ANALYSIS AND MODELLING OF PAVEMENT CONDITION INDEX

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ABSTRACT

The development of a PCI (Pavement Condition Index) model integrated with Paver and ArcGIS involves creating a robust system for assessing and managing pavement conditions. Paver software facilitates data collection and analysis, while ArcGIS enables spatial visualization and analysis. This integration aims to enhance the accuracy and efficiency of evaluating pavement conditions, leading to better-informed decision-making in prioritizing maintenance strategies. To determine the Level of Service (LOS) for a specific road segment using PCI, the model evaluates the pavement condition by considering various distress factors such as cracking, rutting, surface deterioration, and other observable issues. These distresses are assigned numerical values, allowing the PCI to quantify the overall pavement condition, which in turn determines the LOS. Following the PCI assessment, maintenance priorities can be established based on the severity of distresses identified. Higher priority should be given to segments with lower PCI scores, indicating more significant distresses that require immediate attention. Conversely, segments with higher PCI scores may need less urgent maintenance but should still be monitored to prevent further deterioration. The integration of PCI, Paver, and ArcGIS offers a comprehensive approach to pavement management, enabling data-driven decision-making and efficient allocation of resources for pavement maintenance and rehabilitation, thereby ensuring safer and more durable road infrastructure.

Keywords: Pavement condition index, ArcGIS, paver, LOS

1. INTRODUCTION

A transportation infrastructure's base ensures that goods and people are moved consistently and effectively. Economic progress is dependent on efficient mobility. One of the more crucial forms of transportation for economic growth is the road. Roads are essential to a nation's growth and development because they provide access to social, medical, and educational resources and provide economic opportunities. Roads contribute to both cultural and economic growth. For these reasons, road infrastructure is thought to be the most important of all public assets. Roads are regarded as the most crucial public resource that actually contributes to the development and growth of a country. Due to time and constant use, road infrastructure ages and needs maintenance. Because of constant use and aging, road infrastructure needs to be renewed, maintained, and upgraded. To maintain and improve the road infrastructure's usability, proper maintenance is required. In accordance with pavement condition index values determined by Pavement Condition Index (PCI), pavement distresses were assigned. In order to predict pavement distress quantities, statistical models were created that took into account pavement age, socioeconomic features, climate, and average daily traffic (ADT). It was envisaged that this project would combine the use of GIS and PAVER systems to gather and evaluate data on pavement degradation.

A pavement section's general state can be determined using its pavement condition index (PCI), a numerical value that ranges from 0 to 100. In order to assess the effectiveness of the road infrastructure and service levels, numerous municipalities use the PCI, which is extensively utilized in asset management and transportation civil engineering. It constitutes a statistical metric that necessitates a manual pavement survey. The US Army Corps of Engineers created this index initially as a rating system for airport pavement, but it was later adjusted for roadway pavements and standardized by the ASTM.

This paper introduces the crucial role of road infrastructure in economic growth, emphasizing the need for regular maintenance and upgrades due to continuous use and aging. It highlights the importance of the

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Pavement Condition Index (PCI), a numerical value from 0 to 100, for assessing pavement conditions and guiding maintenance efforts. The chapter explains that the PCI, developed by the US Army Corps of Engineers and standardized by ASTM, is vital for evaluating road infrastructure effectiveness and service levels. This study addresses the challenges in India's road maintenance practices, which rely heavily on subjective judgment and often lack comprehensive data analysis. Integrating PAVER and ArcGIS with a pavement management system is proposed to improve the analysis of PCI, severity levels, and maintenance priorities, thereby enhancing road infrastructure management. The study aims to identify and classify pavement distresses, display conditions on a topographic sheet, develop a PCI prediction model, study the impact on Level of Service (LOS), and suggest maintenance strategies. The scope includes the integration of ArcGIS and PAVER software for PCI calculation and determining LOS to facilitate better maintenance decisions. The chapter also outlines the report structure, detailing the content of each subsequent chapter, from literature review and methodology to prediction model development, effects of PCI on LOS, and project conclusions.

