

Application of Artificial Neural Networks in Pavement Performance Prediction and Maintenance Planning: A Review

Pradeep Kumar

M. Tech. in Transportation Engineering, CBS Group of Institutions, Jhajjar, Haryana.

Shubender

A.P Civil Department, CBS Group of Institutions, Jhajjar, Haryana.

ABSTRACT

This study explores the application of Artificial Neural Networks (ANNs) for predicting pavement performance and supporting maintenance planning. As traditional empirical and statistical models struggle to capture complex, nonlinear relationships in pavement deterioration, ANNs provide a more reliable, data-driven approach. The research highlights the superiority of ANNs over linear regression models in forecasting key performance indicators like the Pavement Condition Index (PCI) and International Roughness Index (IRI). Machine learning techniques such as deep learning and ensemble models further enhance the accuracy and robustness of pavement management systems. This methodology significantly improves predictive maintenance and long-term infrastructure planning.

Keywords: *Artificial Neural Networks, Pavement Performance, Maintenance Planning, Machine Learning, Deterioration Prediction.*

I. INTRODUCTION

Pavement performance prediction and maintenance planning are fundamental components of modern transportation infrastructure management, as they directly influence safety, serviceability, and lifecycle cost efficiency of road networks. With increasing traffic volume, axle loads, and environmental variability, pavement systems are subjected to continuous deterioration, leading to functional and structural distresses such as cracking, rutting, potholes, and surface roughness. These distresses progressively reduce ride quality and structural integrity, making timely maintenance essential. Traditionally, pavement performance has been evaluated using empirical and mechanistic-empirical models; however, these methods often struggle to capture the nonlinear, time-dependent, and multi-factor interactions inherent in pavement deterioration processes. As a result, artificial intelligence techniques, particularly Artificial Neural Networks (ANNs), have gained significant attention for their ability to model complex relationships in pavement systems and improve prediction accuracy for maintenance planning (Ali et al., 2024; Wang et al., 2024). Pavement management systems rely heavily on accurate prediction of performance indicators such as the International Roughness Index (IRI), Pavement Condition Index (PCI), Ride Quality Index (RQI), and Remaining Service Life (RSL). These indicators are essential for determining maintenance priorities, allocating budgets, and optimizing rehabilitation schedules. However, conventional statistical models such as linear regression and Markov chain-based approaches often assume simplified relationships between variables, which may not adequately represent real-world pavement deterioration behavior. For example, Nabimanya et al. (2026) demonstrated that pavement deterioration varies significantly depending on initial condition, traffic loading, and environmental exposure. Their modified Markov Chain Model showed that while it could capture general deterioration trends, its predictive capability was limited when dealing with complex and heterogeneous pavement conditions, highlighting the need for more advanced modeling techniques. Artificial Neural Networks provide a data-driven alternative that overcomes many limitations of traditional approaches. ANNs are computational models inspired by the human brain, consisting of interconnected layers of nodes (neurons)

