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DEFINITION OF AN INTERVENTION POLICY FOR ROAD MAINTENANCE AND CONSERVATION: COST-BENEFIT ANALYSIS IN BENGUELA, ANGOLA

DEFINIÇÃO DE UMA POLÍTICA DE INTERVENÇÃO PARA MANUTENÇÃO E CONSERVAÇÃO DE ESTRADAS: ANÁLISE DE CUSTOS E BENEFÍCIOS EM BENGUELA, ANGOLA

DEFINICIÓN DE UNA POLÍTICA DE INTERVENCIÓN PARA EL MANTENIMIENTO Y CONSERVACIÓN DE CARRETERAS: ANÁLISIS DE COSTOS Y BENEFICIOS EN BENGUELA, ANGOLA

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ABSTRACT

Considering the accelerated degradation of road infrastructure in Angola and its socioeconomic impacts, this study aims to propose an efficient intervention policy for road maintenance and conservation, focusing on cost-benefit analysis. To this end, a mixed-methods investigation was conducted, combining qualitative (semi-structured interviews) and quantitative (surveys and technical inspections) methods in the municipality of Benguela. In this way, it is observed that the absence of formal conservation plans, insufficient funding, and the predominance of a reactive management model are the main obstacles. Recurring pathologies in flexible pavements are identified, such as cracks, alligator cracking, and deformations. Four types of intervention are proposed, ranging from localized actions to complete redesign, which allows us to conclude that the adoption of preventive policies, based on cost-benefit analyses and supported by emerging technologies, is essential to ensure the sustainability of the road network and optimize public resources.

Keywords: Road Maintenance. Flexible Pavements. Cost-Benefit Analysis. Asset Management. Benguela.

RESUMO

Considerando a degradação acelerada da infraestrutura rodoviária em Angola e seus impactos socioeconómicos, objetiva-se propor uma política de intervenção eficiente para a manutenção e conservação de estradas, com foco na análise de custos e benefícios. Para tanto, procede-se a uma investigação de abordagem mista, combinando métodos qualitativos (entrevistas semiestruturadas) e quantitativos (inquéritos e inspeções técnicas) no município de Benguela. Desse modo, observa-se que a ausência de planos formais de conservação, a insuficiência de financiamento e a predominância de um modelo de gestão reativo são os principais entraves. Identificam-se patologias recorrentes em pavimentos

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flexíveis, como fissuras, pele de crocodilo e deformações. Propõem-se quatro tipologias de intervenção, desde ações localizadas até redimensionamento completo, o que permite concluir que a adoção de políticas preventivas, baseadas em análises custo-benefício e apoiadas por tecnologias emergentes, é essencial para garantir a sustentabilidade da rede rodoviária e otimizar os recursos públicos.

Palavras-chave: Manutenção Rodoviária. Pavimentos Flexíveis. Análise Custo-Benefício. Gestão de Ativos. Benguela.

RESUMEN

Considerando la degradación acelerada de la infraestructura vial en Angola y sus impactos socioeconómicos, el objetivo es proponer una política de intervención eficiente para el mantenimiento y conservación de carreteras, con enfoque en el análisis de costos y beneficios. Para ello, se procede a una investigación de enfoque mixto, combinando métodos cualitativos (entrevistas semiestructuradas) y cuantitativos (encuestas e inspecciones técnicas) en el municipio de Benguela. De este modo, se observa que la ausencia de planes formales de conservación, la insuficiencia de financiamiento y el predominio de un modelo de gestión reactivo son los principales obstáculos. Se identifican patologías recurrentes en pavimentos flexibles, como fisuras, piel de cocodrilo y deformaciones. Se proponen cuatro tipologías de intervención, desde acciones localizadas hasta redimensionamiento completo, lo que permite concluir que la adopción de políticas preventivas, basadas en análisis de costo-beneficio y apoyadas por tecnologías emergentes, es esencial para garantizar la sostenibilidad de la red vial y optimizar los recursos públicos.

Palabras clave: Mantenimiento de Carreteras. Pavimentos Flexibles. Análisis de Costo-Beneficio. Gestión de Activos. Benguela.

