AI-Enabled Road Condition Monitoring: A Scalable and Affordable Approach

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ABSTRACT

The condition of U.S. road infrastructure continues to deteriorate, with over 39% of public roadways rated in poor or mediocre condition and an annual economic impact exceeding $160 billion. Traditional visual inspection methods are slow, labor-intensive, and often subjective, while high-end survey vehicles and smartphone-based alternatives either lack scalability or measurement reliability. To address this gap, we present a scalable, AI-assisted approach for automated pavement condition monitoring using visual data collected from city-wide deployments. The proposed framework detects surface defects and assigns standardized condition scores aligned with industry-accepted rating systems. Field testing in two Indiana cities—West Lafayette and Fort Wayne—spanned over 2,000 miles and resulted in more than 13 million geo-referenced image captures. Results demonstrate the system's potential to support timely, consistent, and cost-effective evaluations of roadway health. This work highlights the importance of integrating AI with data-driven inspection practices to improve the sustainability and efficiency of municipal pavement management.

INTRODUCTION

Roads and highways form the backbone of the US economy, enabling over 3.2 trillion miles of annual travel and facilitating the movement of a significant portion of the $28.2 trillion worth of commodities shipped across the country [1]. Despite their critical role, US roads received a 'D +' grade from the American Society of Civil Engineers in 2025, underscoring widespread issues, including poor pavement conditions, increased vehicle damage, and increased economic costs [1].

Driving on deteriorated roads imposes substantial economic burdens, costing mo-

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torists $164 billion annually, equivalent to $718 per driver, due to increased vehicle repairs, accelerated depreciation, higher fuel consumption, and additional tire wear [2]. Moreover, approximately 39% of America's 4 million miles of public roadways are currently rated in poor or mediocre condition, further amplifying safety risks and repair expenditures [1].

The current approach to road maintenance relies heavily on manual inspections, where trained raters visually evaluate pavement conditions in the field. Although widely used, this method is time-consuming, subjective, and potentially dangerous to field crews [3]. To improve efficiency, several Departments of Transportation have adopted high-end survey vehicles such as the Autonomous Road Analyzer (ARAN), which integrates precision sensors for rapid data collection. However, the prohibitive cost of such platforms limits their widespread use. On the other end of the spectrum, smartphone-based systems using accelerometers or video feeds offer a low-cost alternative but suffer from noisy data, limited field of view, and reduced accuracy, particularly in poor lighting or when damage is outside the wheel path [4].

Addressing these gaps, this paper presents a novel, cost-effective method utilizing AI-driven RGB-D (color and depth) data for automating road condition assessments. The proposed system employs affordable, vehicle-mounted sensors combined with advanced AI algorithms to detect and quantify road defects rapidly and accurately. The approach significantly reduces inspection costs, enables frequent monitoring, and supports preventative maintenance strategies, ultimately contributing to safer roads and substantial economic savings.

END TO END ROAD CONDITION ASSESSMENT

This study proposes a high-level framework for automated road condition evaluation that integrates AI-based visual analysis with standardized scoring logic. The system processes roadway imagery captured using affordable, vehicle-mounted sensors to identify surface distresses, including alligator, transverse, and longitudinal cracking, as well as patches, potholes, and manholes.

Rather than relying on subjective visual ratings, the system mimics expert reasoning to assign condition scores aligned with standards such as the Pavement Surface Evaluation and Rating (PASER) system. This approach improves consistency, transparency, and scalability—allowing for more frequent assessments without incurring the costs of manual inspection or high-end survey vehicles.

By decoupling defect detection from condition scoring, the system can adapt to multiple rating standards and local agency needs. This modularity makes it suitable for broad deployment across cities with diverse pavement management practices.

