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(RESEARCH ARTICLE)

INTEGRATION OF FLEXIBLE PAVEMENT CONDITION ASSESSMENT DATA FOR ENHANCING THE RELIABILITY AND OPTIMIZATION OF ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENTS (ESIAS) ON THE INZIA BRIDGE–LOANGE BRIDGE SECTION (RN1, DR CONGO): LINKAGES BETWEEN PAVEMENT EVALUATION STUDIES AND ENVIRONMENTAL IMPACTS IN ROAD INFRASTRUCTURE PROJECTS

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ABSTRACT

National Road 1 (RN1), a vital artery of the Democratic Republic of the Congo (DRC), exhibits accelerated degradation along the Pont Inzia – Pont Loange section. Conventional Environmental and Social Impact Assessments (ESIAs) rely on theoretical traffic estimates without incorporating actual pavement condition data. The objective of this paper is to analyze current ESIA practices in road projects in the DRC in order to build sustainable, transparent, and socially accepted road infrastructures, and to make studies more reliable—thereby ensuring project sustainability and fostering a resilient society in the face of climate change threats—by relying on a cross-analysis methodology of technical aspects and impacts linked to the cycle: Auscultation – Reliability – Optimization – Sustainable Global Impact.

An auscultation campaign was conducted by the National Laboratory of Public Works (Laboratoire National de Travaux Publics [LNTP]), involving deflection measurements using the Benkelman beam, longitudinal roughness testing, and surface distress surveys. The results indicate an average deflection of 85/100 mm, an average International Roughness Index (IRI) of 6.2 m/km, and a Pavement Condition Index (PCI) of 38/100, reflecting a pavement in a plastic phase nearing the end of its useful life. A global statistical analysis over an extended route of 529.6 km reveals 145.8 km in good condition (29.4%), 333.6 km in fair condition (61.1%), and 50.2 km of critical failure points (9.5%). Correlation with environmental data demonstrates that this deteriorated state severely harms the environment: a 22% overconsumption of fuel, an 18% increase in CO_2 emissions, and PM_{10} dust generation three times higher than the regulatory standard. We propose an optimized ESIA matrix integrating auscultation indicators as quantitative inputs. Making pavement studies reliable means guaranteeing project sustainability and building a society resilient to climate change threats.

Keywords: Integration, Auscultation, Pavement, Reliability, Optimization, Environmental impact.

1 INTRODUCTION

In the Democratic Republic of the Congo, road infrastructures are an essential lever for economic growth, territorial integration, and access to basic services. However, road works generate significant environmental and social impacts, hence the legal requirement for Environmental and Social Impact Assessments (ESIAs) enshrined in the framework law on the environment (Democratic Republic of the Congo [DRC], 2011). Flexible pavements, which predominate in the DRC, deteriorate rapidly under the combined effects of heavy traffic, tropical climate, and a chronic maintenance deficit (Centre Expérimental de Recherches et d'Études du Bâtiment et des Travaux Publics [CEBTP], 1984). Auscultation (deflection, IRI, cracking, bearing capacity) is the benchmark tool for assessing their structural condition.

The Pont Inzia – Pont Loange section of RN1 crosses an environmentally sensitive savanna and gallery forest zone in the Kwilu and Kwango provinces. Built prior to the country's independence, this road has undergone several rehabilitations and maintenance operations—the most recent rehabilitation having been executed by Chinese enterprises—yet the pavement currently exhibits widespread potholes, longitudinal and transverse cracks, rutting, and alligator cracking. Structurally, the overall condition is marked by critical sand encroachment (silting) and a proliferation of longitudinal cracks, transverse cracks, and fatigue cracking (alligator/crocodile cracking). A major black spot is located at the Lukeni Bridge and in the urban crossing of Kikwit at the Mandanda bend, where severe silting and clogged drainage ditches cause water stagnation, deterioration of sidewalks and shoulders, widespread surface cracking, fatigued bitumen, and erosion gullies threatening engineering structures.

A paradox currently exists in the DRC: the ESIA is carried out prior to construction works based on theoretical traffic volumes, without accounting for the actual condition of the pavement, despite the procedural mechanisms established by national regulations (DRC, 2014). Yet, the condition of a flexible pavement directly influences its environmental footprint: a degraded road increases fuel consumption, air pollution, noise, road insecurity, and shoulder erosion (Kerali, 2000). The shortcomings of current ESIAs are characterized by poor integration of reliable technical data on actual pavement conditions, a lack of correlation between technical diagnostics and environmental impacts, and assessment methods poorly adapted to local Congolese realities.