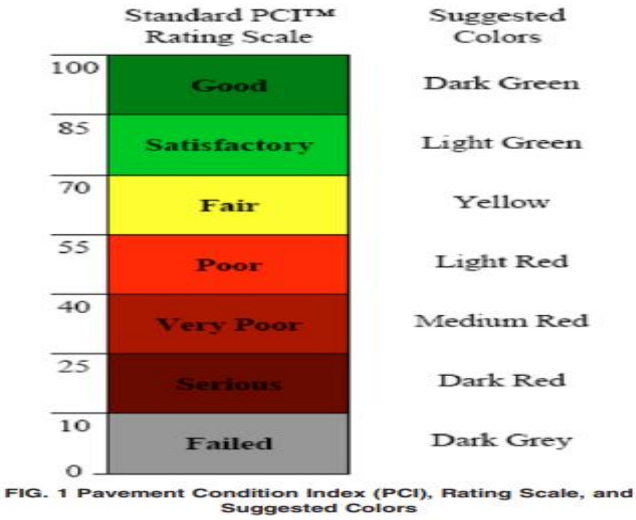

Figure 1: Pavement Condition Index Rating Scale

For every road segment or project, a Pavement Condition Rating (PCR) score between 0 and 100 is calculated; a number of 100 denotes no problems. In cases when there are faults, a 'Deduct' value is subtracted from 100 to produce the PCR. A pavement segments "deduct" is a numerical value ranging from 0 to 100 that is allocated to a combination of flaws found therein. It is acquired by giving each distress a deductible value. It is obtained by giving each sort of distress, along with its degrees of severity and extent, a deduct value. The subtract values within a specific segment. Subtracting a 'Deduct' value from 100. 'Deduct' is a number from 0 to 100 that is assigned to a combination of defects observed in a pavement segment. It is obtained by assigning deduct value to each distress type and its levels of severity and extent. The deduct values in a given segment.

2. METHODOLOGY

The research methodology employed in this study involved a systematic approach including literature review, data collection, processing, analysis, and interpretation to evaluate the impact of the Pavement Condition Index (PCI) on the Level of Service (LOS) of road segments. A literature review was conducted to understand pavement condition indexing, performance evaluation, pavement deterioration models, and methodologies used in previous studies. The study was carried out on a segment of the Main Central Road (MC Road), also known as State Highway 1 (SH1), in the Kottayam district of Kerala, India, selected based on its significance and varying pavement conditions. Field data collection included pavement distress data through visual inspection, geometric characteristics using measuring tapes and GPS, and traffic data recorded via video-based automatic traffic counters and radar guns. Roadway inventory details such as section identification and dimensions were documented. PCI was determined using Micro PAVER software by inputting distress data, classifying severity, and applying the PCI calculation algorithm. Computed PCI values were integrated with ArcGIS software for geospatial visualization of pavement distress severity. A regression model was developed using SPSS software, considering PCI as the dependent variable and traffic volume, vehicle speed, distress severity, pavement age, and deduct value as independent variables to predict future pavement conditions. The effect of PCI on LOS was analyzed using the Highway Capacity Manual (HCM) framework, evaluating free-flow speed variations, PCI-LOS relationships, and the impact of pavement conditions on vehicle speeds and road capacity. Based on findings, an optimized maintenance strategy was proposed, prioritizing preventive maintenance for satisfactory PCI sections, corrective maintenance for moderately distressed sections, and rehabilitation for poor condition sections to ensure efficient resource allocation for sustainable pavement management.

3. STUDY AREA

The selected field of study is The Main Central Road, also referred to as MC Road, is a busy state highway in the Indian state of Kerala which starts at Kesavadasapuram in Trivandrum and finishes at Angamaly, a Kochi suburb in the Ernakulam District. It is known as Kerala Public Works Department State Highway 1. In the 1790s, Raja Keshavadasa, the Dewan of Travancore, constructed the route. Thiruvananthapuram–Angamaly Greenfield Highway is a proposed new highway that is currently in the early stages of building. It runs parallel to MC Road.

3.1. Data required

Among the data that was collected were the following elements:

- Pavement condition data: This database contained the following information for each road section: section identification, section type, section location, section dimensions, and the Present Serviceability Rating (PSR) along with other relevant information.
- Additional variables: this database contained the following: a) the inventory of roadway geometry (name, arterial, collector, or local); b) traffic data. The inventory also included the following variables: length (m); width (m); type (divided or non-divided); and directions (one- or two-way).