FIELD TESTING AND RESULTS

To evaluate the performance and usability of the system, extensive real-world testing was conducted in two Indiana cities of differing scales: West Lafayette, a smaller city with 183 lane miles of asphalt roads across 1,123 road segments, and Fort Wayne, a significantly larger city with 1,856 lane miles and 8,482 road segments. Testing focused exclusively on asphalt roads, which dominate urban infrastructure; according to the National Asphalt Pavement Association, 93% of U.S. roads are paved in asphalt [5].

Data collection in West Lafayette took place over two days—December 11 and 12, 2025—and resulted in a total of 1,262,236 RGB-D image pairs. In Fort Wayne, data collection occurred across 18 driving days between January 27 and March 15, 2025. The extended timeline was due to inclement weather conditions, including snow and rain, as well as the need to wait for roads to dry completely to avoid capturing water-filled potholes. In total, 12,057,784 RGB-D image pairs were collected in Fort Wayne.

Several logistical factors affected the data collection process in both cities, including limited daily sunlight hours, variable weather conditions, and traffic flow. However, the most significant challenge was optimizing the driving path to ensure complete coverage of all roads. Initially, this process required labor-intensive manual planning with frequent roadside stops to consult maps and confirm coverage. To address this, a custom mobile application was developed to streamline the route-planning process. The app overlays road segments onto a map, marking roads yet to be covered in yellow and those already driven in red. This visual guidance allows drivers to make on-the-fly navigation decisions, significantly improving efficiency compared to the original manual approach (Figure 1).

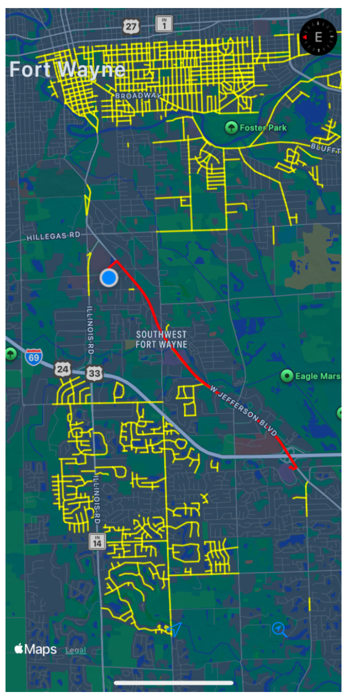

Figure 1. Screenshot of the route-viewing IOS application used during field testing. Roads yet to be driven are highlighted in yellow, while roads already covered are marked in red.

Before proceeding with city-wide deployment in Fort Wayne, a pilot study was conducted on four representative roads comprising a total of 60 road segments. The system's PASER ratings were compared to manual assessments conducted by a trained pavement inspector. Of these 60 segments, the system matched the human rating on 49 segments, identified defects missed by the human in 4 segments, and disagreed in 7 segments. This yields an accuracy of 88.3%. These results validated the reliability of the automated system and informed the decision to proceed with full-scale deployment. Data collected from West Lafayette and Fort Wayne, Indiana enabled a comprehensive spatial evaluation of road conditions across both cities. Analysis revealed a high frequency of alligator cracking and widespread pothole damage.

The PASER score distribution for West Lafayette is shown on the left side of Figure 2. The results reveal a concentration of road segments in the lower scoring range (scores 2–4), indicating significant surface deterioration. The temporal trend, shown on the right side of Figure 2, highlights a clear decline in the city's weighted average PASER score—from 6.10 in 2020 to 3.41 in 2024. This trajectory follows the typical pavement deterioration curve, where conditions rapidly worsen after a threshold if maintenance is delayed. PASER data from 2020 to 2022 was provided by the City of West Lafayette; no data was available for 2023. The degradation observed between 2022 and 2024 emphasizes the importance of more frequent inspections and proactive maintenance. These findings support the effectiveness of the automated system in delivering accurate, scalable, and timely evaluations for data-driven roadway management.