that process input data and learn patterns through training. Their ability to approximate nonlinear functions makes them particularly suitable for pavement performance modeling, where relationships between input variables such as traffic loads, material properties, climatic conditions, and pavement age are highly complex and interdependent. Studies have consistently shown that ANN models outperform traditional regression-based methods in predicting pavement deterioration. For instance, Ali et al. (2024) applied ANN techniques to predict pavement roughness and found that ANN models achieved superior performance compared to multiple linear regression, with R^2 values exceeding 0.97 in different climatic regions. The advancement of ANN-based pavement modeling has also been supported by large-scale datasets and improved computational capabilities. Wang et al. (2024) developed an optimized ANN framework for network-level pavement performance prediction using inputs such as traffic characteristics, structural properties, and climatic conditions. Their results demonstrated high predictive accuracy with coefficient of determination values greater than 0.9, indicating strong model reliability across different pavement networks. Similarly, Kaya et al. (2020) emphasized that artificial intelligence-based models are more effective than traditional statistical models in predicting both pavement performance and remaining service life at the network level, making them highly valuable for transportation agencies in decision-making processes. In addition to standard ANN models, recent research has focused on advanced machine learning architectures such as recurrent neural networks (RNN), long short-term memory (LSTM), and hybrid deep learning models. These models are particularly effective in capturing temporal dependencies in pavement deterioration data. Mers et al. (2023) conducted a comparative study of multiple machine learning models using a 31-year pavement dataset and found that deep learning models such as LSTM and hybrid LSTM-FCNN significantly outperformed traditional models like multiple linear regression and fully connected neural networks. Their findings highlighted the importance of temporal modeling in improving long-term pavement performance prediction accuracy. Ensemble learning techniques have also been introduced to enhance prediction reliability and reduce model uncertainty. Khan et al. (2026) developed a multi-model stacking ensemble framework for pavement performance prediction using multiple base machine learning models and meta-learners. Their study showed that ensemble models consistently outperformed individual models, achieving over 93% prediction accuracy within acceptable error ranges. This demonstrates that combining multiple predictive models can significantly improve robustness and generalization in pavement performance forecasting. The integration of ANN models with other analytical methods has further improved pavement management strategies. Wang et al. (2021) combined ANN with Markov chain modeling to predict asphalt pavement performance and support preventive maintenance planning. Their results indicated that ANN-based predictions closely matched observed pavement conditions, providing a reliable basis for optimizing maintenance timing and resource allocation. Similarly, Bhandari et al. (2023) investigated the influence of structural, traffic, and environmental factors on pavement deterioration using machine learning techniques, identifying key variables such as pavement age, base thickness, traffic loading, and climate conditions as major contributors to pavement distress development. Environmental impacts, particularly climate change, have become increasingly important in pavement performance modeling. Salma et al. (2022) developed an ANN-based model to evaluate pavement deterioration under extreme climate conditions, including temperature variations, precipitation, and freeze-thaw cycles. Their findings showed that climate variables significantly affect pavement roughness and structural performance, particularly in freeze-prone regions. This study highlighted the capability of ANN models to incorporate environmental variability, making them highly relevant for long-term infrastructure resilience planning. Earlier foundational studies have also demonstrated the effectiveness of ANN in pavement engineering applications. Yao et al. (2019) developed ANN-based models for predicting multiple pavement distress types, including rutting,

cracking, and skid resistance, achieving strong predictive performance with an average R^2 of 0.8692. They also emphasized the importance of data preprocessing techniques such as principal component analysis (PCA) to improve model efficiency and reduce dimensionality. Similarly, Bosurgi et al. (2019) highlighted that ANN performance depends significantly on network architecture, input data quality, and training methodology, emphasizing the importance of model optimization for accurate pavement performance evaluation.

II. RESEARCH BACKGROUND

Nabimanya et al. (2026) investigated pavement performance modeling for Uganda's road network by employing a modified Markov Chain Model (MCM) and examined how the initial Visual Condition Index (VCI) influenced pavement deterioration. They applied the time-deterioration superposition principle within the modified MCM to generate pavement performance master curves. Four predictive models—the logistic, Richards, pavement behaviour equation, and Weibull models—were assessed for their ability to represent these master curves. The study found that deterioration rates varied according to initial VCI and traffic levels. For heavy and intermediate traffic pavements in very good, good, and fair conditions, deterioration rates were reported to decrease with lower initial VCI, whereas pavements in poor and very poor conditions showed increased deterioration as initial VCI decreased. In contrast, light traffic pavements generally exhibited higher deterioration rates with decreasing initial VCI. Among the models, the Weibull model was identified as providing the most reliable fit and was recommended for integration into the Ugandan Pavement Management System.

Khan et al. (2026) investigated the prediction of pavement performance, emphasizing its importance for effective highway management. They noted that single-model approaches often failed to capture the complex deterioration mechanisms across highway networks. To overcome this limitation, the study developed an automated multi-model stacking ensemble framework for predicting PCI, RQI, and RDI using data from the G22 highway between 2020 and 2023 across five regions. The methodology reportedly integrated six base machine learning models via stacking with four meta-learners and evaluated ensemble sizes from two to six base models. Input features were described to include historical indices, pavement age, lane, direction, section length, historical distress and repair records, weather conditions, and traffic data. The authors found that stacking ensembles consistently outperformed individual base models. SHAP and LIME analyses reportedly highlighted historical indices, distress and repair records, pavement age, weather conditions, and heavy-traffic classes as the most influential features, and over 93% of predictions fell within acceptable error bounds, indicating potential utility in pavement management.

