The step-by-step procedure followed is as follows:

* Calculate the average of IRI and rutting,
* Compute the ratio of response to average response for each data record for IRI and rutting,
* Sum up the ratios and record it as Spurn Response (r),
* Square the responses (r2),
* Calculate mean of the response,
* Compute standard deviation,
* Calculate UCL, and LCL for two standard deviations from the mean,
* Identify outliers, and
* Introduce section borders such that the outlier data falls in a different section.

The results of the analyses are given in Table 5 and Figure 6. In addition to these, sectioning was performed using the C-charts method for IRI and rutting individually in order to check reliability of the approach. Later, the mean of the responses in each homogeneous section obtained from spurn-based C-charts method was calculated. The control limits for the spurn computed from the dataset of over 560 datapoints of the Kakinada to Rajanagaram road section with 95% confidence interval were: variance = 0.7221, standard deviation = 0.849, UCL = 3.698, and LCL = 0.301. For these homogeneous sections, the average values of IRI responses and rutting responses were computed.

In order to select a maintenance strategy, a scale for spurn should be defined. For this purpose, the IRC guidelines for rutting, and APRDC guidelines for IRI were used. The details are given in Tables 6 and 7.

**Table 5: Sample representation of** **first 10 response values of IRI and rut depth used for calculating spurn**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S.No.** | **Chainage** | **IRI** | **Rut depth** | **Xi/μ**  **(IRI)** | **Xi/μ**  **(Rut depth)** | **Spurn (r)** | **r2** | **Sectioning** |
| 1 | 0.1 | 6.25 | 8.73 | 1.79 | 2.57 | 4.372 | 19.119 | 1 |
| 2 | 0.2 | 8.98 | 7.32 | 2.58 | 2.15 | 4.743 | 22.501 |
| 3 | 0.3 | 6.91 | 3.68 | 1.98 | 1.08 | 3.073 | 9.445 | 2 |
| 4 | 0.4 | 7.77 | 5.08 | 2.23 | 1.49 | 3.733 | 13.94 | 3 |
| 5 | 0.5 | 4.34 | 5.49 | 1.24 | 1.62 | 2.868 | 8.23 | 4 |
| 6 | 0.6 | 4.18 | 3.43 | 1.2 | 1.01 | 2.215 | 4.909 |
| 7 | 0.7 | 5.69 | 8.77 | 1.63 | 2.58 | 4.222 | 17.825 | 5 |
| 8 | 0.8 | 6.31 | 4.95 | 1.81 | 1.46 | 3.275 | 10.731 | 6 |
| 9 | 0.9 | 3.2 | 1.46 | 0.92 | 0.43 | 1.352 | 1.828 |
| 10 | 1.0 | 5.24 | 5.11 | 1.5 | 1.5 | 3.016 | 9.098 |
|  |  | μ = 3.475 | μ = 3.392 | μ = 1 | μ = 1 |  |  |  |



**Figure 6: Spurn vs Chainage using C-charts method**

**Table 6: Classification pavement condition based on IRI**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **APRDC Guidelines** | | | **IRC Guidelines** | | |
| **IRI (m/km)** | **Classification** | **Indication** | **IRI (m/km)** | **Classification** | **Indication** |
| 0-4.0 | Good |  | 0-2.0 | GOOD |  |
| 4.0-6.0 | Average |  | 2.0-3.0 | AVERAGE |  |
| >6.0 | Poor |  | >3.0 | POOR |  |

**Table 7: Classification pavement condition based on Rut depth – APRDC and IRC Guidelines**

|  |  |  |
| --- | --- | --- |
| **Rut Depth (mm)** | **Classification** | **Indication** |
| 0-5.0 | Good |  |
| 5-10 | Average |  |
| >10 | Poor |  |

## 3.2 Analysis

As the dataset of the pavement between Kakinada and Rajanagaram belonged to the State of Andhra Pradesh, local guidelines were considered for pavement classification as good, average, or poor based on the parameters (IRI and rutting). After sectioning was performed based on spurn value, the segment-wise average IRI and rutting were calculated to mark the condition of the pavement based on IRC and APRDC guidelines. Further, the total dataset was classified based on the condition criteria for IRI and rutting, as specified in Tables 6 and 7. Note that the APRDC guidelines for rutting are similar to the IRC guidelines. Sectioning for a sample of data points is shown in Figures 7 and 8.