1 INTRODUCTION

Road infrastructure plays a fundamental role in the socio-economic development of any nation, functioning as a vector of territorial integration, facilitator of trade and promoter of population mobility. In Angola, particularly in the municipality of Benguela, the accelerated degradation of roads is a serious obstacle to economic growth and the quality of life of the population (Jensen, 2016). The absence of structured maintenance policies has resulted in predominantly corrective interventions, characterized by high costs and low durability (Branco et al., 2011). This scenario is aggravated by climate change, which intensifies extreme weather events, accelerating degradation processes (IPCC, 2022).

The efficient management of road maintenance requires the adoption of preventive approaches and the performance of cost-benefit analyses that guide the allocation of resources, which are often scarce (Pais, 1999). In this context, the definition of an intervention policy based on technical and economic evidence becomes imperative. Emerging technologies, such as Building Information Modeling (BIM) for infrastructure and IoT (Internet of Things) sensors for real-time monitoring, offer new opportunities to optimize the lifecycle management of road assets (Costin et al., 2018).

Based on this problem, the general objective of this article is to propose an efficient intervention policy for the maintenance and conservation of roads, prioritizing cost optimization and socioeconomic benefits. Specific objectives include: (1) identifying the main drivers of road wear and tear under local conditions; (2) analyze existing maintenance methods; (3) investigate the impacts of preventive and corrective strategies; (4) formulate guidelines based on cost-benefit analyses; and (5) estimate the economic and social benefits of the proposed policies, integrating climate resilience considerations.

The research, of an applied nature, adopts a mixed approach and uses the case study in the municipality of Benguela, combining surveys of technicians, semi-structured interviews with professionals in the sector and detailed technical inspections on four urban roads.

2 THEORETICAL FRAMEWORK

2.1 ROAD MAINTENANCE MANAGEMENT AND THE SUSTAINABILITY PARADIGM

Road infrastructure management has evolved from a reactive paradigm to a proactive, data-driven one, in which preventive maintenance plays a central role in maximizing pavement life and minimizing costs throughout the life cycle (Branco et al., 2011). The adoption of Pavement Management Systems (SMP) allows for informed decision-making, based on performance indicators and robust economic analysis (Freitas and Pereira, 2001). Recently, the concept was expanded to Transportation Asset Management Systems (TAMS),

which adopt a holistic view of the asset, incorporating sustainability and resilience criteria (FHWA, 2020).

Conservation can be classified as current, periodic and rehabilitation, depending on the nature, periodicity and objective of the intervention (EP, S.A., 2008). While current conservation aims to ensure minimum services, rehabilitation aims to recover or improve the structural and functional characteristics of the pavement. The incorporation of circular economy criteria, such as the recycling of materials in situ, has become a fundamental premise for the sustainability of the sector (Gomes, 2005; Santos & Ferreira, 2021).

2.2 PATHOLOGIES OF FLEXIBLE PAVEMENTS AND THE INFLUENCE OF ENVIRONMENTAL CONDITIONS

Flexible pavements, predominant in the Angolan network, are subject to a set of pathologies that reflect the interaction between traffic demands, climatic conditions and the quality of materials and construction (Pereira et al., 1999). The "Catalogue of Road Pavement Degradations" (EP, S.A., 2008) groups these pathologies into families, the most relevant being:

- ***Cracking***: Includes isolated, longitudinal, transverse cracks and the "crocodile skin", the latter resulting from fatigue of the structure and indicative of advanced structural failure. The combined action of infiltrated water and dynamic loads accelerates this process (Ongel et al., 2022).
- ***Deformations***: These manifest as wheels, subsidence and undulations, associated with problems with the bearing capacity of the foundation or pavement layers, often exacerbated by high temperatures and heavy loads (Zhou et al., 2020).
- ***Disaggregation***: Involves the loss of materials from the wear layer, including naked, "cat's head" and "nests" or pits. Climate action, namely rainfall and drought cycles, is a determining factor (Almeida et al., 2023).

The identification and correct diagnosis of these pathologies are fundamental for the selection of the most appropriate intervention techniques.

2.3 INNOVATIVE INTERVENTION TECHNIQUES AND COST-BENEFIT ANALYSIS

Conservation and rehabilitation techniques range from surface treatments (e.g., cold micro-agglomeration, bituminous coatings) to structural reinforcement with the application of new layers or the use of geosynthetics (Branco, 2013). The recycling of pavements, whether cold, hot or deep, emerges as a sustainable alternative, promoting the saving of natural

resources and the reduction of waste (Gomes, 2005; Thenoux et al., 2021). Asphalt materials modified with polymers and additives improve fatigue and temperature performance, increasing the service life of the intervention (Zhou et al., 2020).