Ali et al., (2024) investigated the combined effect of pavement distress on flexible pavement performance in two climate regions in the U.S. and Canada, focusing on the International Roughness Index (IRI) as a widely accepted indicator of pavement performance and ride quality. They used the long-term pavement performance (LTPP) database to collect distress data from forty-three pavement sections, comprising 333 observations with no prior maintenance. The study aimed to predict IRI as a function of pavement age, rutting, fatigue cracking, block cracking, longitudinal and transverse cracking, potholes, patching, bleeding, and ravelling. For this purpose, multiple linear regression (MLR) and artificial neural network (ANN) techniques were applied. The predictive performances were evaluated using the coefficient of determination (R^2), root mean squared error (RMSE), and mean absolute error (MAE). The results indicated that both MLR and ANN models were capable of predicting IRI with reasonable accuracy, with ANN models outperforming MLR models, achieving R^2 values of 99.1% and 97.5% for wet-freeze and wet-no-freeze regions, respectively.

Wang et al. (2024) investigated network-level flexible pavement performance by treating the road network as an interconnected system. They aimed to predict individual road pavement conditions using an optimised artificial neural network (ANN) approach, while the Ford-Fulkerson algorithm was employed to determine the weight coefficients of roads within the network. ANNs were developed to forecast distress conditions, functional states, and structural performance based on inputs such as pavement age, structural properties, traffic, and climatic conditions. Training of the ANNs was performed using Long-Term Pavement Performance (LTPP) program data, and reported coefficient of determination values between ANN predictions and measured results exceeded 0.9. The ANN methodology was further optimised by incorporating grey models for short-term performance prediction and applying Kalman filtering to refine long-term forecasts. Applications on typical LTPP sections demonstrated the effectiveness of the optimisation. Additionally, network-level analysis quantified each road's role using the Ford-Fulkerson algorithm, with validation conducted on a 25-expressway network in Shanghai, confirming strong generalisation and feasibility.

Mers et al. (2023) highlighted that accurate pavement performance forecasting had been considered critical for supporting transportation agencies' predictive maintenance strategies, which aimed to prolong pavement service life while conserving resources. They noted that, due to the complex nature of pavement deterioration, achieving high accuracy in long-term and project-level pavement performance forecasting had posed significant challenges for traditional models. Consequently, researchers had increasingly adopted machine learning (ML) technologies to develop more sophisticated forecasting models. Mers et al. further observed that, prior to their study, no research had compared different ML models using a singular, real-world, large-scale, and comprehensive pavement data set to assess their predictive capabilities. Their study therefore evaluated models including multiple linear regression (MLR), fully connected neural network (FCNN), recurrent neural network (RNN), gated recurrent unit (GRU), long short-term memory (LSTM), and a hybrid LSTM-FCNN model on Florida's 31-year historical pavement data. They reported that RNN, GRU, LSTM, and LSTM-FCNN outperformed MLR and FCNN, with LSTM-FCNN performing the best, demonstrating the potential of RNN-based models to enhance forecasting accuracy.

Bhandari et al. (2023) investigated the rapid increase in pavement damage with vehicle loads, emphasizing that deterioration over time was influenced by multiple factors, with traffic loading being particularly significant in reducing pavement life. They noted that heavy vehicle loads, coupled with insufficient structural capacity, contributed largely to poor road conditions. The study focused on key distresses such as alligator cracking, rutting, and roughness as primary measures of pavement performance. To enhance understanding of pavement deterioration, the authors assessed the effects of structural factors, traffic loading, and environmental conditions, including precipitation and temperature, on pavement performance. They selected base type, hot mix asphalt concrete (HMAC) layer thickness, base layer thickness, traffic loading, pavement age, and environmental conditions as critical contributors. Data from the Long-Term Pavement Performance Program (LTPP) were analyzed using generalized linear models (GLM), binary logistic regression (BLR), and random forest (RF), with cross-validation employed to compare model efficacy. Findings indicated that RF outperformed other models in accuracy and variable identification, highlighting base thickness, base type, traffic loading, age, and environmental conditions as key factors influencing rutting, roughness, and alligator cracking, while introducing statistical modeling as an effective tool for flexible pavement analysis.