The objective of this research is to answer the following research question: How can auscultation parameters serve as quantifiable environmental indicators to make ESIAs more reliable and improve the performance of road projects in the DRC through better integration of flexible pavement auscultation results?

2 MATERIAL AND METHODS

2.1 Study Area and Cartographic Route

The studied section lies along RN1 under a humid tropical climate, resting on sandy soils. The Annual Average Daily Traffic (AADT) is 425 vehicles/day, 60% of which are heavy trucks, in an area subject to severe water erosion threatening to sever the roadway. The geolocation and cartographic survey of the analyzed road network, from the initial diagnostic to the geographical boundaries of the project, are formalized and spatialized in Figures 1, 2, and 3 below:

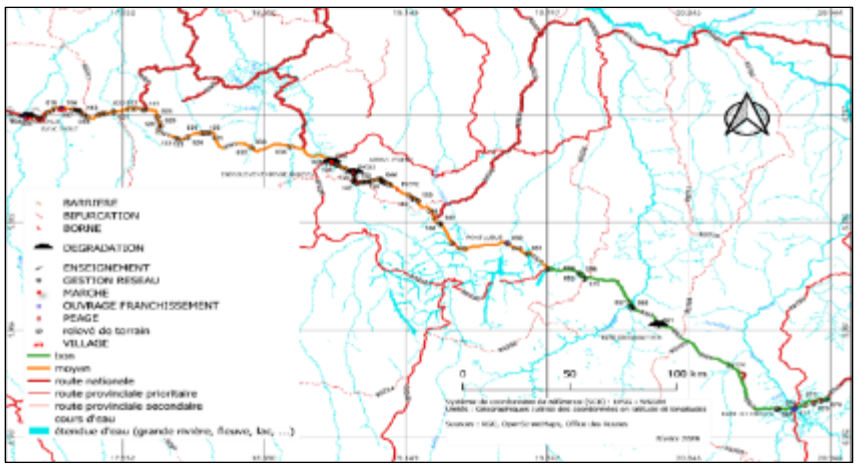


Figure 1: Map of All Route Coordinates (Villages, Milestones, Tollgates – February 2026)



Figure 2: Map of Pavement Nature and Surface Distresses (Field Survey)

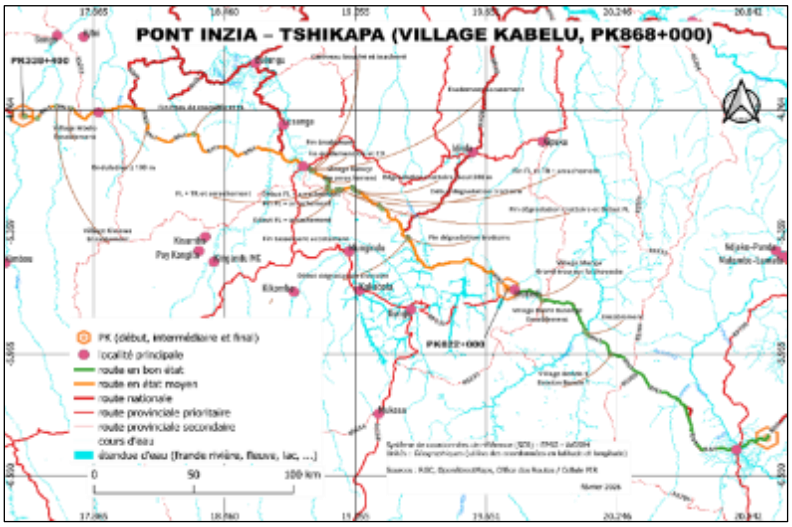


Figure 3: Map of Pavement Condition from Pont Inzia – Loange to Tshikapa (Kabelu Village, PK868+000)

2.2 Methodological Framework and Auscultation Campaign

The methodological framework cross-references environmental regulations in the DRC (DRC, 2011, 2014), existing ESIA reports, and physical field data. The auscultation campaign was conducted during the dry season (June 2025) over an extended route analyzed by the LNTP team:

- **Bearing Capacity:** Measurement of maximum deflection \(d_{(90)}\) using the Benkelman beam at 200 m intervals, in accordance with tropical pavement design and auscultation standards (CEBTP, 1984).
- **Longitudinal Evenness/Roughness:** Use of a laser profilometer to analyze the International Roughness Index (IRI) in m/km (Sayers et al., 1986).
- **Surface Distresses:** Application of the VIZIR method (Laboratoire Central des Ponts et Chaussées [LCPC], 1991) and calculation of the Pavement Condition Index (PCI) in accordance with standard ASTM D6433 (ASTM International, 2024).
- **Environmental & Social Indicators:** Measurement of PM_{10} particulates (portable sensor), noise levels (dB), water sampling in drainage ditches, and structured surveys with local residents.

