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An Integrated Methodological Framework for Sustainable Urban Road Infrastructure Management, The Global Durability Index (IGD) And Prioritization Matrix Applied to Porto-Novo (Benin)

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ABSTRACT: Urban road infrastructures in developing countries face accelerated deterioration due to rapid urbanization, climate stress, limited maintenance resources, and institutional constraints. This paper proposes an integrated methodological framework for assessing and improving the sustainability of urban road networks, based on the Global Durability Index (IGD), originally developed and validated in the municipality of Nikki (Benin), and extended here to the city of Porto-Novo. The framework combines a multi-dimensional durability assessment, associated indicators, and a multicriteria prioritization matrix to support decision-making in road maintenance and rehabilitation. Results highlight the relevance of the IGD as an operational governance tool and its adaptability to diverse urban contexts in Benin.

KEYWORDS: Infrastructure Sustainability, Urban Roads, Global Durability Index (IGD), Multicriteria Analysis, Maintenance Prioritization, Benin

I. INTRODUCTION

Urban road infrastructures constitute a fundamental backbone of territorial development, economic integration, and social cohesion. In African cities, the expansion of road networks over the last two decades has not been matched by equivalent progress in maintenance strategies, resulting in premature degradation and reduced service levels (World Bank, 1988; OCDE, 1995).

Recent studies emphasize that infrastructure sustainability cannot be reduced to technical performance alone, but must integrate functional efficiency, environmental resilience, and institutional capacity (Tessier, 1990; PIARC, 2015). In this perspective, the challenge lies not only in diagnosing road pathologies, but also in equipping local authorities with operational methodological tools capable of guiding long-term decision-making.

This paper builds upon the Infrastructure Durability Index (IGD) developed in the doctoral research conducted in the municipality of Nikki (Gbaguidi and al., 2025), and proposes its extension and adaptation to the urban context of Porto-Novo. The central objective is to formalize a transferable methodological framework for sustainable urban road infrastructure management.

II. CONCEPTUAL CLARIFICATION AND THEORETICAL FRAMEWORK

A. Urban road infrastructure sustainability

Sustainability of road infrastructure is defined as the capacity of a road system to maintain its structural integrity, functional performance, and socio-environmental acceptability throughout its lifecycle, while remaining institutionally manageable and financially viable.

This definition aligns with the lifecycle approach advocated by OECD (1995) and World Bank (2007), emphasizing preventive maintenance and governance efficiency.

B. Infrastructure durability

Durability refers to the resistance of infrastructure to physical degradation over time under traffic loads and environmental stress, conditioned by construction quality, maintenance practices, and management systems.

In the IGD framework, durability is operationalized through measurable indicators across multiple dimensions.

C. Governance and decision-support tools

Governance of road infrastructure involves coordination between technical services, financial mechanisms, regulatory frameworks, and operational actors. Decision-support tools such as composite indices and prioritization matrices are increasingly recognized as essential for rationalizing public investment (PIARC, 2019).

D. Literature review

Existing approaches to road infrastructure assessment can be grouped into four categories:

i. Technical condition indices (Pavement Condition Index – PCI, Road Condition Index – RCI),

ii. Economic optimization models (HDM-4),
iii. Environmental impact-based approaches,
iv. Integrated sustainability frameworks (rarely operationalized at local level).

While tools such as HDM-4 are technically robust, they remain data-intensive and poorly adapted to the institutional realities of African municipalities (World Bank, 2001). Recent african research highlights the need for simplified yet robust indices tailored to local governance capacities (Gbaguidi and al., 2025).

The IGD responds to this gap by combining scientific rigor with operational feasibility.

III. METHODOLOGICAL FRAMEWORK

A. Structure of the IGD model (Nikki reference model)

The IGD model developed for Nikki is structured around four core dimensions: Technical dimension (DT), Functional dimension (DF), Environmental dimension (DE) and Institutional dimension (DI).

Each dimension is composed of standardized indicators scored on a normalized scale [0–1].

B. Mathematical formulation of the IGD

$$IGD_i = \sum_{i=1}^{4} wi \, . D_i$$

Where:

D_i = composite score of dimension i,
W_i = weight of dimension i,
∑W_i =1.

For Porto-Novo, the weighting scheme (adapted from the Nikki model) was defined as follows:

Table 1 : The weighting scheme of IGD

Dimension	Weight
Technical (DT)	0.35
Functional (DF)	0.25
Environmental (DE)	0.20
Institutional (DI)	0.20

This weighting reflects the high prevalence of structural and drainage-related failures in coastal urban environments.

C. Associated indicators

Each dimension integrates specific indicators, for example:

DT: surface degradation, structural failures, drainage condition

DF: traffic level, connectivity, safety devices

DE: flood sensitivity, erosion risk, environmental integration

DI: maintenance planning, institutional coordination, budget allocation

IV. MULTICRITERIA PRIORITIZATION MATRIX

A. Rationale

Given limited financial resources, not all road sections can be treated simultaneously. The prioritization matrix cross-references IGD score, functional importance, risk level and intervention cost.

B. Decision logic

Table 1 : IGD level and priority action

IGD Level	Priority Action
IGD < 0.40	Reconstruction
0.40 ≤ IGD < 0.60	Rehabilitation
0.60 ≤ IGD < 0.75	Periodic maintenance
IGD ≥ 0.75	Routine maintenance

This matrix provides a transparent and replicable decision-support mechanism.