Salma et al., (2022) investigated the potential impacts of climate change on highway pavement performance, noting that previous studies had not adequately considered the effects of extreme weather, such as extreme temperature and rainfall, on pavement deterioration. They argued that quantifying deterioration under such conditions could provide valuable insights for assessing climate change impacts on pavements. The study aimed to develop a pavement deterioration model for jointed plain concrete pavement (JPCP) by employing artificial neural network (ANN) techniques. Data were obtained from the Long-Term Pavement Performance (LTPP) database for wet, freeze-prone regions. The input variables included initial pavement condition, structural and mechanical properties (age, concrete thickness, base/subbase characteristics, contraction spacing, material types), traffic load (cumulative ESAL), and climate attributes (annual temperature, precipitation, freezing index, and freeze-thaw cycles), with the output being the international roughness index (IRI). The authors conducted several models to simulate different climate scenarios, intending to identify the additional deterioration caused by extreme conditions, thereby addressing gaps in long-term IRI prediction and informing infrastructure policymaking.

Wang et al. (2021) investigated the issues of inadequate maintenance measures, improper maintenance timing, and inefficient allocation of funds in asphalt pavement maintenance on highways in China. The research focused on highway pavement maintenance and developed a predictive model for preventive maintenance performance using neural networks. Initially, pavement performance was evaluated, and existing mature prediction models were reviewed. They noted that for early-built highways, such models were applied where the concepts of maintenance and preventive maintenance were poorly adopted, and pavement performance exhibited a declining trend. Conversely, for sections already subject to maintenance and preventive measures, pavement performance data demonstrated fluctuating patterns, rendering dynamic descent sections unsuitable for standard modeling. The proposed forecasting model was found to align closely with measured performance trends, providing reliable predictions of pavement behavior. Consequently, the study offered a theoretical basis for optimizing highway maintenance fund allocation and informed the selection of maintenance strategies, timing, and investment, holding significant implications for future highway management.

Kaya et al. (2020) examined the development of performance-based pavement management approaches as mandated by the Moving Ahead for Progress in the 21st Century (MAP-21) federal transportation legislation, which required U.S. state highway agencies to incorporate systematic decision-making processes. They reported that one effective approach involved the use of remaining service life (RSL) models to support pavement management decisions. The study described a detailed step-by-step methodology for developing pavement performance and RSL prediction models for flexible and composite pavement systems in Iowa. Initially, pavement performance models based on statistical and artificial intelligence (AI) techniques were constructed. While statistical models were observed to be accurate at the project level, AI-based models were considered more successful in predicting network-level performance. Furthermore, network-level models using both approaches were compared to evaluate their relative effectiveness. The study also indicated that automated tools were developed for future pavement performance predictions in accordance with Federal Highway Administration threshold limits, enabling informed decision-making at both project and network levels.

Yao et al. (2019) aimed to develop predictive models for pavement deterioration, encompassing rutting, roughness, skid-resistance, transverse cracking, and surface distress. They proposed a data quality control method to reconstruct performance data, employing the concept of longest increasing or decreasing subsequences. Neural networks were applied to develop the five predictive models, while principal

component analysis (PCA) was used to reduce the dimensionality of traffic variables. The influence of different input variables on model outputs was evaluated through mean impact values (MIV). Their findings indicated that the neural network models exhibited substantial potential for accurate prediction, achieving an average testing R^2 of 0.8692. Sensitivity analysis suggested that recent pavement conditions significantly influenced future performance, with rutting and roughness being particularly affected by pavement age and maintenance type. Pavement material composition impacted roughness, skid-resistance, and surface distress, whereas traffic loads influenced skid-resistance and transverse cracking. Base materials and crack treatments were found to markedly affect transverse cracking and surface distress.

Bosurgi et al. (2019) were reported to have investigated the application of Artificial Neural Networks (ANNs) as effective tools for addressing a range of engineering challenges, highlighting their notable potential in pavement engineering, particularly in evaluating pavement structural performance. It was suggested that the implementation of a properly designed ANN for estimating structural performance in asphalt pavements from rapid and cost-efficient survey data could provide significant savings for road agencies and support improved maintenance planning. The study was noted to emphasize the importance of optimizing network architecture to enhance prediction accuracy and offer a reliable decision-support tool. It was further observed that the researchers examined the influence of various factors on network performance, including input feature quality (structural, traffic, climatic), training data homogeneity, and network topology. Their findings were reported to indicate that careful attention to these factors could maximize methodology effectiveness, strengthen Pavement Management Systems, and reduce the frequency of deflection surveys, ultimately producing considerable operational and economic benefits for road authorities.