Cost-benefit analysis (CBA) is a crucial tool for assessing the economic efficiency of the different intervention alternatives. Modern CBAs go beyond direct construction costs, incorporating Life Cycle Cost (LCC), which includes construction, maintenance, operation, and dismantling costs, and evaluate tangible and intangible social benefits, such as reducing accidents, reducing travel time, reducing pollutant emissions, and increasing infrastructure resilience (Santos, 2015; OECD, 2021).

3 METHODOLOGY

The study was carried out in the municipality of Benguela, Angola, focusing on four urban roads paved with Hot Machined Bituminous Concrete (CBUQ): Avenida Dr. António Agostinho Neto, Rua General Pereira D'ça, Rua Dr. Carlos Tavares and Rua Cidade de Moçamedes.

A mixed approach to research was adopted, based on three main instruments:

a) Surveys: Applied to technicians in the highway sector (engineers, architects, construction technicians), with the objective of characterizing maintenance practices, the existence of formal plans and the criteria for prioritizing interventions (n=7). The sample was selected for convenience, but seeking to cover the main public and private institutions in the sector.

b) Semi-structured interviews: Conducted with professionals from different institutions (INEA, Provincial Road Services, private companies), aiming to obtain qualitative perceptions about the management model, improvement plans and support needs (n=6). The interviews were recorded, transcribed and subject to thematic content analysis.

c) Technical inspections: Carried out in loco following technical standards, with photographic and georeferenced records of pathologies, allowing an objective assessment of the state of degradation of the pavements. The severity of the pathologies was classified as Low, Medium or High based on the extent and depth.

The processing of quantitative data was carried out through descriptive statistical analysis, while qualitative data were treated through content analysis, with open and axial coding to identify emerging categories and themes.

4 RESULTS AND DISCUSSIONS

4.1 SURVEYS: MAINTENANCE PLANNING AND PRACTICES

The surveys revealed a significant lack of formal planning, with 57.1% of respondents stating that there is no road maintenance plan in their organizations. Preventive maintenance is mostly carried out annually (42.9%) or biennially (28.6%), which shows an insufficient frequency in relation to needs, especially when compared to the recommendations of countries with mature networks, which suggest systematic inspections every six months or annually (FHWA, 2020).

The main obstacle identified was insufficient funding (53.8%), followed by the absence of planning and preventive management (23.1%). In the definition of priorities, the physical state of the road (30.8%) and the cost-benefit analysis (23.1%) are the most used criteria, while social factors, such as the impact on accessibility, have less weight (7.7%). This technical-economic approach, although relevant, neglects important dimensions of sustainable development, such as equity in access to services (OECD, 2021).

These results point to a management model that is predominantly reactive and conditioned by budgetary constraints, corroborating the literature that associates the lack of continuous funding with the accelerated degradation of infrastructures (Branco et al., 2011; Thenoux et al., 2021).

4.2 INTERVIEWS: PERCEPTIONS ABOUT THE MANAGEMENT MODEL AND THE NEED FOR INNOVATION

The interviews confirmed and deepened the weaknesses identified in the investigations. The evaluation of the current maintenance model was unanimous and negative, being described as "deficient", "insufficient" and "reactive". The formal existence of the Road Rescue Plan (PSE) was mentioned, but its implementation was considered limited and barely visible on the ground, as illustrated by the statement of one interviewee: "It exists, but it is not implemented. There is a lack of supervision and continuity."

For the implementation of improvements, the interviewees highlighted the need to:

a) Strengthening of technical and human resources capacity, with specific training in asset management;
b) Creation of specific and protected budget lines for conservation in the General State Budget;
c) Reactivation of maintenance brigades in partnership with the private sector;
d) Adoption of digital technologies, as mentioned by one interviewee: "We need tools to monitor roads constantly, not just when they are already destroyed."

This last suggestion aligns with global trends in the implementation of Digital Twins for infrastructures, which allow simulating performance and predicting failures (Costin et al., 2018).

