RESEARCH PAPER

Analysing the Factors Affecting Life Cycle Cost Analysis for Achieving Sustainability in Indian Roads

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Abstract
This study investigates the vital convergence of life cycle cost analysis and sustainability within Indian road infrastructure. A thorough review of the literature over the past 30 years found 56 important life cycle cost analysis parameters that are necessary for overall sustainability in economic, social, and environmental areas. By finding strong links between these factors and the overall sustainability of Indian roads, the study shows that life cycle cost analysis is a key factor in making the road network more resilient in the future. To strengthen the findings, 51 experts from reliable organisations, such as NHAI, PWD Maharashtra, and private contractors, engaged in an extensive opinion survey. Using the Likert Scale, this quantitative assessment gave policymakers important tools for making decisions about long-term road development. The results show that using eco-friendly materials is the most important thing to do to reduce the carbon footprint of road projects. The incorporation of renewable energy sources, especially solar panels, has become an essential element for sustainable energy production, diminishing dependence on non-renewable resources and fostering a commitment to green infrastructure. The study included semi-structured interviews, which added insights from industry experts to the expert opinion survey. The information that was collected shows that everyone agrees on important sustainability factors for Indian road projects. It stresses the need to reduce carbon emissions and use eco-friendly methods. The report lists the most important factors that experts have identified and calls for all parties involved in road development to work together to make sure that the approach is cohesive and long-lasting. This study serves as a guiding light, motivating stakeholders to work towards a future that is greener, more open to everyone, and more economically vibrant. It is important to keep exploring and improving the search for sustainable road infrastructure.
Keywords: - Indian Roads, Life Cycle Cost Analysis, Net Present Value, Sustainability.
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1. Introduction

Roads are a significant method of transport in India. India has a network of more than 6,215,797 kilometres (3,862,317 mi) of roads starting around 1 December 2021. This is the second biggest road network on the planet, after US with 6,853,024 kilometres. As of 31st Walk 2020, 70.00% of Indian roads were cleared. As of March 2020, India has finished and put into user over of 136,440 kilometres of at least four path parkways interfacing a large number of its significant assembling, business and social focuses [2]. A relative evaluation of contending design choices in view of their separate life cycle costs over their economic life. The time of life accepted by the planner for an item or task, under his normal degrees of purpose, support, fix and removal. That time of life over which a speculation keeps on being the smallest expense elective for meeting a specific goal. The absolute of work, material and other related costs brought about in doing review, preventive upkeep (counting substitution) and fix on are source, and on its frameworks and parts. The absolute of working expenses chargeable to creation of the given item, incorporates direct costs like material, work, and shop overheads. The adjustment of complete expense brought about by differing the result by one unit. These expenses might include: wellbeing, security, protection, utilities (other than energy), garbage removal and some other costs not explicitly characterized somewhere else in this norm. Amount of all expenses caused to get, use, keep up with, lastly discard an item or administration including the time and exertion of purchasing [12].

In 2021-22, the absolute consumption distribution towards highway developments (NHAI) was 57,350 crores. The authority focus of highway development has been kept at 12,000 km for the ongoing monetary year. The service had developed 13,327 kms in 2020-21 and 10,457 km in 2021-22. As indicated by the correlations of both the financial years 2020-21 and 2021-22 the development has been diminished by the service. Notwithstanding development of public interstates, state legislatures are likewise reinforcing their street organization. Maharashtra, for instance apportioned ₹18 billion during FY 2020 for the support of its roads. For the advancement of roads in country and in reverse regions, ₹15,000 crores were declared in the Association Spending plan 2021 to Pradhan Mantri Gram Sadak Yojana (PMGSY). Numerous different tasks like Bharat Mala, availability of significant ports, extraordinary road improvement program for the North-East locale, street advancement projects in left wing impacted regions, are additionally in the works [2].
A large portion of the road projects consider just monetary expense and not life cycle cost. At the point when we consider life cycle costing, this cost can influence the GDP (Gross domestic product) economy of the country. By utilizing LCCA in road, it can compute life cycle cost of roads, which serves to the developing to the economy of country. LCCA is a course of assessing the monetary presentation of a design over as long as it can remember. Ineffectively kept up with streets compel versatility, essentially raise vehicle working expenses, increment mishap rates and their related human and property costs, and are required to have been bargain. To diminish these sorts of issues in future, concentrate on life cycle cost examination of roads required [16] Net present value strategy (NPV) as per specialists, NPV is considered as the monetary mark of decision to perform LCCA on the grounds that it can measure expenses and advantages of street choices into a solitary worth, while limiting future incomes into the present. Be that as it may, it ought to possibly be utilized when all choices have a similar examination period. In any case, these conditions think about every one of the periods of a street's life cycle, as examined in the past segments, and the choice to work out a NPV for the road organization or potentially street client in view of ostensible expenses as well as genuine expenses [12].
Objective