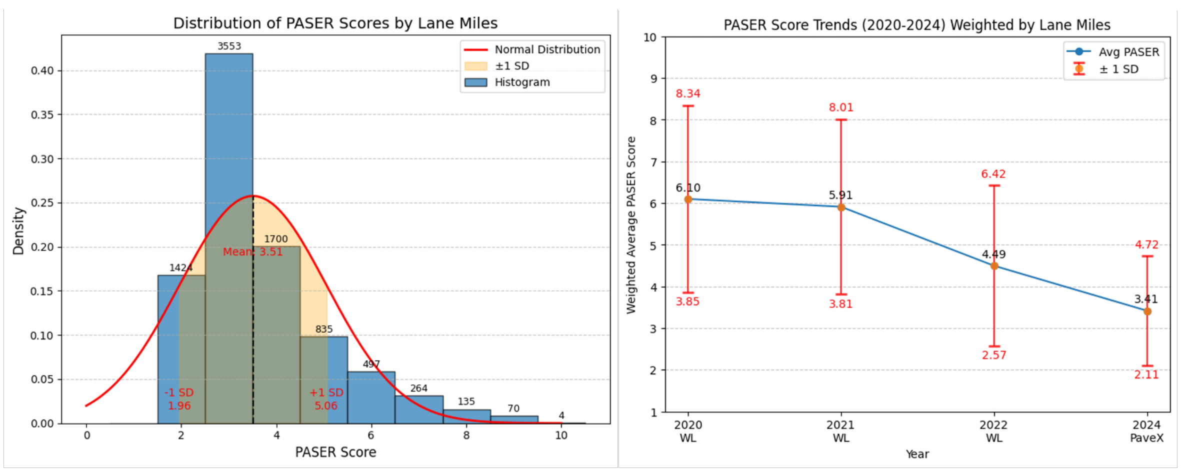

Figure 2. (Left) Distribution of PASER scores and (right) 2020–2024 PASER trends in West Lafayette, Indiana, both weighted by lane miles.

CONCLUDING REMARKS

This study presents a low-cost, AI-powered system that enables fast, accurate, and scalable road condition assessments. By automating defect detection and PASER scoring, cities can shift from infrequent, manual inspections to frequent, data-driven maintenance. Field tests in Indiana demonstrated the system's effectiveness and potential for real-world deployment. With broader adoption or crowd-sourced integration, this technology can help cities fix roads before they fail—improving safety, extending pavement life, and reducing repair costs.

REFERENCES

1. American Society of Civil Engineers. 2025. “2025 Report Card for America’s Infrastructure,” Tech. rep., American Society of Civil Engineers, https://infrastructurereportcard.org.
2. TRIP. 2024. “Key Facts about the U.S. Surface Transportation System,” Tech. rep., TRIP, Washington, D.C., https://tripnet.org.
3. Attoh-Okine, N. and O. Adarkwa. 2013. “Pavement Condition Surveys – Overview of Current Practices,” Tech. rep., Delaware Center for Transportation.
4. Souza, V. M. 2018. “Asphalt pavement classification using smartphone accelerometer and Complexity Invariant Distance,” *Engineering Applications of Artificial Intelligence*, 74:198–211, ISSN 0952-1976, doi:10.1016/j.engappai.2018.06.003.
5. Brian. 2022, “Asphalt or Concrete – How Local Transportation Departments Decide,” https://aegisasphalt.com/asphalt-or-concrete-how-local-transportation-departments-decide, aegis Asphalt Construction.
6. Zhang, A., K. C. Wang, B. Li, E. Yang, X. Dai, Y. Peng, and C. Chen. 2017. “Automated pixel-level pavement crack detection on 3D asphalt surfaces using a deep-learning network,” *Computer-Aided Civil and Infrastructure Engineering*, 32(10):805–819, doi:10.1111/mice.12291.
7. Maeda, H., Y. Sekimoto, T. Seto, T. Kashiyama, and H. Omata. 2018. “Road damage detection and classification using deep neural networks with smartphone images,” *Computer-Aided Civil and Infrastructure Engineering*, 33(12):1127–1141, doi:10.1111/mice.12412.