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Decision Making Process in Rigid Pavement Design an Economic Approach by Mcda and Lcca

Partap Sing Ghale[1], Prapti Lalpuriya[2], Ankita Sharma[3]

[1]*Student, M. Tech (Transportation Engineering), Parul University, India*

[2]*Assistant Professor, Department of Engineering, Parul University, India*

[3]*Assistant Professor, Department of Engineering, Parul University, India*

Abstract: -

Designing rigid pavements involves two major critical decision-making processes to balance performance with cost-effectiveness and sustainability. This paper discusses an integrated approach of MCDA and LCCA for the optimal design of rigid pavements. While MCDA considers a wide array of criteria, including structural integrity, material selection, environmental impact, and user comfort, among other concerns, LCCA reflects the long-term economic implications comprising construction costs, maintenance costs, and end-of-life costs.

The key decision-making parameters have been identified, and weights are assigned to them with the contribution of the stakeholders in order to make it practically relevant. The application of the proposed framework in case studies has demonstrated that the developed study framework can easily rank different design alternatives and select the most economically viable solution with a minimum sacrifice of sustainability and performance.

The results indicate that integrating MCDA with LCCA offers transparency for stakeholder involvement in rigid pavement design. This economic approach is oriented toward resource optimization and long-term infrastructure sustainability. With the capability to be adapted to project conditions ranging in their parameters, the proposed methodology can become a strong tool for policymakers, engineers, and planners. This paper tends to move toward sustainable and economically viable pavement solutions for the complexities of decision-making in infrastructure projects.

Keywords*:* Rigid Pavement Design, Multi-Criteria Decision Analysis (MCDA), Life Cycle Cost Analysis (LCCA), Economic Decision Making, Pavement Engineering, Cost-Benefit Analysis

1. Introduction

Rigid pavement design and construction are of prime concern in developing sustainable infrastructure to ensure durability, safety, and economy in transportation networks. Due to increasing economic burdens and demands on sustainability, decisions in pavement design need to be addressed systematically, keeping in view the knowledge of engineering, environmental, and financial considerations in balance. Developed complexity forced both the researchers and the practitioners towards advanced methodologies like MCDA and LCCA to reach an optimum economic solution.

Rigid pavements, conventionally constructed from cement concrete, have a reputation for very high structural strength and durability under repeated heavy loads and severe environmental conditions. However, their design is a multi-trade-off among material costs, construction timelines, maintenance actions, and environmental burdens. Traditional pavement design approaches focus on engineering parameters, with only scant attention paid to economic and sustainability parameters. It is this gulf that makes the rationale behind a holistic decision-making structure combining quantitative and qualitative aspects quite relevant.

MCDA provides a sound platform on which various conflicting criteria may be evaluated and priority sought from the stakeholders on objectives that involve cost-effectiveness, durability, and sustainability, among others. On its part, LCCA is an important tool in pavement design, carrying out an economic evaluation of the various alternatives of pavement design throughout their life span, from construction to maintenance and rehabilitation. Combining both methods creates a comprehensive framework for selecting the most appropriate pavement design alternative from a technical and economic point of view.

This study demonstrates how MCDA and LCCA can be applied to choose the most appropriate rigid pavement design option while focusing on economic efficiency and sustainability in the long term. This coupled approach steers engineers, policymakers, and project stakeholders toward making informed decisions that best respond to budgetary limitations and infrastructural requirements. In the same way, this research develops an economic-based approach toward sustainable transport systems that support economic growth with minimal environmental impacts.

2. Objectives

The present study focuses on the development of a unified decision-making framework in the design of rigid pavement, integrating MCDA and LCCA. The present study will scrutinize various design alternatives based on economic efficiency, durability, sustainability, and priority of stakeholders in recommending the best optimal alternative for sustainable long-term pavement performance and cost-effectiveness.

3. Literature Review

The design and selection of rigid pavements are of prime importance from the viewpoint of their contribution to the long-term performance, economic feasibility, and sustainability of transportation infrastructure. Recently, a number of researchers have embraced decision-making frameworks like MCDA and LCCA with the aim of addressing challenges in pavement designs. Those are synthesized herein in order to present the state of the art with respect to the identified emerging trends, challenges, and opportunities.