The pavement condition quantities were measured and the gathered data was presented using the following software.

4. DATA COLLECTION AND ANALYSIS

Table 1: Inventory data of the selected road stretches

No.	Name of the road stretch	Length in Km	Width in m	No. of stretches
1	Pakalomattom - Kuravilangad	2	7	12
2	Thurithipally- Kalayilpadi	2.5	7	10
3	Mandiram – Chingavanom	2	7	10
4	Mariyappally- Manippuzha	2	7	12
5	Kumaranelloor- Sankranti	2.5	7	8
6	Muthumoola- Vazhappally	2	7	15
7	Pallom -Nattakom	2	7	8
8	Mavilangu - Pallom	2	7	8
9	Gandhinagar Jn- Carithas Jn	2	7	8
10	Kalikavu- Vempally	2	7	10

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4.1. Types of distress were identified

- Alligator crack
- Bleeding
- Edge crack
- Pothole
- Depression
- Corrugation
- Patching and Utility Cut Patching
- Weathering

4.2. Analysis Of Pavement Condition Index

Table 2: Analysis of pavement condition index

No.	Name of the road stretch	PCI	Severity level
1	Pakalomattom - Kuravilagadu	58	fair
2	Thurithipally- Kalayilpadi	62	fair
3	Mandiram – Chingavanom	55	Poor
4	Mariyappally- Manippuzha	67	fair
5	Kumaranelloor- Sankranti	82	satisfactory
6	Muthumoola- Vazhappally	31	Very poor
7	Pallom -Nattakom	68	fair
8	Mavilangu - Pallom	67	fair
9	Gandhinagar Jn- Carithas Jn	78	satisfactory
10	Kalikavu- Vempally	59	fair

4.3. Pavement condition in GIS data base

The collection and analysis of data for pavement condition assessment along ten road stretches on State Highway 1 (SH1). Primary surveys gathered inventory details, such as road stretch names, lengths (2-2.5 km), widths (7m), and the number of sections (8-15), segmented based on distress severity and road conditions. Secondary surveys identified distress types (alligator cracking, bleeding, edge cracking, potholes, etc.) and their severity levels (low, medium, high). Distress parameters were normalized to percentages of total area affected. The Pavement Condition Index (PCI) was calculated using Micro PAVER software, considering distress densities and deduct values for each distress type and severity level. PCI values were computed for each sample unit, reviewed for consistency, and aggregated for the entire pavement section. GIS integration visualized PCI data spatially, aiding in maintenance planning. Maintenance strategies based on PCI and traffic volume were developed. Strategies included preservative treatments, routine maintenance, patching, and reconstruction, tailored to the condition of each road segment. A summary table listed PCI values and recommended maintenance measures for each road stretch, highlighting the importance of considering both PCI and traffic volume for effective pavement management.

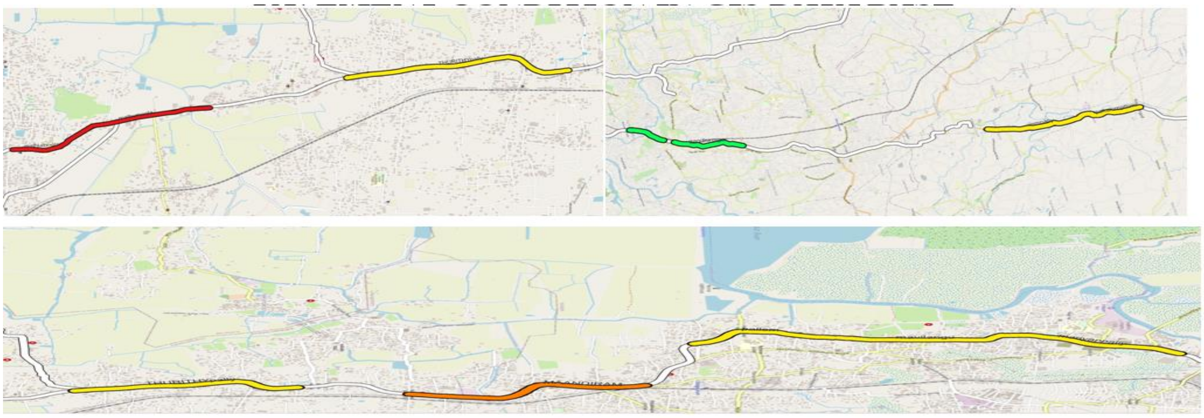

Figure 2: Showing pavement condition in GIS data

4.4. Prediction Model For Pavement Condition Index

The developed model for Pavement Condition Index (PCI) with the corresponding coefficient of determination (R-squared value) is presented as follows:

PCI=97.887-9.911 X1-.557 X2-.409 X3-.258X4-.076X5+.883X6 **(1)**

Correlation coefficient= 0.993

Where, PCI: Pavement Condition index

X1: No. of three wheelers (PCU)
X2: No. of three wheelers (PCU)
X3: No. of LCV (PCU)
X4: No. of HV (PCU)
X5: Total volume
X6: average travel speed of the road stretch

The correlation coefficient for this model is 0.993, indicating a strong relationship between the independent variables (traffic volume, severity, age, speed) and the dependent variable (PCI). developed and validated a prediction model for Pavement Condition Index (PCI) using various parameters such as traffic volume, severity, road age, average travel speed, and vehicle types. The model was developed using 70% of the collected data and validated using the remaining 30%. Statistical analyses, including descriptive statistics, correlation analysis, and multiple linear regression, were conducted using SPSS software to understand the relationships between the variables and to develop the prediction model. The model was found to have a high correlation coefficient (0.993), indicating a strong relationship between the independent variables and the dependent variable (PCI). The regression analysis resulted in a model equation = 97.887 - 9.911X1 - 0.557X2 + 0.409X3 - 0.258X4 - 0.076X5 - 0.883X6 where X1 to X6 represent different independent variables related to traffic volume, sveerity, and speed. The model's statistical validity was assessed using the t-test and the R-squared value, which measures the proportion of the variance in the dependent variable that is predictable from the independent variables. While exact statistical validity metrics were not provided, the high correlation coefficient suggests that the model is likely to be statistically valid. Model validation was performed by comparing observed and predicted PCI values, resulting in small error margins (APE and MAPE) for various road segments. The model's high accuracy suggests that it can effectively estimate PCI values, aiding in proactive maintenance planning and decision-making. Overall, this chapter demonstrates the use of SPSS to develop a robust prediction model for PCI, enabling efficient management of road infrastructure and optimal pavement performance.

4.5. Level of Service of The Road Segment

The vehicle flow speed data and level of service of each segment were given below. the equation used to the calculation of Percentage of Free Flow Speed is

$$PFFS = \frac{ATS}{FFS} \times 100 \quad (2)$$

Where: PFFS –percentage free flow speed for direction;

ATS –estimated travel speed for direction(mil/hr);

FFS –estimated free flow speed (mil/hr).

Table 3: The vehicle flow speed data and level of service

Sl.No.	Road segment	ATS	FFS	PFFS	LOS
1	Pakalomattom-Kuravilagadu	38	58	65.52	C
2	Thurithipally- Kalayilpadi	32	54	59.26	C
3	Mandiram – Chingavanom	22	42	52.38	D
4	Mariyappally-Manippuzha	44	61	72.13	C
5	Kumaranelloor - Sankranti	47	60	78.33	B
6	Muthumoola -Vazhappally	28	48	58.33	D
7	Pallom -Nattakom	42	56	75	B

4.6. Effect Of Los on PCI

Table 4: PFFS and PCI values for the seven selected road segments

Location	PCI	PFFS
Pakalomattom - kuravilagadu	58	64.51
Thurithipally- Kalayilpadi	62	66.66
Mandiram – chingavanom	55	48.27
Mariyappally- manippuzha	67	71
Kumaranelloor- sankranti	82	75
Muthumoola- Vazhappally	31	40.74
Pallom -nattakom	68	74.19

This relationship underscores the importance of maintaining good pavement conditions to ensure high LOS, highlighting the need for regular maintenance and timely rehabilitation of road segments to improve traffic performance and reduce vehicle operating costs.