a. Identification of Life Cycle Cost Analysis Parameters for incorporating sustainability in Indian Roads.
b. Assess Sustainability Factors: To evaluate the key factors affecting the sustainability of Indian roads, including environmental impact, carbon emissions reduction, and integration of renewable energy sources.
c. Use Life Cycle Cost Analysis (LCCA): To use LCCA as an important tool for making decisions about road projects, taking into account all costs over the project's entire life cycle and finding the best balance between economic and environmental factors.
d. Create Sustainable Strategies: Create plans for making road construction and maintenance more cost-effective and environmentally friendly. These plans should include integrated planning, new construction methods, regular maintenance, and making decisions based on data.

2. Literature Review

In recent years, the sustainability assessment of road infrastructure projects has become very popular. Many studies have stressed the importance of including environmental, social, and economic factors in project evaluations. Vijayakumar et al. (2021) [29] emphasised the significance of social sustainability, especially via community involvement and social equity in project planning. Their systematic review underscored that the integration of these elements amplifies the enduring advantages for local communities. Kapatsa et al. (2023) [18] also looked into sustainability indicators for road infrastructure in Tanzania. They stressed how important environmental factors in the area are for making projects last. Husnain et al. (2021) [15] put forth a life cycle sustainability-based decision-making framework that encompasses environmental, economic, and social dimensions throughout the project life cycle, offering a holistic resource for infrastructure developers. Gede et al. (2020) [13], in their examination of sustainability assessment methodologies, pinpointed deficiencies in existing frameworks, advocating for additional research to enhance and advance these evaluative instruments.

Life cycle assessment (LCA) and life cycle cost analysis (LCC) have become indispensable instruments in sustainability evaluations, especially concerning road infrastructure. Wesam et al. (2021) [30] and Alberto et al. (2023) [4] examined the application of LCA and LCC, emphasising their essential function in evaluating the environmental and economic effects during the entire life cycle of a project. These studies showed important improvements in LCA methods and pointed out areas for future research that could make road networks more sustainable. Ahmad et al. (2022) [3] offered a critical analysis by integrating various perspectives on sustainable road infrastructure, promoting a comprehensive strategy for tackling sustainability issues. Uppuluri et al. (2024) [28] looked into an inverted pavement design as an innovative solution that combined LCA and LCC to improve sustainability by lowering environmental impacts while increasing economic efficiency. Alireza and Stephen (2021) [5] also applied the LCA and LCC framework to road drainage systems, stressing the importance of including drainage infrastructure in larger sustainability evaluations. Finally, localised assessments, as illustrated by Mohammad and Hossein (2017) [20] in urban transport systems, underscored the significance of micro-scale sustainability evaluations in urban infrastructure planning.