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**Figure 7: Mean of each section of IRI vs Chainage – APRDC guidelines**



**Figure 8: Mean of each section of rut depth vs chainage**

In order to define a scaling for spurn for treatment type selection, the section-wise means of IRI and rutting were compared and contrasted with the section-wise mean of spurn. After thorough observation, the treatments were categorized into four major groups: preventive, corrective, major rehabilitation, and reconstruction. The section was suggested with “preventive maintenance”, if both IRI and rutting were in acceptable limits, which reflected in a spurn value between 0 and 2. Similarly, the other scales were defined for treatments. The details of the spurn scaling for each treatment type is given in Table 8. Also, the graphical representation of section-wise treatments is given in Figure 9. Further, Table 9 shows comparison of the results of section-wise means of IRI, rutting, and spurn to check rationality of the defined classification.

**Table 8: Classification pavement treatment types based on spurn**

|  |  |  |  |
| --- | --- | --- | --- |
| **SPURN Value** | **Pavement Condition** | **Treatment type** | **Indication** |
| 0-2.0 | Good | Preventive |  |
| 2.0-4.0 | Moderate | Corrective |  |
| 4.0-6.0 | Poor | Major Rehabilitation |  |
| >6.0 | Alarming | Reconstruction |  |

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**Figure 9: Pavement maintenance treatments based on** **spurn**

As the C-charts method was used for sectioning different parameters, the length of each section varied amongst the parameters. When the spurn value indicates a specific treatment to a respective segment, the same treatment should be given to all the segments in the particular section. In Table 9, the spurn value for the segment 0.1 indicated a major rehabilitation to be performed. Therefore, the same treatment was suggested to all the segments of the section. The segments 0.2, 0.3, and 0.4 were also treated with the major rehabilitation treatment. By this classification, necessary treatments were given to the pavements efficiently.

After successful comparison and classification using APRDC data, an attempt was made to test the defined scale with the IRC classification for the dataset using the available guideline (IRC 82: 2015). It was concluded that based on IRC guidelines for IRI, most of the sections were classified as poor sections, whereas for rutting most of the sections were in good condition. The spurn-based classification has provided better classification, which is economical and novel for rural roads, especially given the budget allocated for these types of roads. The comparison is also shown in Table 9. Note the APRDC guidelines for rutting are similar to IRC guidelines, as given in Table 7.

**Table 9: Treatment type classes of IRI, Rutting, and Spurn**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Chainage (km)** | **Mean of Each Section (IRI) – APRDC Guidelines (m/km)** | **Mean of Each Section (IRI) – IRC Guidelines (m/km)** | **Mean of Each Section (Rut Depth) (mm)** | **Mean of Each Section (spurn)** |
| 0.1 | 7.4775 | 7.4775 | 8.734 | 4.558 |
| 0.2 | 7.4775 | 7.4775 | 5.00 | 4.558 |
| 0.3 | 7.4775 | 7.4775 | 5.00 | 3.073 |
| 0.4 | 7.4775 | 7.4775 | 5.00 | 3.733 |
| 0.5 | 4.737 | 4.737 | 5.00 | 2.542 |
| 0.6 | 4.737 | 4.737 | 5.00 | 2.542 |
| 0.7 | 4.737 | 4.737 | 8.77 | 4.222 |
| 0.8 | 6.31 | 6.31 | 3.181 | 2.262 |
| 0.9 | 3.802 | 3.802 | 3.181 | 2.262 |
| 1 | 3.802 | 3.802 | 3.181 | 2.262 |

### **3.3 Validation of the Proposed Approach**

In order to test the performance of the defined spurn-based pavement sectioning and classification, the data pertaining to thirteen road sections of the East Godavari district, Andhra Pradesh was used. Amongst them, the results of two road sections are presented below.

* 43 km long undivided sealed bituminous road section between Mandapeta and Jonnada, and
* 14 km long undivided sealed bituminous road section between Dwarapudi and Yanam.

### **Mandapeta to Jonnada Road**

The road connecting Mandapeta and Jonnada of East Godavari district covering a stretch of 14 km is an undivided sealed bituminous pavement. The spurn-based C-charts method was used to delineate the pavement as homogenous sections. Further, the section-wise means of IRI, rut, and spurn were calculated. The sections were classified based on IRC and APRDC, and later spurn values were tabulated with suitable color coding (as given in Tables 6 through 8) in Table 10 for one km stretch of the road section. From IRC guidelines, all the road sections were in the poor condition, whereas, the sections were in good condition for rutting. The spurn-based classification analyzed this complex incidence, and corrective maintenance strategy was suggested as well.