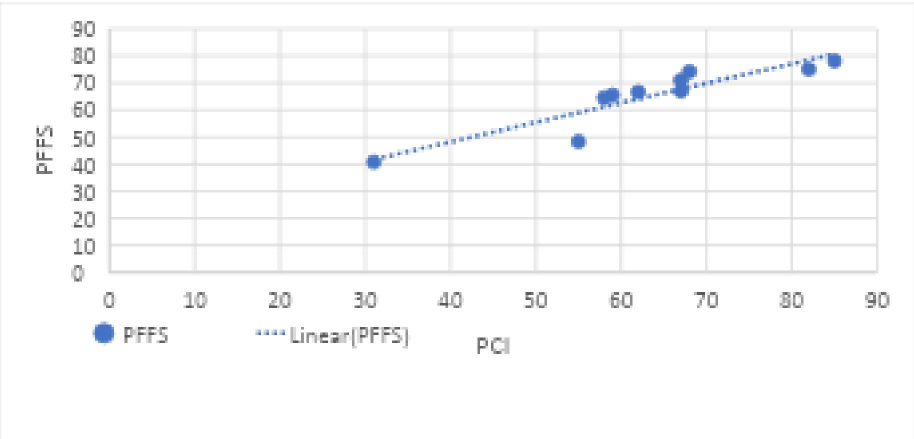

Figure 3: Graph of PFFS and PCI values for the seven selected road segments

For this study, the effects of the Pavement Condition Index (PCI) on the Level of Service (LOS) of the two-lane class highways have been expressed by the following equation:

$$PFFS = 0.7217\ PCI + 19.346 \quad (3)$$

Here, the Percent Free Flow Speed (PFFS) is used as the measure of LOS. The chapter explores the relationship between Pavement Condition Index (PCI) and Level of Service (LOS) for two-lane class III highways. It begins by explaining the significance of PCI and LOS in assessing road conditions and traffic operations. Field measurements were conducted to determine LOS based on factors such as vehicle speeds, volume, lane width, and pavement condition, with higher PCI values indicating better LOS due to smoother road surfaces. The study reveals several key points regarding the effect of PCI on LOS. Firstly, higher PCI values generally correspond to better ride quality and comfort for drivers and passengers, while lower PCI values lead to a bumpy and uncomfortable driving experience. Secondly, pavement conditions directly affect vehicle speeds, with poor conditions forcing drivers to reduce speeds, increasing travel times, and reducing LOS. Conversely, good pavement conditions support higher speeds and more consistent travel times, improving LOS. Safety is another important factor, as deteriorated pavements with low PCI values often pose safety hazards, leading to accidents and vehicle damage. Improved pavement conditions enhance road safety, contributing positively to LOS. Additionally, roads with higher PCI values require less frequent and less intensive maintenance, reducing costs and disruptions. Poor pavement conditions increase vehicle operating costs due to higher fuel consumption and repairs, indirectly affecting LOS.The chapter also discusses the level of service for specific road segments based on PFFS calculations, highlighting areas that require immediate rehabilitation. It emphasizes the importance of incorporating pavement condition in determining LOS and underscores the need for regular maintenance and rehabilitation to ensure safe, comfortable, and efficient travel on highways.

5. CONCLUSIONS

The study identified various pavement distresses, with alligator cracking being the most prevalent, significantly affecting pavement performance. The spatial analysis of PCI values revealed considerable variation across the study area, ranging from 31 to 82, with the lowest PCI observed at Muthumoola–Vazhappally and the highest at Kumaranelloor–Sankranti. The developed regression models demonstrated high predictive accuracy, with an R^2 value of 0.963, confirming their reliability in assessing pavement conditions. A strong correlation was found between PCI and Level of Service (LOS), where segments with higher PCI values exhibited smoother surfaces, higher vehicle speeds, and improved travel efficiency, whereas lower PCI values corresponded to rougher surfaces and reduced speeds. These findings underscore the necessity of timely pavement maintenance to sustain road serviceability and enhance user experience. The study meets its objectives by providing a robust methodology for assessing pavement conditions and their impact on LOS, contributing to more effective pavement management strategies. However, limitations such as the exclusion of environmental factors and long-term pavement deterioration trends suggest the need for future research incorporating machine learning techniques and larger datasets to refine predictive models and optimize maintenance planning. The practical implications of this study highlight the importance of integrating GIS-based visualization and predictive modeling in decision-making processes to prioritize road maintenance efforts efficiently.

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This research was conducted independently, and no funding or support was received from any organization or entity that could pose a conflict of interest.

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