3.1 Rigid Pavement Design: Technical and Economic Perspectives

PCC-based rigid pavements boast durability, structural strength, and resistance to heavy traffic loads. However, PCC concrete has a very high initial construction cost. Current practices in pavement designs usually adopt methods which emphasize technical parameters such as load-bearing capacity, climatic conditions, and material properties. The most common guides include those proposed by the AASHTO in 1993 and IRC:58-2015. However, integration of economic and sustainability factors in these design decisions is becoming increasingly important because constructing modern highways has become so expensive and environmentally sensitive.

3.2 Role of LCCA in Rigid Pavement Design

LCCA is a well-established economic analysis tool allowing the comparison of pavement design alternatives by their total cost over a preselected service life. This technique considers the initial construction cost, maintenance and rehabilitation costs, user costs, and salvage value (Walls & Smith, 1998). Various studies, such as that of Del Ponte et al., 2020, have shown that LCCA could provide insightful information on the long-term economic performance of rigid pavements, especially when extended to include environmental costs such as the calculation of greenhouse gas emissions.

The inclusion of LCCA within decision-making frameworks has been recommended by several national guidelines, among which are those by FHWA. However, the effectiveness of LCCA is normally limited by the availability and reliability of the input data, such as the price of materials, forecasted traffic, and discount rates. Probabilistic LCCA methods have recently been proposed to account for such uncertainties, making this technique much sounder (Zhou et al., 2021).

3.3 Multi-Criteria Decision Analysis (MCDA): A Complementary Approach

MCDA allows for a structured approach to analyzing various, often conflicting, criteria in pavement design, such as cost, durability, environmental impact, and social acceptability. Some of the common methods used in pavement design include AHP, TOPSIS, and ELECTRE. These methods make possible the consideration of qualitative and subjective factors that, normally, cannot be taken into consideration within an LCCA.

For instance, Santos et al. (2017) used AHP to provide a framework for prioritizing pavement alternatives by stakeholders' preference, which highlighted issues regarding sustainability and performance metrics. TOPSIS has also been used in the ranking of pavement materials concerning their environmental impacts along with the corresponding economic ones; thus, it will certainly be applicable for green infrastructure projects too (Sharma et al., 2019).

3.4 Combination of MCDA and LCCA

One of the most promising approaches toward making intelligent pavement design decisions is integrating MCDA and LCCA. Whereas LCCA quantifies the economic view of pavement alternatives, MCDA considers a wide array of criteria related to environmental, technical, and social concerns. This integrated framework has already been applied in various case studies, including the impact of pavement material choice on urban roads-Ibrahim et al. 2022 and highway maintenance strategies-Kumar et al. 2020.

Regarding MCDA and LCCA integration, one of the main issues is the compatibility between qualitative and quantitative data. Hybrid models that combine fuzzy MCDA with probabilistic LCCA-HA have been proposed by Hajiali et al. (2023) that may potentially enhance the decision-making capability to consider uncertainty and subjective judgment during the evaluation process.

3.5 Challenges and Future Directions

Though having their own advantages, some challenges are associated with the use of MCDA and LCCA in the design of a rigid pavement:

- **Uncertainty in Data:** Input data into LCCA normally requires accurate estimates of either material cost or traffic prediction, which is generally not feasible or has large variance.
- Success in MCDA is hugely dependent on active stakeholder participation in defining the criteria and weight assignment, which may be subjective and inconsistent.
- Sustainability metrics are also largely unexplored in both the LCCA and MCDA methods, especially when related to developing nations.

Future studies should, therefore, be directed to develop standardized frameworks which incorporate MCDA and LCCA with a focus on sustainability and resilience. Improvement in digital technologies such as BIM and AI is promising for the enhancement of data collection, analysis, and visualization in the design of pavements.