### **Dwarapudi to Yanam Road**

The road connecting Dwarapudi and Yanam of East Godavari district covers a stretch of 43 km and is an undivided sealed bituminous pavement. Similar procedure as described before was adopted, and the results of 1 km road section are shown in Table 11. For this pavement section, the mean of rutting was quite high, whereas the section IRI was acceptable. spurn developed suggested that the pavement should be reconstructed, as high rutting will lead to massive structural failure.

**Table 10: Mandapeta to Jonnada road: Comparison of pavement condition or treatment classification as per IRC, APRDC, and spurn**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Chainage**  **(km)** | **Mean of each section (IRI) (as per APRDC) (m/km)** | **Mean of each section (IRI) (as per IRC) (m/km)** | **Mean of each section (rut depth) (mm)** | **Mean of each section (spurn)** |
| 0.1 | 4.489 | 4.489 | 3.492 | 2.048 |
| 0.2 | 4.489 | 4.489 | 9.068 | 3.563 |
| 0.3 | 4.489 | 4.489 | 4.736 | 2.164 |
| 0.4 | 4.489 | 4.489 | 4.736 | 2.164 |
| 0.5 | 4.489 | 4.489 | 4.736 | 2.164 |
| 0.6 | 4.489 | 4.489 | 4.736 | 2.164 |
| 0.7 | 4.489 | 4.489 | 4.736 | 2.164 |
| 0.8 | 4.489 | 4.489 | 4.736 | 2.164 |
| 0.9 | 4.489 | 4.489 | 4.736 | 2.164 |
| 1 | 4.489 | 4.489 | 4.736 | 2.164 |

**Table 11: Dwarapudi to Yanam road: Comparison of pavement condition or treatment classification as per IRC, APRDC, and spurn**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Chainage (km)** | **mean of each section (IRI) (as per APRDC) (m/km)** | **Mean of each section (IRI) (as per IRC) (m/km)** | **Mean of each section (rut depth) (m)** | **Mean of each section (spurn)** |
| 0.1 | 3.974 | 3.974 | 4.332 | 2.308 |
| 0.2 | 3.974 | 3.974 | 4.332 | 2.308 |
| 0.3 | 3.974 | 3.974 | 4.332 | 2.308 |
| 0.4 | 3.974 | 3.974 | 4.332 | 2.308 |
| 0.5 | 3.974 | 3.974 | 4.332 | 2.308 |
| 0.6 | 3.974 | 3.974 | 4.332 | 2.308 |
| 0.7 | 3.974 | 3.974 | 14.284 | 5.642 |
| 0.8 | 3.974 | 3.974 | 14.284 | 5.642 |
| 0.9 | 3.974 | 3.974 | 14.284 | 5.642 |
| 1 | 3.974 | 3.974 | 14.284 | 5.642 |

# Conclusions and Recommendations

After referring to all the existing methods, it was concluded that the existing methods perform sectioning using one parameter as the input. The objective of this study was to provide optimum maintenance strategy to rural roads based on bi-parametric homogeneous sectioning using C-charts method. A dimensionless quantity called *spurn* was defined, which included IRI and rutting as the distress criteria. Scaling was defined for spurn in order to suggest four different types of treatments for the homogeneous sections. Fourteen road sections of the APRDC dataset retrieved from the state roadway agency in India were considered. All the 14 sections were made up of sealed bituminous pavement types. Amongst those, one was considered for defining spurn and the remaining sections were used for verification of the rationality of the defined approach. The scope of the study was confined to bituminous pavements only. However, similar approach could be adopted for cement concrete pavements.

It was found that the spurn-based sectioning was quite efficient in suggesting appropriate pavement maintenance strategies to the homogeneous sections compared to the existing approaches in the literature. The rational sectioning method could be applied globally for sectioning as well as treatment selection for rural roads, specifically where budget constraints are found to exist. The innovative spurn-based segmentation is anticipated to provide optimum maintenance interventions, thereby improving the efficiency of the roadway infrastructure. Further, the suggested maintenance strategies would reduce wastage of materials and emissions, hence conserving the natural resources in the vicinity of villages, in turn creating an ambience to establish smart villages within a larger community conglomerate. Most importantly, the study could be extended further by incorporating additional parameters to the *spurn* metric to obtain more reliable quantification of pavement condition as well as sectioning.

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