Santos, J., et al (2015) [25], LCCA for asphalt the board, this scientist infers that another life cycle cost examination framework in light of an improvement model thinking about asphalt execution OPTIPAVE, created and customised to help asphalt planners to pick the best asphalt structure for a street thruway [1]. Gaikwad, T., et al. (2019) [12] conducted a life cycle cost analysis of road asphalts. The cost of the road over its lifetime It is the interaction for figuring out the total cost of road asphalts, including the cost of building them. To diminish the existence cycle cost of road asphalts it is important to manage the underlying expense and have to learn preventive keeps up with of asphalts. Ravinder, S., & Rajesh, M. (2022) [24], life cycle costing in the Indian setting, that's what specialists express, the structure and program modified in view of that system for getting ready life cycle cost examination (LCCA) remembered for this system are models that anticipate asphalt execution, client cost and mishap rates at works zones, and conceivable recovery plans. Moins, B., et al (2020) [21], Executing life cycle cost examination in street designing, work out cost of Life Cycle Costing (LCA) it gets life cycle cost investigation (LCCA), support to grave methodology i.e., unrefined components, blend creation, street development, use and keeps up with, end of life street development, landfill, reusing weather conditions reusing or reuse is liked over the utilization of new materials relies upon the effect of different elements. Arthur, C., et al (2008) [7] claimed that the purpose of this research is to design a pavement by Michigan Department of Transportation (MDOT) with the help of various stage which helps in projecting LCCA and maintenance schedule of different types of pavements. With help of this, LCCA choices the minimum cost of pavement design. Above maintaining the various case studies i.e., four case studies are involved, most non LCCA design section have the lower accumulated the LCCA design section. It remains to be seen if the non LCCA design section will provide additional measure maintenance activities in the future and thus have higher life cycle cost towards the ends of the pavement service life.

The life cycle of road:

a) Raw material, b) Mixture production, c) Road construction, d) Use and maintenance, e) End of life road construction & Landfill

Sinha, K., & Tien, F. (1991) [27] found that this paper looks at the need to consider the degree of asphalt execution related with every option in a day- to-day existence cycle cost assessment work out. Two methodologies are portrayed for integrating asphalt execution contemplations into life-cycle cost investigation. A mathematical model is introduced to represent the effect of asphalt execution thought on dynamic in view of life-cycle costs that a mathematical model fundamentally affects the results of LCCA. The consolidation of asphalt execution thought into a monetary investigation gives a more complete assessment of various asphalt systems. Babashamsi, P., et al (2016) [8] stated that assessment of asphalt life cycle cost examination models is including, client cost prohibitionis one of the significant investigations. Highway users bring about this expense, which incorporate postpone costs, vehicle working expense, (for example, fuel, tires, motor oil, and vehicles keeps up with) and some other mishap cost. Moins, B., et al (2020) [21], Carrying out life cycle cost examination in road designing, a basic survey on strategic system decisions, Road development can incorporate that (yet isn't restricted to) the accompanying perspectives: getting free from the site, uncovering, treating the base or establishment with concrete or lime and compacting it, building compacting the different street layers, and coordinating the different subordinate street offices (e.g., Lighting and signs). Goh, Kai, and Jay Yang. (2010). [14] consolidated manageability estimates in life-cycle monetary decision making for parkway other hand express that life cycle costing can be utilized for a wide range of items, the reason and nature of the examination anyway relies upon the item. As talked about above life cycle costing was initially intended for acquisition purposes. i.e., to be utilized according to a perspective of a client. Hoxha, E., et al (2020) [16] claim that Passer Life cycle assessment of roads, Virgin material savings and reduced transport distance minimize the environmental burdens of roads construction work. Berge, Z., & Huang, Y. et al (2004) [9], used probabilistic life cycle cost, the number of studies and investigation shows that the effect of corrosion and cracks induced deterioration on life cycle performance of concrete structure, includes sensitivity analysis in order to identify the most significance parameter to affecting road performance.

