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A Review of International Roughness Index (IRI) performance models for Flexible, Semi-Rigid, and Composite Pavements in Double-Carriageway

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Abstract
The International Roughness Index (IRI) is a widely accepted indicator for evaluating pavement surface condition and ride quality. Accurate prediction of IRI progression is essential for effective pavement management, maintenance planning, and lifecycle cost optimization. This paper presents a comprehensive review of IRI performance models for flexible, semi-rigid, and composite pavements, with a specific focus on double-carriageway roads subjected to varying traffic and environmental conditions. The study examines empirical, mechanistic–empirical, and data-driven modeling approaches, highlighting their assumptions, input parameters, and limitations. Comparative analysis reveals that flexible pavements exhibit faster roughness progression, whereas composite pavements demonstrate superior long-term performance but require more complex modeling frameworks. The review also identifies critical research gaps, including the lack of localized calibration, limited application of machine learning techniques, and insufficient consideration of lane-wise deterioration in double-carriageway systems. The findings aim to support researchers and practitioners in selecting appropriate IRI prediction models and improving pavement management strategies, particularly in developing countries.

Keywords: International roughness index (IRI), pavement performance, flexible pavement, semi-rigid pavement, composite pavement, double-carriageway roads, pavement management system

Introduction

Road infrastructure plays a vital role in economic development, and maintaining pavement quality is essential for ensuring safety, comfort, and efficiency. The International Roughness Index (IRI) has become the standard metric for quantifying pavement surface roughness and serviceability worldwide. It reflects the longitudinal profile of a road and directly influences vehicle operating costs, ride comfort, and maintenance decisions.

Pavement systems are generally classified into flexible, semi-rigid, and composite types, each exhibiting distinct structural behavior and deterioration patterns. Double-carriageway roads, characterized by separated lanes for opposing traffic, experience uneven load distribution due to varying traffic intensities, particularly in heavy vehicle lanes. This leads to differential roughness progression, making accurate IRI modeling more challenging.

This paper reviews existing IRI performance models across different pavement types and evaluates their applicability to double-carriageway roads. The objective is to identify strengths, limitations, and research gaps in current modeling approaches.

Fundamentals of IRI Performance Modeling

IRI progression models are developed to predict the increase in pavement roughness over time. These models typically incorporate factors such as traffic loading, environmental conditions, material properties, and initial construction quality.

1. Influencing Factors

Key factors affecting IRI progression include:

- **Traffic Loading:** Measured in equivalent single axle loads (ESALs)
- **Climate:** Temperature fluctuations, rainfall, and moisture
- **Material Properties:** Elastic modulus, layer thickness
- **Structural Distress:** Cracking, rutting, potholes

2. Types of Models

- **Empirical Models:** Based on observed field data
- **Mechanistic–Empirical Models:** Combine physical behavior with empirical calibration
- **Data-Driven Models:** Use machine learning techniques such as artificial neural networks (ANN)

IRI Models for Different Pavement Types

1. Flexible Pavements

Flexible pavements consist primarily of asphalt layers over granular bases. IRI progression in these pavements is strongly influenced by rutting, fatigue cracking, and environmental aging.

Common models, such as those used in HDM-4, relate IRI to cumulative traffic loading and surface distress. These models are relatively simple but highly sensitive to environmental and traffic variations.

2. Semi-Rigid Pavements

Semi-rigid pavements incorporate cement-treated base layers, which provide higher stiffness compared to flexible pavements. However, they are prone to shrinkage and reflection cracking, which significantly contribute to roughness progression.

IRI models for semi-rigid pavements often include additional parameters related to crack propagation and base layer properties.

3. Composite Pavements

Composite pavements combine asphalt surfaces with rigid (cement concrete) base layers. These pavements exhibit slower roughness progression due to their structural strength.

However, modeling IRI in composite pavements is complex, as it must account for interactions between layers, thermal stresses, and joint behavior.

Comparative Analysis

A comparative evaluation of pavement types indicates significant differences in IRI progression:

Parameter	Flexible Pavement	Semi-Rigid Pavement	Composite Pavement
Roughness Progression	High	Moderate	Low
Maintenance Frequency	High	Medium	Low
Modeling Complexity	Low	Medium	High
Durability	Moderate	High	Very High

Composite pavements generally outperform other types in terms of long-term roughness performance but require sophisticated modeling techniques.

IRI Modeling in Double-Carriageway Roads

Double-carriageway roads present unique challenges for IRI prediction due to:
- Uneven traffic distribution between lanes
- Higher loading in slow/heavy vehicle lanes
- Variations in maintenance practices

Lane-wise modeling is essential to accurately capture deterioration patterns. However, most existing models assume uniform traffic distribution, limiting their applicability.

Recent Advances in IRI Prediction

Recent developments in IRI modeling include:
- **Machine Learning Approaches:** ANN, support vector machines (SVM), and regression trees
- **Smart Monitoring Systems:** Use of sensors and real-time data collection
- **Big Data Integration:** Combining traffic, climate, and structural data for improved prediction

These approaches offer higher accuracy but require large datasets and computational resources.

Challenges and Research Gaps

Despite significant progress, several challenges remain:
- Lack of localized calibration for developing countries
- Limited data availability for composite pavements
- Insufficient focus on lane-specific deterioration
- Underutilization of advanced data analytics techniques

Addressing these gaps is crucial for improving prediction accuracy and pavement management systems.

Conclusion

This review highlights the importance of accurate IRI performance modeling for different pavement types. Flexible pavements show rapid deterioration, while composite pavements offer superior long-term performance. However, their modeling complexity poses challenges. Double-carriageway roads require lane-specific models to capture uneven deterioration patterns.

Future research should focus on integrating machine learning techniques, improving data collection systems, and developing region-specific models to enhance prediction accuracy and decision-making.

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