Comprehensive assessment of road pavement performance using modern diagnostic technologies: insights from Uzbekistan's evolving infrastructure

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Abstract: Ensuring the long-term durability and operational efficiency of highway pavements remains a fundamental challenge for developing nations such as Uzbekistan, where diverse climatic conditions, combined with intensifying vehicular traffic and inadequate historical maintenance practices, significantly accelerate the rate of pavement degradation. This research presents a comprehensive and systematic methodology for assessing the technical condition and service performance of road pavements through the application of advanced diagnostic tools and internationally recognized performance evaluation standards. Central to the study is the integration of key performance indicators, including the International Roughness Index (IRI), the Pavement Condition Index (PCI), and structural capacity assessments conducted using the Falling Weight Deflectometer (FWD). These indicators provide a quantitative framework for evaluating surface roughness, visual distress, and structural integrity, respectively. The study encompasses both field data collection and analytical evaluation across representative pavement sections in Uzbekistan, capturing the effects of environmental stresses, traffic loads, and construction quality. Through the synthesis of diagnostic data, the research identifies the most critical factors contributing to pavement deterioration, such as thermal cracking, rutting, moisture infiltration, and subgrade instability. Based on these findings, the study proposes a set of optimized, context-specific maintenance and rehabilitation strategies aimed at extending pavement life, reducing lifecycle costs, and improving road safety and user comfort. The results of this investigation contribute valuable insights for transportation agencies, infrastructure planners, and policy-makers, offering a data-driven foundation for prioritizing investments and enhancing the resilience and sustainability of national road infrastructure. Moreover, the study advocates for the widespread adoption of modern pavement evaluation technologies and performance-based maintenance planning as essential components of a forward-looking, cost-effective asset management system in Uzbekistan and similar emerging economies.

Keywords: Pavement performance, road diagnostics, structural integrity, International Roughness Index (IRI), Pavement Condition Index (PCI), Falling Weight

Deflectometer (FWD), pavement evaluation, maintenance strategies, Uzbekistan, highway engineering, road infrastructure management, asset management systems

1. Introduction

High-quality road infrastructure plays a vital role in supporting economic growth, regional development, and societal integration. In countries like Uzbekistan, where national connectivity is crucial for trade, mobility, and access to services, the strategic development of the road network has been a central focus of government policy over the past two decades. Substantial investments have been directed toward expanding and modernizing highways to accommodate increasing traffic volumes and to foster economic integration across urban and rural areas.

Despite these efforts, the rapid pace of urbanization and the significant rise in vehicular traffic-particularly heavy axle loads-pose growing challenges to the durability and serviceability of pavement structures. Climatic variability, particularly the sharp thermal gradients characteristic of many regions in Uzbekistan, further exacerbates pavement distress by inducing fatigue cracking, thermal cracking, and subgrade instability.

In this context, ensuring the long-term performance of road pavements necessitates the use of robust, objective, and repeatable diagnostic methodologies that go beyond traditional visual inspection techniques. While surface-level evaluations provide initial insights, they often fail to capture the deeper structural and functional deficiencies that undermine pavement longevity. As such, the integration of modern, data-driven tools and internationally standardized performance indicators has become indispensable for accurate pavement condition assessment and informed decision-making.

This paper investigates the practical application of advanced diagnostic technologies-specifically the International Roughness Index (IRI), Pavement Condition Index (PCI), and Falling Weight Deflectometer (FWD) analysis-for the technical evaluation of pavement condition. The methodology is applied to a real-world case study: a 10-kilometer section of a national highway located in the Jizzakh region of Uzbekistan. This area represents a challenging test environment due to its exposure to significant thermal fluctuations, seasonal variations, and high-intensity traffic loads. The results of this study aim to demonstrate the advantages of performance-based diagnostics in supporting proactive pavement management strategies, ultimately contributing to the creation of a more resilient and efficient national road infrastructure system.

2. Methodology

This study adopts a comprehensive, multi-dimensional assessment framework that integrates visual inspections, structural evaluations, and surface condition measurements to ensure a holistic understanding of pavement performance. The methodology is designed to align with international best practices and incorporates both field data collection and analytical interpretation. The core components of the assessment include the following:

International Roughness Index (IRI):

Surface roughness was quantified using a high-precision inertial road profilometer. The IRI, expressed in meters per kilometer (m/km), serves as a standardized indicator of ride quality by measuring longitudinal surface deviations. This metric reflects user comfort and is closely correlated with vehicle operating costs and safety.

