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Multi-Parametric Delineation Approach for Homogeneous Sectioning of Asphalt Pavements †

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Abstract: Maintenance of homogeneous road sections is one of the approaches to economizing the overall management of pavement systems. The objective of this study was to develop a multi-parameter-based delineation approach to segmenting the pavements into subsections in a way that considers multiple pavement characteristics. Deflection bowl parameters, pavement functional performance, surface layer modulus, and traffic were analyzed to develop a multi-parametric delineation index (MPDI), which was used in C-charts-based segmentation to obtain homogeneous sections. Importantly, the segmentation processes were automated using a deep neural network designed for rational implementation by practitioners. The devised approach was found to be efficient in segmenting the pavements, selecting the sections that are in direst need of maintenance, and necessitating prompt response from the agencies.

Keywords: homogeneous sectioning; deflection bowl parameters; delineation; pavement maintenance; C-charts; functional performance

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1. Introduction

Roadway maintenance and rehabilitation are critical to sustaining the economy of any nation. In 2021, the roadway network in the United States of America (USA) was ranked with a 'D' grade by the American Society of Civil Engineers (ASCE) [1]. According to the International Transport Forum, France spent EUR 2 billion on the maintenance of roadway infrastructure. This was found to be the highest amongst 63 participating countries, although the spending details were not available for India [2]. With the growing importance of preserving the existing pavement infrastructure, the Government of India initiated asset recycling processes to monitor and manage pavements in order to ensure that they cater to traffic needs during their remaining service lives [3]. In order to plan a maintenance intervention, it is essential to collect present pavement condition data and predict future performance. Additionally, it is essential to segment the pavements based on similar characteristics so as to establish an optimum level of maintenance intervention at the project level. The existing homogeneous sectioning methods include cumulative difference approach (CDA), absolute difference approach (ADA) [4–7], Bayesian algorithm [8], cumulative sum [9], quality control charts [10], and minimization of sum of squared error approach [11], all of which consider individual pavement performance parameter at a time for delineating the pavement sections.

In another study, Donev and Hoffmann [12] considered rutting, surface defects, and alligator approaches cracking in sectioning pavements based on similar characteristics for project-level maintenance applications. However, the outcomes were found to be suitable for short measurement series and were obtained with a methodology that may not be suitable for application elsewhere, especially in emerging economies [13]. Further, artificial intelligence (AI) techniques were used for pavement delineation, which reduced the tedious analysis process when using a single parameter for segmentation. However, the use of AI techniques for segmentation using multiple parameters was yet to be verified [14]. A recent study tested the performance of the C-charts method in segmenting the roadway sections that utilize two parameters: the international roughness index (IRI) and rutting [6]. It was found that the bi-parametric approach developed in the study was efficient in the segmentation process compared to the traditional methods. However, there is a need to explore the interaction of the other parameters such as deflection and traffic in the pavement segmentation process.

It is noteworthy that the previous studies only used one pavement condition parameter at a time when segmenting pavement sections. These studies repeated the procedure later for the remaining parameters to obtain the optimum homogenous segmentation. This was found to be monotonous, resulting in a rigorous analysis of the results, and tedious, possibly leading to erroneous results if the analyses were to be delayed. Therefore, there is a need to develop a multi-parametric-based sectioning approach, where multiple parameters can be considered simultaneously for use in sectioning. Thus, the objective of this research study was to develop a multi-parameter-based delineation approach (MPDA) to segment the pavements into subsections with similar features encompassing functional, structural, and traffic characteristics. It is envisioned that the developed approach would certainly reduce the analysis costs and duration and help the decision-making authorities to identify the optimum homogeneous sections at the project level.

2. Multi-Parametric Delineation Approach Framework

C-charts are among the statistical quality control methods widely used to monitor the defects in the production process, as well as for several engineering applications. The C-charts method was basically used for the data, which were obtained in a count-type fashion. Since homogeneous sectioning was performed for different pavement performance parameters that were measured at regular intervals, the data was presumed to be in a count-type arrangement. The results of the C-chart-based pavement homogeneous segmentation were better than those of the other segmentation methods [9]. Therefore, C-charts were used to perform homogeneous segmentation, with consideration given to multiple pavement characteristics. A series of tasks was performed to develop the MPDA for the homogeneous sectioning of roads.

- Metric formulation: a procedure was formulated to identify the parameters of homogeneous sectioning, pre-processing of data, and formulation of a multi-parametric delineation index (MPDI) as a function of identified parameters for sectioning and calculation of the control limits for MPDI, which included mean, standard deviation, and the upper control limit and lower control limit from the entire dataset.
- C-charts-based MPDA: a process that was adopted to construct C-charts for MPDI for each road section in the dataset. This could identify the outlier data and helped us to segment the sections between the outliers as homogeneous sections.
- Validation of the developed approach was undertaken as the final step.