2.3 Integration Method and Digital Tools

The model relies on a correlation matrix that converts each technical auscultation indicator into an environmental and social impact variable. Based on the link with a high International Roughness Index (IRI), the pavement is considered degraded and uncomfortable, inducing higher vehicle operating costs and increased rolling resistance tied to structural fatigue (Sayers et al., 1986). The simulation of road user costs and maintenance strategies was performed using the World Bank's HDM-4 software, the international benchmark in road asset management (Kerali, 2000).

3 RESULTS

3.1 Global Statistical Analysis of the Road Corridor Condition

Field investigations quantified the condition of the road platform over a total cumulative length of 529.6 km. Physical failure points correspond to zones of critical degradation (Table 1).

Table 1: Global Statistics of the Road Corridor Condition (Pont Inzia – Loange – Tshikapa)

Corridor Condition	Cumulative Length (km)	Percentage (%)
Good condition	145.8	29.4%
Fair condition	333.6	61.1%
Failure points	50.2	9.5%
Grand total	529.6 km	100%

Note. These data graphically reflect a predominance of fair condition, flanked by zones of imminent structural failure requiring urgent intervention.

To support this statistical table, the proportional distribution of structural degradation across the 529.6 km route is illustrated by the three-dimensional chart in Figure 4 below:

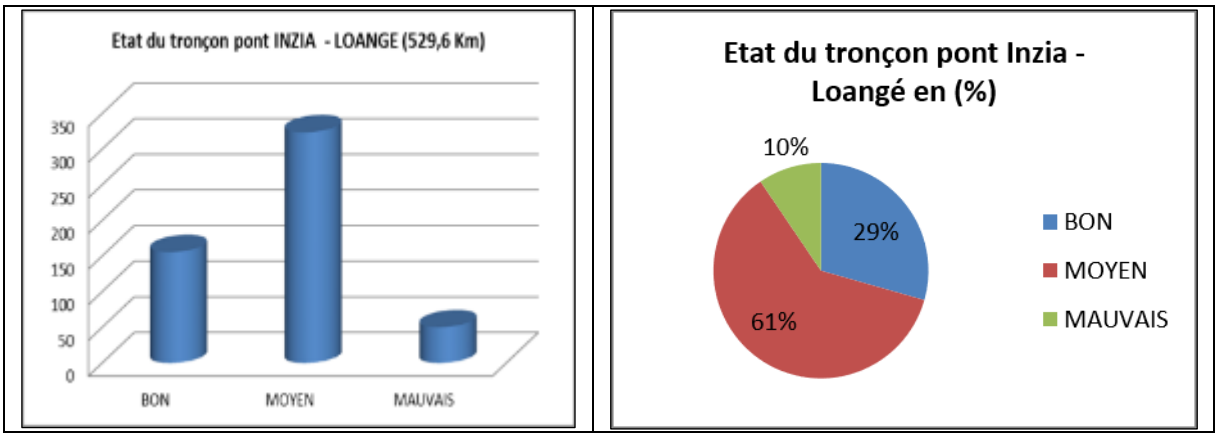


Figure 4: Representative Chart of the Condition of the Pont Inzia – Loange Section (529.6 km)

3.2 Structural and Functional Diagnostic of Critical Points

The auscultation campaigns conducted by the National Laboratory of Public Works (LNTP) reveal critical structural and functional degradation of the pavement through the following key indicators:

- **Deflection d(90) :** Average value of 85.4/100 mm (SD = 21.3), well above the permissible threshold (< 50/100 mm), confirming an under-designed and water-saturated subbase according to tropical pavement benchmarks (CEBTP, 1984).
- **IRI:** Average of 6.2 m/km; 78% of the section displays an IRI > 4.5 m/km (classified as "very poor" by the World Bank; optimal threshold < 2.5 m/km) (Sayers et al., 1986).
- **PCI:** Recorded at 38/100 ("poor / very poor" according to ASTM International, 2024), with dominant distresses identified per the VIZIR catalog (LCPC, 1991) consisting of potholes (42%), alligator cracking (30%), and rutting (18%).