4. Research Methodology

4..1 Problem Identification

- Highlight the challenges in connection with economic viability as well as performance regarding the design of rigid pavement.
- The integration of MCDA and LCCA is needed in the decision-making process.

4.2 Data Collection

In this stage, pavement materials, methods of construction, maintenance costs, traffic loads, and environmental factors are identified.

Case studies, field surveys, and literature review to support the data.

4.3 Multi-Criteria Decision Analysis (MCDA)

- Spotting the key decision criteria, which is cost, durability, environmental impact, etc.
- Employing an MCDA technique such as AHP (Analytic Hierarchy Process), TOPSIS, or VIKOR for evaluating and giving rank to the alternatives.
- Weight assignment by involving the stakeholder.

4.4 Life-Cycle Cost Analysis (LCCA)

- Computation of initial construction costs, maintenance cost, and end-of-life cost at every pavement alternative
- Discounting Costs over the Pavement's Life Span to yield NPV.

4.5 Integration of MCDA and LCCA

- Employing MCDA and LCCA outcomes to identify the most feasible pavement design alternative which would be cost-effective and sustainable.
- Decision-making Matrices Development for visualizing Outcomes.

4.6 Validation and Sensitivity Analysis

- Validation of the Methodology by Real Project Data or Case Study.
- Sensitivity analysis which checks the strength and sensitivity of results against variations in the Input parameter.

4.7 Recommendations

- Summarize the findings and recommend the best alternative for rigid pavement design.
- Highlight the broader implication of integrating MCDA and LCCA in infrastructure projects.

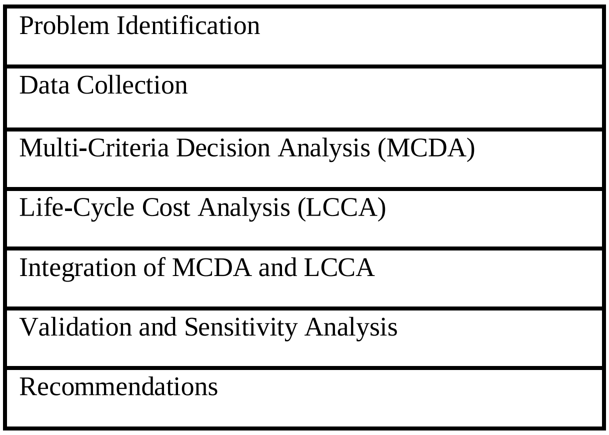

Fig -1: Flowchart of Research Methodology

5. Expected Results

The outcomes anticipated can be summarized below.

- **Optimal Pavement Design:** Most economically effective rigid pavement design identification using MCDA and LCCA.
- **Cost-Effectiveness:** The main reason for determining the cost savings within the life cycle by integrating economic, environmental, and technical considerations.
- **A Decision-Making Framework:** A sound framework is laid down for making decisions regarding the balance between initial construction cost and future maintenance and operational expenses.
- **Sustainability Impact:** The impact of sustainability on cost-effectiveness pertaining to material choices and methods of construction.
- **Policy Implication:** Recommendation to policymakers to adopt economic analysis in pavement design to enhance the level of efficiency in planning infrastructure development.

6. Conclusion

MCDA combined with LCCA can provide a robust decision-making framework for satisfying rigid pavement design requirements concerning technical, environmental, and economic problems. This paper demonstrates how MCDA allows one to conduct an integrated, structured analysis of multiple design alternatives with respect to a wide array of criteria, while LCCA selects among those alternatives which are economically viable for the lifetime of pavements.

Benefits associated with such a well-integrated approach may include increased clarity of decisions made, comparability of options, and long-term sustainability. In addition, this integrated approach considers non-cost issues during its analysis, like environmental impact, durability, and demands regarding maintenance.

As stated, the results confirm that the proposed methodology could enable different stakeholders, such as engineers, policy-makers, or investors, to make enlightened decisions in order to optimize the allocation of resources and achieve cost-effectiveness without loss of quality. Based on this, further research could be devoted to testing the proposed framework for other infrastructure systems and investigate the potential for integrating emerging technologies in the AI environment to achieve real-time decision support.

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