2.1. Multi-Parametric Delineatoin Index

The necessity of segmenting the pavements that have the most similar characteristics formed the basis for the selection of multiple parameters for segmentation. The pavement deflection bowl parameters such as peak deflection, base layer index (BLI), middle layer index (MLI), and lower layer index (LLI), being representative of the structural integrity of the pavement system, were chosen. Additionally, a metric called unified pavement health index (UPHI) was utilized after its development by the authors. This value indicated the functional condition of the pavements based on their current distress levels on a scale of 0 to 100. In addition to these, higher traffic volumes that increase the rate of deterioration were also selected, along with the modulus corresponding to the structural capacity of the pavement system. The data from 26 road sections in the State of Andhra Pradesh, India, was used for this study, including: falling weight deflector (FWD) deflections, distresses, roughness, traffic measured in terms of annual average daily traffic, and existing pavement layer thickness details. The distresses were used to assess the present functional condition of the pavement in terms of UPHI, a functional performance measuring unit devised by the authors to rate the pavements on a scale of 1 to 100, where 100 points indicates a very good condition of the pavement and 1 signifies that the pavement needs to be reconstructed. Surface layer modulus was calculated using KGPBACK^{TM} software using FWD deflections and existing pavement thickness data.

2.2. MPDI Formulation

A dimensionless parameter called MPDI was formulated with the normalized values of all the parameters, as show in Equation (1). Note that the normalized parameters were added to account for the individual contribution of each of the parameters during homogeneous sectioning.

$$MPDI_i = \frac{UPHI_i}{\mu_{UPHI}} + \frac{DO_i}{\mu_{D0}} + \frac{BLI_i}{\mu_{BLI}} + \frac{MLI_i}{\mu_{MLI}} + \frac{LLI_i}{\mu_{LLI}} + \frac{AADT_i}{\mu_{AADT}} + \frac{E_i}{\mu_E} \quad (1)$$

where i = datapoint; μ_{UPHI} = mean UPHI of the entire dataset (1781 data points); μ_{BLI} = mean BLI, µm; μ_{MLI} = mean MLI, µm; μ_{LLI} = mean LLI, µm; μ_{AADT} = mean AADT; and μ_E = mean back-calculated elasticity modulus of surface layer, MPa

The control limits identify an unexpected variation in the quality control process. In the past, researchers [15,16] have also used two standard deviations (in place of three standard deviations) to recognize the warning limits without compromising the quality of the established control limits and the process capability. Thus, in this study, the control limits of the MPDI accounted for the use of two standard deviations to rationally ascertain the homogeneous segments and the overall process stability.

3. Results

C-charts were constructed for MPDI for the whole dataset, covering 1,781 data points. The points that crossed the UCL and LCL were recorded as outliers. Section boundaries were introduced to the chart when the curve crossed either UCL or LCL. The data points that were present between any two section boundaries were regarded as "homogeneous segments". Based on the mean MPDI of the homogeneous segments, 34 homogeneous section types were defined, and maintenance strategies were suggested based on mean MPDI, whose details are available in Peraka [17]. The homogeneous sections of a road section and C-charts for the MPDI in the State of Andhra Pradesh between chainages of 22.41 and 28.71 km are shown in Figure 1. In the entire dataset of 26 road sections, a total of 389 homogeneous sections belonging to 34 homogeneous section categories were identified. Amongst all the sections, 57.58% of them were found to need corrective maintenance, while 25.96% would require minor rehabilitation. The minimum length of the homogeneous section was found to be 300 m (<500 m), which was appropriate for project-level maintenance applications, as also reported by Jannat et al. [18].

In order to validate the developed approach, the results were compared to the homogeneous sections obtained using CDA. There was such a section for each parameter considered in the formulation of MPDI. The results revealed that the MPDI approach was better for homogeneous segmentation. Finally, the data processing and basic computations involved in the calculation of MPDI, C-charts, and segmentation were automated using a regression-type feed-forward deep neural network approach.

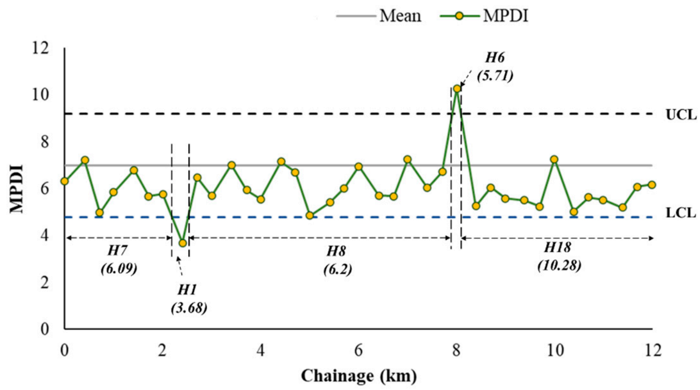

Figure 1. MPDA-based Homogeneous Sectioning of a Road Section in Andhra Pradesh State.

4. Conclusions and Recommendations

The delineation process developed in this study considered multiple parameters for the segmentation of asphalt pavements to accord maintenance activities. The major conclusions and recommendations are as follows:

- MPDI-based categorization for maintenance treatment selection: MPDI-based pavement maintenance selection scale was defined to provide insights into the roadway practitioners in order to select appropriate maintenance interventions for the designated homogeneous sections.
- Automation of delineation process: the DNN would serve as a one-stop solution for pavement segmentation in order to potentially help the practitioners in project-level maintenance applications.
- Recommendation: The multi-parametric delineation approach developed in this research study considered seven parameters in order to obtain the homogeneous roadway segments using a C-chart-based approach. However, other pavement characteristics must also be incorporated in future for better segmentation. These should be validated using the current method.

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