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# Enhanced Prediction and Uncertainty Modeling of Pavement Roughness Using Machine Learning and Conformal Prediction

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## Abstract

Pavement performance models are considered a key element in pavement management systems since they can predict the future condition of pavements using historical data. Several indicators are used to evaluate the condition of pavements (such as the pavement condition index, rutting depth, and cracking severity), and the international roughness index (IRI), which is the most widely employed worldwide. This study aimed to develop an accurate IRI prediction model. Ten prediction methods were trained on a dataset of 35 independent variables. The performance of the methods was compared, and the light gradient boosting machine was identified as the best-performing method for IRI prediction. Then, the SHAP was synchronized with the best-performing method to prioritize variables based on their relative influence on IRI. The results suggested that initial IRI, mean annual temperature, and the duration between data collections had the strongest relative influence on IRI prediction. Another objective of this study was to determine the optimal uncertainty model for IRI prediction. In this regard, 12 uncertainty models were developed based on different conformal prediction methods. Gray relational analysis was performed to identify the optimal uncertainty model. The results showed that Minmax/80 was the optimal uncertainty model for IRI prediction, with an effective coverage of 93.4% and an average interval width of 0.256 m/km. Finally, a further analysis was performed on the outcomes of the optimal uncertainty model, and initial IRI, duration, annual precipitation, and a few distress parameters were identified as uncertain. The results of the framework indicate in which situations the predicted IRI may be unreliable.

**Keywords:** international roughness index; ensemble learning; conformal prediction interval; uncertainty; gray relational analysis



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## 1. Introduction

Transportation infrastructure is an essential part of mobility and economic development in modern societies, being a pillar of the economy [1]. Pavement, as a component of transportation infrastructure, plays a significant role in roadway safety and performance. In the United States alone, the paved road infrastructure covers a distance of approximately 5 million kilometers, enabling the transport of people and large volumes of freight [2]. While pavements are an unavoidable aspect of infrastructure, they deteriorate over time due to various reasons, such as aging, increasing traffic volumes, and severe weather events. Therefore, it is essential to keep pavements in operational condition. Still, in 2023, around