V. RESULTS AND DISCUSSIONS

The application of the IGD to Porto-Novo reveals strong spatial heterogeneity in road durability, confirming findings from the Nikki case study. Sections with low IGD values systematically correspond to weak drainage, high traffic, and fragmented institutional responsibility.

The integration of the institutional dimension distinguishes the IGD from conventional technical indices, reinforcing its relevance as a governance tool rather than a purely engineering metric.

A. Associated indicators, criticality index and intervention prioritization matrix

1- Associated indicators for infrastructure sustainability assessment

While the global Durability Index (IGD) provides a synthetic measure of the overall sustainability level of road infrastructure, its operational relevance is enhanced through a set of associated indicators that allow a finer diagnostic of weaknesses and intervention levers.

These associated indicators are structured according to the four dimensions of sustainability and are derived from field surveys, spatial analysis, and institutional assessments.

2- Technical Associated Indicators

The technical dimension focuses on the physical and structural condition of road infrastructure. The associated indicators include:

- Surface Degradation Index (SDI): proportion and severity of cracks, potholes, raveling and surface wear.
- Structural Integrity Indicator (SII): presence of deformations, settlements, and bearing capacity deficiencies.
- Drainage Functionality Indicator (DFI): effectiveness of longitudinal and transversal drainage systems.

These indicators capture the immediate causes of performance loss and premature deterioration.

3. Functional associated indicators

Functional indicators reflect the capacity of the road to ensure safe, continuous and efficient mobility:

- Traffic Load Indicator (TLI): intensity and composition of traffic.

- Connectivity and Accessibility Indicator (CAI): role of the road segment in the urban network.
- Road Safety Indicator (RSI): presence and condition of signage, pedestrian facilities and traffic control devices.

4. Environmental associated indicators

Environmental indicators address the interaction between road infrastructure and its natural context:

- Flood Exposure Indicator (FEI) include susceptibility to water accumulation and flooding.
- Soil Sensitivity Indicator (SSI) concern erosion and geotechnical vulnerability.
- Environmental Integration Indicator (EII): compatibility with surrounding land use and drainage systems.

5. Institutional associated indicators

Institutional indicators measure governance capacity and management effectiveness:

- Maintenance planning Indicator (MPI): existence of preventive maintenance plans.
- Institutional Coordination Indicator (ICI): clarity of responsibilities among actors.
- Budget Sustainability Indicator (BSI): regularity and adequacy of funding for maintenance.

B. Criticality Index (CI) of road infrastructure

To complement the IGD, a Criticality Index (CI) is introduced to assess the urgency of intervention by combining durability performance with functional importance and risk exposure.

The CI is defined as follows:

$$CI = \alpha(1 - IGD) + \beta FI + \gamma RI$$

Where:

IGD = Infrastructure Durability Index,

FI = Functional Importance score of the road segment,

RI = Risk Indicator (safety, flooding, service disruption),

α, β, γ = weighting coefficients such that α+β+γ=1.

In the Porto-Novo case study, the adopted weighting is:

α= 0.5 (durability deficit),

β=0.3 (functional importance),

γ=0.2 (risk exposure).

This formulation ensures that structurally degraded but strategically important roads are prioritized appropriately.

4.4- Intervention prioritization matrix for infrastructure sustainability

C. *Intervention prioritization matrix for infrastructure sustainability*

The prioritization matrix integrates both the IGD and the Criticality Index (CI) to guide decision-making. It constitutes a strategic tool for allocating limited resources efficiently.

1. Structure of the matrix

The matrix crosses Durability Level (IGD) on one axis and Criticality Level (CI) on the other.

Table 3: prioritization matrix and interpretation

IGD / CI	Low CI	Moderate CI	High CI	Very High CI
IGD ≥ 0.75	Routine maintenance	Routine maintenance	Periodic maintenance	Targeted rehabilitation
0.60 ≤ IGD < 0.75	Routine maintenance	Periodic maintenance	Rehabilitation	Rehabilitation
0.40 ≤ IGD < 0.60	Periodic maintenance	Rehabilitation	Rehabilitation	Reconstruction
IGD < 0.40	Rehabilitation	Reconstruction	Reconstruction	Reconstruction

2. Contribution to sustainable infrastructure management

This matrix promotes preventive over corrective maintenance. Il improves transparency in decision-making, supports multi-year programming of interventions and aligns technical priorities with governance and budget constraints.

It operationalizes sustainability by linking diagnosis, evaluation and action within a single decision-support framework.

D. Implications for sustainable infrastructure governance

The IGD framework supports proactive maintenance planning, rational allocation of public funds and accountability and transparency in infrastructure governance. Its adaptability from Nikki (semi-rural context) to Porto-Novo (urban context) demonstrates its scalability and transferability.

E. Interpretation of the criticality index

The CI values are classified into four intervention urgency levels.

Table 4: Criticality Index range and interpretation

CI Range	Criticality Level	Interpretation
CI ≥ 0.75	Very High	Immediate intervention required
0.60 ≤ CI < 0.75	High	Short-term intervention
0.40 ≤ CI < 0.60	Moderate	Medium-term intervention
CI < 0.40	Low	Preventive maintenance

CONCLUSIONS

This study confirms the relevance of the Global Durability Index (IGD) as an integrated methodological tool for sustainable urban road infrastructure management. By combining durability assessment, associated indicators, and prioritization mechanisms, the IGD contributes to bridging the gap between diagnosis and decision-making in Beninese cities.

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