3.3 Visual Evidence of Pathologies and Associated Environmental Impacts

Direct visual and geotechnical auscultation highlights severe degradation of the road platform, drainage network, and retaining structures. The main field observations are structured as follows:

3.3.1 Sand Encroachment and Water Stagnation on the Pavement

In the urban crossing of Kikwit at the Mandanda bend as well as on the Lukeni Bridge, chronic blockage of drainage collectors induces heavy stagnation of runoff water. This lack of drainage outlets accelerates bitumen fatigue and generates widespread alligator cracking (Figure 5; LCPC, 1991).



Figure 5: Widespread Surface Cracking and Alligator Cracking Along the Road Right-of-Way

3.3.2 Geotechnical Instability and Slope Landslides

The lack of roadside protection causes massive failures of earth masses (Figure 6). These regressive landslides destroy sidewalks and directly threaten to sever the national highway link.



Figure 6: Slope Landslide and Earth Burial Along the Roadside at Bondo Village

3.4 Diagnostic of Engineering Structures and Drainage Networks

While certain sections of the route exhibit a stable geometric profile, downstream discharge structures bear the full brunt of siltation and erosion gullies (Figure 7), creating a risk of structural collapse over the Lonji River at Mungunga village.



Figure 7: Risk of Roadway Severance Over the Lonji River at Mungunga Village

4 DISCUSSION

4.1 Causes of Observed Methodological Gaps

Comparative analysis reveals that highway engineers work quantitatively over the short-to-medium term (bearing capacity, deformation, layer thickness), whereas environmental experts rely on long-term qualitative data based on surveys (biodiversity, climate, social impact). The root causes of this disconnect lie in:

- A lack of institutional cross-functionality, with both groups of experts working in silos without conducting joint field inspections.
- The absence of conversion of physical indicators (deflection, moduli, IRI) into measurable environmental and social impact indicators (Kerali, 2000).
- Insufficient reliable local technical data, weakening the relevance of compensatory measures proposed in conventional ESIAs required by legislation (DRC, 2014).
- Budgetary pressures and tight deadlines leading to the rapid drafting of purely administrative ESIAs disconnected from the actual pavement structure.

4.2 Consequences on Overall Project Performance

This technical disconnect triggers cascading failures:

- **Technical & Economic:** Under-design of pavement structures relative to local geotechnical constraints (CEBTP, 1984), premature road deterioration, execution delays, substantial budget overruns (22% fuel overconsumption modeled via HDM-4), and discouragement of domestic and international investments.
- **Environmental & Social:** Water stagnation exacerbating regressive erosion, an 18% increase in CO_2 emissions (Kerali, 2000), proliferation of harmful dust (PM_{10} three times higher than the standard), high risks of traffic accidents, social conflicts with local communities, and loss of credibility for public institutions.

4.3 6-Step Optimized Integration Model

The proposed model breaks down siloed workflows by introducing a unified logical chain:

- Auscultation → Reliability → Optimization → Sustainable Global Impact. This virtuous cycle operates as follows:
- Collect (Data): Simultaneously gather technical parameters (bearing capacity, IRI, drainage) and socio-environmental parameters (noise, PM_{10}, resident feedback).
- Translate (Impacts): Convert mechanical defects into tangible impacts (e.g., degraded road = fuel overconsumption and dust = respiratory illnesses).
- Map (GIS): Overlay damaged road zones onto sensitive natural or inhabited areas.
- Consult (Stakeholders): Bring together engineers, ecologists, and sociologists to jointly validate solutions in the field.
- Target (ESMP): Replace conventional full-scale resurfacing with targeted rehabilitation, avoiding unnecessary deforestation and borrow pits/quarries.
- Monitor & Evaluate: Conduct periodic post-rehabilitation monitoring of technical and environmental indicators to trigger preventive maintenance on time.

5 CONCLUSION

Integrating mechanical auscultation data transforms ESIAs from a mere administrative formality into a high-performance eco-design tool for road infrastructures in Sub-Saharan Africa. On the Pont Inzia – Pont Loange section, integrated rehabilitation represents an economic, ecological, and social urgency.

To optimize roads in the DRC, technical auscultation (deflection, IRI, PCI) must be made mandatory prior to validation by the Congolese Environment Agency (ACE), alongside establishing a national framework linking technical parameters to environmental impacts. This requires an interdisciplinary approach from the preliminary design phase and data-driven preventive maintenance. Finally, closer collaboration is needed between the Roads Authority (Office des Routes) and the Ministry of Environment, centralizing data on an accessible GIS platform, involving local communities and donors, and enforcing legal sanctions for non-compliance with the Environmental and Social Management Plan (ESMP) (DRC, 2011, 2014).

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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