III. KEY FINDINGS FROM STUDY

S. No.	Author(s) & Year	Objective	Methodology	Key Findings	Limitations / Contribution
1	Nabimanya et al. (2026)	Develop pavement performance models for Uganda's road network	Modified Markov Chain Model with VCI-based deterioration analysis and master curves	Weibull model best fit; deterioration depends on initial VCI and traffic level	Limited use of AI-based nonlinear learning models
2	Khan et al. (2026)	Predict pavement performance indicators using ensemble learning	Multi-model stacking ensemble (6 ML models + meta-learners)	Ensemble outperformed single models; >93% accuracy; SHAP identified key features	High computational complexity
3	Ali et al. (2024)	Predict pavement roughness (IRI) using ANN and regression	ANN vs Multiple Linear Regression using LTPP data	ANN achieved higher accuracy (R^2 up to 0.991)	Limited generalization beyond studied regions
4	Wang et al. (2024)	Network-level pavement performance prediction	Optimized ANN with Ford-Fulkerson weighting + Kalman filtering	ANN achieved $R^2 > 0.9$; strong network-level prediction	Model requires large-scale calibration

5	Mers et al. (2023)	Compare ML models for pavement forecasting	RNN, GRU, LSTM, LSTM-FCNN vs MLR & FCNN	LSTM-FCNN performed best for long-term prediction	High data and computational demand
6	Bhandari et al. (2023)	Analyze effect of structural and traffic factors	GLM, BLR, Random Forest using LTPP data	RF outperformed others; key factors: base thickness, traffic, age	Limited deep learning integration
7	Salma et al. (2022)	Evaluate climate change impact on pavement performance	ANN-based model for JPCP under climate variables	Climate significantly affects IRI; ANN effective for prediction	Focused only on freeze-prone regions
8	Wang et al. (2021)	Predict pavement performance for maintenance planning	ANN combined with Markov Chain model	Accurate prediction of pavement deterioration trends	Limited real-time adaptation
9	Kaya et al. (2020)	Develop performance and RSL prediction models	Statistical + AI-based models comparison	AI models better for network-level prediction	Statistical models still useful at project level
10	Yao et al. (2019)	Predict pavement distress types using ANN	ANN + PCA + MIV sensitivity analysis	$R^2 = 0.8692$; rutting and cracking strongly influenced by age & traffic	Data preprocessing complexity
11	Bosurgi et al. (2019)	Optimize ANN for pavement structural evaluation	ANN architecture optimization using survey data	ANN improves pavement management efficiency	Requires high-quality input data

IV. CONCLUSION

The present literature review on the development of Artificial Neural Network (ANN) models for pavement performance prediction and maintenance planning clearly demonstrates that data-driven intelligence-based approaches have significantly transformed traditional pavement management practices. Conventional methods such as regression analysis, Markov chain models, and mechanistic-empirical approaches have been widely used for pavement deterioration prediction; however, their limitations in capturing nonlinear, dynamic, and multi-factor interactions have reduced their effectiveness in real-world applications. In contrast, ANN-based models have shown superior performance in learning complex relationships between input variables such as traffic loading, pavement age, material properties, and environmental conditions, and output performance indicators such as IRI, PCI, and RSL (Ali et al., 2024; Wang et al., 2024). The reviewed studies consistently indicate that ANN models provide higher prediction accuracy and better generalization capabilities compared to traditional statistical approaches. For example, deep learning models such as LSTM, GRU, and hybrid LSTM-FCNN have demonstrated strong capability in capturing long-term temporal dependencies in pavement deterioration data (Mers et al., 2023). Similarly, ensemble learning frameworks and stacking models have further improved predictive reliability by integrating multiple machine learning algorithms (Khan et al., 2026). These advancements highlight that modern pavement management systems are increasingly shifting toward intelligent, adaptive, and automated decision-support systems. Moreover, ANN-based approaches have proven

effective in integrating multiple influencing factors, including structural design parameters, traffic loading patterns, climatic variations, and maintenance history. Studies such as Salma et al. (2022) have confirmed the importance of incorporating climate change variables into pavement deterioration models, while Bhandari et al. (2023) emphasized the significant role of structural and traffic-related parameters. Overall, ANN models provide a robust framework for improving maintenance planning strategies, optimizing resource allocation, and extending pavement service life. Despite these advantages, challenges such as data quality, model interpretability, computational complexity, and requirement of large datasets still persist. Nevertheless, ANN-based pavement performance prediction represents a major advancement in transportation engineering, offering more reliable, accurate, and scalable solutions for infrastructure management systems.