4.3 TECHNICAL INSPECTIONS: PAVEMENT CONDITION AND STRUCTURAL DIAGNOSIS

The inspections allowed the identification and cataloguing of the main pathologies present in the studied pathways, as summarized in Table 1. The analysis revealed a direct correlation between traffic intensity and the severity of structural pathologies.

Table 1

Main pathologies identified in the flexible pavements of Benguela

Way	Identified Pathologies	Gravity	Probable structural cause
Av. A. A. Neto	Longitudinal/transverse cracks, Cracks, "Crocodile skin", Pots/Holes	Discharge	Fatigue of the structural assembly, water infiltration.
Rua Gen. Pereira D'ça	"Crocodile Skin", Exudation, Disaggregation	Medium-High	Base layer fatigue, excessive bitumen.
Dr. Carlos Tavares Street	Fissures, "Crocodile Skin"	Average	Bitumen aging, incipient fatigue.
Rua Cidade de Moçâmedes	"Nests (Graves)", Ripple, "Crocodile Skin"	Medium-High	Localized failure, poor compaction.

Source: Survey data (2025).

Figure 1 illustrates the "Crocodile Skin" pathology, indicative of advanced structural fatigue and often associated with water infiltration that weakens the lower layers (Ongel et al., 2022).

Figure 1

Example of pathology "Crocodile Skin" on Avenida Dr. António Agostinho Neto

Source: Survey data (2025).

The widespread occurrence of these pathologies, especially "crocodile skin", highlights the exhaustion of the useful life of the pavements and the urgency of rehabilitation interventions that go beyond mere corrective maintenance, requiring an approach that restores structural capacity.

4.4 PROPOSAL FOR A STRATEGIC INTERVENTION POLICY

Based on the diagnosis carried out, four types of intervention are proposed, staggered according to the degree of degradation and integrated into a strategic policy:

- ***Type I (Localized / Preventive Intervention):*** Sealing of cracks and plugging of pits. Applicable to floors with incipient degradation (<10% of cracked area). It essentially aims to prevent water from entering.
- ***Type II (Surface / Tactical Rehabilitation):*** Integral milling of the wear layer and application of a new layer (e.g., micro-agglomerate or CBUQ). Suitable for pavements with generalized surface degradation and elevation constraints.
- ***Type III (Structural Reinforcement with Crack Control / Strategic):*** Milling followed by the application of an anti-reflection geogrid and new wear layer. Intended for roads with heavy traffic and significant cracking. Geogrid increases the lifespan of the reinforcement (Almeida et al., 2023).
- ***Type IV (Complete / Structural Resizing):*** Integral execution of the pavement, including base and sub-base layers, and may incorporate in-situ recycling techniques to reduce costs and environmental impact (Thenoux et al., 2021). Required for floors in an advanced state of ruin.

The selection of the typology must be preceded by a cost-benefit analysis that weighs the Life Cycle Cost (LCC) against the benefits in terms of safety, durability, reduction of operating costs for users and environmental gains (OECD, 2021). The policy must be supported by an Asset Management System (EMS) that centralizes inspection, traffic and cost data, allowing the objective and transparent prioritization of interventions.

5 CONCLUSION

The study allowed us to conclude that the current road maintenance policy in the municipality of Benguela is characterized by a reactive, unstructured model with chronic insufficient funding. The absence of formal conservation plans and the low frequency of preventive maintenance result in the accelerated degradation of flexible pavements, with the appearance of serious structural pathologies, such as "crocodile skin", aggravated by local climatic conditions.

The proposal of four types of intervention, from localized actions to complete resizing, offers a range of scalable and economically assessable technical solutions. The cost-benefit analysis, integrating the concept of Life Cycle Cost, emerges as an indispensable instrument for the prioritization of investments, demonstrating that preventive maintenance is financially more advantageous in the long term than emergency corrective interventions. The incorporation of innovative techniques, such as pavement recycling and the use of geosynthetics, combined with the potential of digital technologies for monitoring, can enhance the efficiency and sustainability of interventions.

It is concluded that the implementation of a national road maintenance policy, based on strategic planning, sustainable financing, professionalized technical management and adoption of innovation, is crucial to ensure the durability, safety, resilience and efficiency of the Angolan road network, serving as a foundation for the socio-economic development of the country. Future studies should focus on the economic quantification of the benefits of prevention in the Angolan context and on the development of EMS tools adapted to the local reality.

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