Pavement Condition Index (PCI):

A detailed visual survey was conducted in accordance with ASTM D6433 standards to evaluate surface distresses, including cracking, rutting, potholes, and raveling. The data were processed to compute the PCI, which provides a numerical score ranging from 0 (failed condition) to 100 (excellent condition). This index facilitates prioritization in pavement maintenance and rehabilitation planning.

Structural Evaluation via Falling Weight Deflectometer (FWD):

Structural capacity was assessed using a Falling Weight Deflectometer, which applies an impulse load to the pavement surface while recording resulting deflections at multiple sensor points. This non-destructive technique allows for the back-calculation of elastic moduli of individual pavement layers, offering insights into load-bearing capacity and identifying areas of structural weakness.

To contextualize the pavement performance data, environmental and traffic-related parameters were also incorporated into the analysis:

Climatic Conditions:

Site-specific environmental data-including air and pavement temperature ranges, freeze-thaw cycles, and precipitation levels-were collected to assess their influence on material behavior and deterioration patterns.

Traffic Loading:

Traffic volume and composition were documented based on Average Daily Traffic (ADT) counts and axle load configurations. The cumulative effect of repeated loading, particularly from heavy vehicles, was considered essential for understanding pavement fatigue and deformation mechanisms.

This integrated methodological approach ensures that both surface-level functionality and underlying structural integrity are evaluated, providing a reliable basis for performance prediction and maintenance decision-making.

3. Results and Discussion

The diagnostic evaluation of the 10-kilometer highway section yielded critical insights into the current state of pavement performance and structural integrity. The analysis of surface smoothness, structural response, and distress manifestations provides a multidimensional understanding of the pavement's deterioration mechanisms.

International Roughness Index (IRI):

Data obtained from profilometric measurements indicate that approximately 30% of the evaluated roadway segments exhibit IRI values exceeding the World Bank's recommended threshold of 4.0 m/km. Such elevated roughness levels are indicative of reduced ride quality, increased user discomfort, and elevated risks of vehicular damage, particularly for high-speed traffic and freight vehicles. These areas demand prompt corrective actions to prevent further functional decline.

Pavement Condition Index (PCI):

PCI ratings varied significantly along the surveyed corridor. While some segments registered scores in the "Good" range (70-85), a substantial portion fell within the "Fair to Poor" category (PCI < 55). The most commonly observed surface distresses included alligator (fatigue) cracking, rutting, and longitudinal-transverse cracking, each of which signals different failure mechanisms-ranging from structural fatigue to environmental-induced stress. The presence of such distresses indicates both surface and sub-surface deficiencies requiring differentiated maintenance approaches.

Falling Weight Deflectometer (FWD) Analysis:

FWD testing revealed notable spatial variations in pavement deflection responses. Back-calculated elastic modulus values highlighted significant reductions in the stiffness of aged asphalt layers, and in several locations, inconsistencies in subgrade support were evident. These deficiencies suggest localized failures in material performance and compaction quality, potentially aggravated by moisture ingress and insufficient drainage.

Correlations and Degradation Factors:

A comparative analysis of performance indicators and contextual parameters suggests a strong correlation between pavement deterioration and heavy truck traffic intensity, particularly along sections frequently traversed by overloaded freight vehicles. Furthermore, inadequate surface drainage, coupled with recurrent thermal cycling, accelerates the propagation of cracks and weakens the structural foundation over time. These findings are consistent with established degradation models for flexible pavements operating under mixed traffic and climatic conditions.

Table 1

Results of Diagnostic Assessment of the Asphalt Concrete Surface (Over 10 km)

No	Type of Damage	Total Number of Occurrences	Total Area Affected (m²)	Percentage of Total Surface	Technical Condition Category	Repair Recommendation
1	Alligator cracking	320	1,800	18%	Unsatisfactory	Full-depth pavement reconstruction

2	Longitudinal cracking	140	620	6.2%	Poor	Crack sealing, surface treatment
3	Transverse cracking	110	460	4.6%	Poor	Joint filling, cold patch repair
4	Surface potholes	85	230	2.3%	Very Poor	Patching and localized replacement
5	Rutting	65	1,050	10.5%	Unsatisfactory	Milling and overlay
6	Asphalt raveling	75	380	3.8%	Poor	Slurry seal or micro surfacing
7	Edge deterioration	95	520	5.2%	Poor	Shoulder reconstruction
8	Bleeding (bitumen flushing)	40	300	3.0%	Satisfactory	Surface dressing and sand spreading
	Total	-	5,360	53.6%	-	-