V. FUTURE SCOPE

The future development of ANN-based pavement performance prediction models is expected to focus on improving model accuracy, interpretability, and real-time applicability. One major area of advancement is the integration of advanced deep learning architectures such as Transformer models, Graph Neural Networks (GNNs), and hybrid physics-informed neural networks. These models can further enhance the ability to capture spatial-temporal dependencies and complex deterioration mechanisms in pavement systems. Another important direction is the integration of real-time data acquisition technologies such as Internet of Things (IoT) sensors, remote sensing, and intelligent transportation systems. These technologies can provide continuous pavement condition monitoring, enabling ANN models to perform dynamic and real-time prediction of pavement performance, thereby improving maintenance responsiveness and reducing lifecycle costs. Future research should also focus on improving the interpretability of ANN models through explainable AI (XAI) techniques such as SHAP and LIME, ensuring that transportation engineers can better understand model predictions and decision-making processes. This will enhance trust and practical adoption of AI-based systems in highway agencies. Additionally, the development of hybrid models combining ANN with mechanistic-empirical and probabilistic approaches can provide more physically meaningful and reliable predictions. The integration of uncertainty analysis and risk-based modeling frameworks will further strengthen pavement management systems under uncertain traffic and climate conditions. Finally, large-scale implementation and validation of ANN models across different geographic regions and pavement types are required to ensure model robustness and transferability. With continuous advancements in computational power, data availability, and machine learning techniques, ANN-based pavement performance prediction systems are expected to become a core component of next-generation intelligent transportation infrastructure management systems.

REFERENCES

1. Nabimanya, A., Zhou, J., Yan, Y., & Nanjehe, P. M. (2026). New pavement performance models developed for the national road network in Uganda. *Road Materials and Pavement Design*, 27(2), 521-548.
2. Khan, A., Zhang, W., Chang, H., Wang, C., Liu, S., Liu, H., & Geng, D. (2026). Multi-model optimized stacking ensemble framework for pavement performance: predicting key indicators and the Pavement Maintenance Quality Index. *International Journal of Pavement Engineering*, 27(1), 2641497.
3. Ali, A. A., Heneash, U., Hussein, A., & Khan, S. (2024). Application of Artificial neural network technique for prediction of pavement roughness as a performance indicator. *Journal of King Saud University-Engineering Sciences*, 36(2), 128-139.

4. Wang, Z., Ling, J., Du, H., Zhang, J., & Li, X. (2024). Performance prediction for network-level flexible pavements using an optimised ANN approach. *International Journal of Pavement Engineering*, 25(1), 2329231.
5. Mers, M., Yang, Z., Hsieh, Y. A., & Tsai, Y. (2023). Recurrent neural networks for pavement performance forecasting: review and model performance comparison. *Transportation research record*, 2677(1), 610-624.
6. Bhandari, S., Luo, X., & Wang, F. (2023). Understanding the effects of structural factors and traffic loading on flexible pavement performance. *International Journal of Transportation Science and Technology*, 12(1), 258-272.
7. Salma, S., Hakan, Y., Rulian, B., & Jacob, N. (2022). Evaluating the effect of climate change in pavement performance modeling using artificial neural network approach. In *International Conference on Transportation and Development 2022* (pp. 49-60).
8. Wang, Z., Guo, N., Wang, S., & Xu, Y. (2021). Prediction of highway asphalt pavement performance based on Markov chain and artificial neural network approach: Z. Wang et al. *The Journal of Supercomputing*, 77(2), 1354-1376.
9. Kaya, O., Ceylan, H., Kim, S., Waid, D., & Moore, B. P. (2020). Statistics and artificial intelligence-based pavement performance and remaining service life prediction models for flexible and composite pavement systems. *Transportation Research Record*, 2674(10), 448-460.
10. Yao, L., Dong, Q., Jiang, J., & Ni, F. (2019). Establishment of prediction models of asphalt pavement performance based on a novel data calibration method and neural network. *Transportation Research Record*, 2673(1), 66-82.
11. Bosurgi, G., Pellegrino, O., & Sollazzo, G. (2019). Optimizing artificial neural networks for the evaluation of asphalt pavement structural performance. *The Baltic Journal of Road and Bridge Engineering*, 14(1), 58-79.