In 1979 the bozan was predicted a model predicting time of cover cracking caused by corrosion of embedded reinforced steel. Gaikwad, T., et al (2019) [12] depicts life cycle cost examination of street asphalts, Net present value should be determined and after starting NPV'sis determined for all suitable options ought to be investigated. In the NPV examination the paces of concrete, steel, and bitumen which have been given according to current market rates Ding, T., et al (2013) [11] claimed ideal methodology of asphalt preventive support considering Life Cycle Cost Examination, the idea of asphalt preventive upkeep (PPM) has been acknowledged by increasingly more highway managers. The reason for this study is to do an exhaustive and precise exploration on the ideal procedure choices and life cycle cost examination. Shirole, A., & Patil, A. (2017) [26] stated Life Cycle Cost Investigation of Adaptable Asphalts and Unbending Asphalts in Metropolitan Regions, in this examination paper, cost expected for beginning development and for upkeep of the asphalt is determined by utilizing net present worth technique lifecycle cost investigation strategy. IRC SP-30(2009) gives the recipe for net present value. Organization cost is determined from the area plan paces of public's work divisions (PWD) Pune locale. Aniekwu, A., & Ohorodje, E. (2015) [6], Life Cycle Cost Analysis (LCCA) conveyance model for a metropolitan adaptable and unbending asphalt ,as per 30 creators , NPVt, rc = NPV ru,rc + NPVa,rc… Equation 1 explains us that NPV is consider as the monetary mark of decision to perform LCCA in light of

the fact that it can evaluate cost and advantages of street options into a solitary worth, while limiting future income into the present. Thus, the fundamental benefits of this study are that it think about the worth of time and presents the expense and advantages of choices in a solitary worth.

Equations:

NPVt, rc = NPV ru,rc + NPVa,rc Equation 1 Real total NPV

PWC = ∑ P*n/(1+i) *n Equation 2 Present worth cost (PWC)

The Annualized Cost (AC) of a development is the expense that, if it somehow happened to happen similarly in each extended period of the task lifetime, would give a similar net present expense as the real income succession related with that part.

HOMER works out annualized cost by first computing the net present expense, then, at that point, duplicating it by the capital recuperation factor, as in the accompanying condition. The annualized cost fills in as a helpful measurement for looking at the expenses of various parts since it estimates their overall commitment to the all-out net present expense. It considers a fair expense examination between parts with low capital and high working expenses and those with high capital and low working expenses of development.

CRF (i, N) = i(1+i)N/(1+i) – 1 Equation 3 CRF

Kendall, A., et al (2008) [19], Incorporated Life-Cycle Evaluation and Life-Cycle Cost Examination Model for Substantial Scaffold Deck Applications. Life-cycle cost analysis (LCCA) model was created and applied to build the manageability of substantial-scaffold framework. The target of this model is to look at elective extension deck plans according to a manageability point of view that records for all out life-cycle costs including organization, client, and ecological expenses. A regular substantial extension deck and an option designed cementitious composite connection chunk configuration are inspected. In spite of higher beginning expenses and more noteworthy material-related ecological effects on a for every mass premise, the connection section configuration brings about lower life-cycle costs and decreased natural effects when assessed over the whole life cycle. These outcomes show life-cycle displaying is a significant dynamic apparatus since starting expenses and organization costs are not illustrative of all out life-cycle costs. Moreover, representing development related traffic delay is indispensable to evaluating the absolute monetary expense and natural effect of foundation plan choices.

Bowyer et al (2013) [10], Life cycle cost investigation is a demonstrated monetary examination method in view of very much established financial standards. LCCA is an expense based process; its will probably distinguish the most expense productive structure plan and development techniques over the existence of the asset at a period of building development proprietor ought to just consider the development cost however support, functional and fix cost assume significant part in generally life of structure [22]. Life Cycle Cost Analysis (LCCA) as applied to structures, in some cases likewise alluded to as esteem designing or life cycle costing, includes representing all costs connected with development, activity, upkeep, and removal toward the finish of the helpful existence of a construction. The objective is to give a premise to choose of the most practical plan elective throughout a specific time period, considering expected future expenses as well as beginning expenses of development. LCCA is especially reasonable for the assessment of building plan options that fulfil a necessary degree of building execution, particularly while venture, working, support, and fix costs unique and when elective plans might have different expected help lives [10].