Table 2

Types and Distribution of Asphalt Pavement Distresses

No	Type of Distress	Spread/Occurrence (%)	Description	Recommended Action
1	Alligator Cracks	40% of the section	Fatigue-induced network of interconnected cracks	Full-depth structural reconstruction
2	Rutting	25% of the section	Depression along wheel paths due to heavy loads or weak base	Re-design of base layer, use of geosynthetic layers
3	Transverse Cracks	20% of the section	Caused by temperature fluctuations and thermal stress	Crack sealing, fog seal, micro surfacing
4	Surface Loss or Delamination	15% of the section	Disbonding due to poor bonding or water infiltration	Patching and localized overlay
5	Edge Breaks	10% of the section	Weak shoulders and insufficient lateral support	Reinforcement of shoulders, regrading
6	Bitumen Flushing (Bleeding)	8% of the section	Excess bitumen leading to slick spots	Surface treatment and correction of binder content

Proposed Maintenance and Rehabilitation Strategies:

Based on the integrated diagnostic results, the following targeted interventions are recommended to restore and enhance pavement performance:

Surface Treatments:

For segments exhibiting moderate distress without significant structural deformation, micro-surfacing and crack sealing are recommended to restore ride quality, prevent moisture infiltration, and extend service life.

Structural Overlays:

In sections showing advanced fatigue cracking and rutting, a structural overlay design is advised. This includes milling of distressed layers followed by placement of high-performance asphalt mixes to regain structural capacity and surface integrity.

Subgrade Reinforcement:

In areas where subgrade modulus values fall below critical thresholds, geosynthetic reinforcement or chemical stabilization methods should be employed.

These interventions aim to improve load distribution and prevent recurrence of deep-seated failures.

The combination of advanced diagnostics and context-sensitive rehabilitation planning enables a shift from reactive maintenance to a predictive, performance-based approach, ultimately contributing to cost-effective asset management and improved road user experience.

4. Conclusion

This study highlights the critical value of employing modern, data-driven diagnostic technologies in assessing the technical condition and operational quality of highway pavements. By integrating surface condition metrics such as the International Roughness Index (IRI), visual distress evaluation through the Pavement Condition Index (PCI), and structural analysis using the Falling Weight Deflectometer (FWD), the research demonstrates a comprehensive approach to pavement performance assessment. The findings confirm that these tools not only enhance the accuracy and objectivity of condition evaluations but also provide essential input for prioritized, cost-effective maintenance and rehabilitation planning.

For countries like Uzbekistan, where diverse climatic conditions and increasing traffic volumes exert significant pressure on road infrastructure, the adoption of such advanced assessment methodologies is both timely and necessary. Institutionalizing these practices within national and regional road management agencies will contribute to enhanced road safety, improved user comfort, prolonged service life, and more sustainable use of public resources.

Looking ahead, future research and policy development should focus on the integration of diagnostic data with Geographic Information System (GIS)-based asset management platforms, enabling spatial visualization and long-term tracking of pavement performance. Additionally, leveraging artificial intelligence (AI) and machine learning algorithms for predictive maintenance modeling can further optimize resource allocation and improve the resilience of the national road network in the face of environmental and economic challenges.

References

1. Ganiev I. G. Preventive monitoring railway reinforced concrete bridges //Journal of Tashkent Institute of Railway Engineers. - 2019. - T. 15. - №. 3. - C. 227-232.

2. Ганиев И. Г. Определение среднего срока службы эксплуатируемых бетонных и железобетонных опор железнодорожных мостов //Известия Петербургского университета путей сообщения. - 2008. - №. 3. - С. 201-207.

3. Ганиев И. Г. Расчет безопасного времени работы пролетных строений по величине накопленного износа //Наука и прогресс транспорта. Вестник

Днепропетровского национального университета железнодорожного транспорта. - 2008. - №. 21. - С. 105-106.

4. Sodikov J. Roads Infrastructure Digital Twin Case Study: Uzbekistan //Digital Twin Computing for Urban Intelligence. - Singapore: Springer Nature Singapore, 2024. - С. 209-230.

5. Qarajanova G. T., Saidova R. Advancing Uzbekistan's Infrastructure: Investments in Transport Networks, Energy, and Communications //Academic Journal of Digital Economics and Stability. - Т. 35. - №. 11. - С. 88-101.

6. ESCAP U. N. et al. Digitalization of railway and multimodal transport in North and Central Asia: a subregional inventory of relevant national policies, strategies and programmes. - 2024.

7. Tsereteli M. The economic modernization of Uzbekistan //Uzbekistan's New Face. - 2018. - Т. 82.