3. Research Methodology

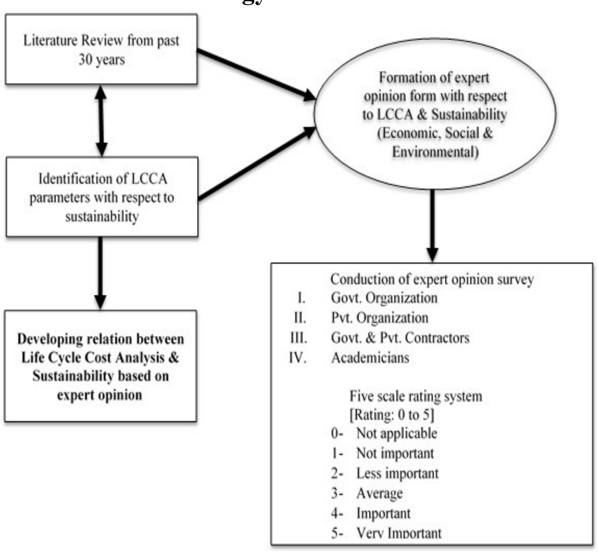


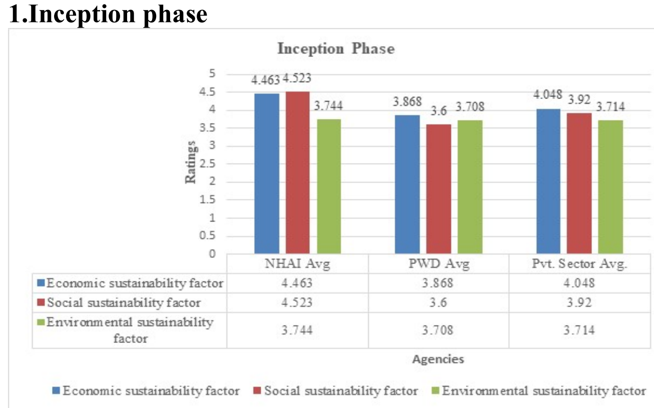
Fig 01: Outline of Research Methodology

4. Data Collection:

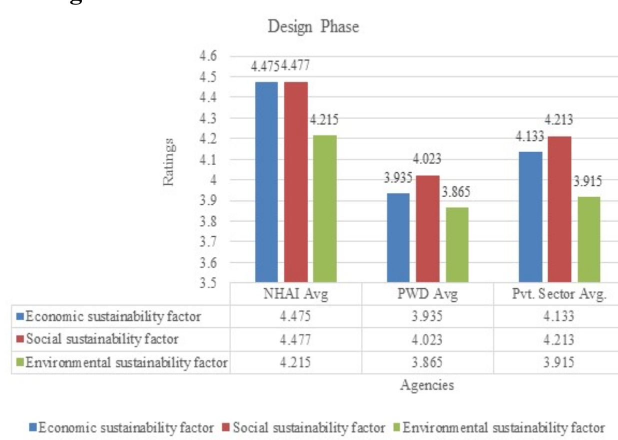
Life Cycle Cost Analysis parameters incorporating sustainability were identified from last 30 years literature survey (secondary data) for Indian roads.

Total 51 semi-structured expert opinion survey were conducted which includes Government organizations, private organizations, academicians, Government & Private contractors and details are attached in (Appendix 1):

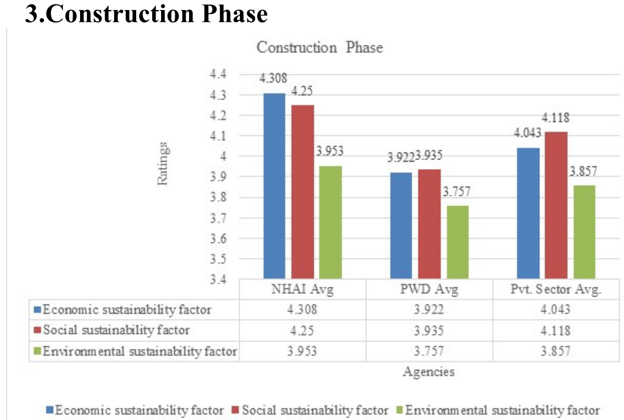
1.Inception phase



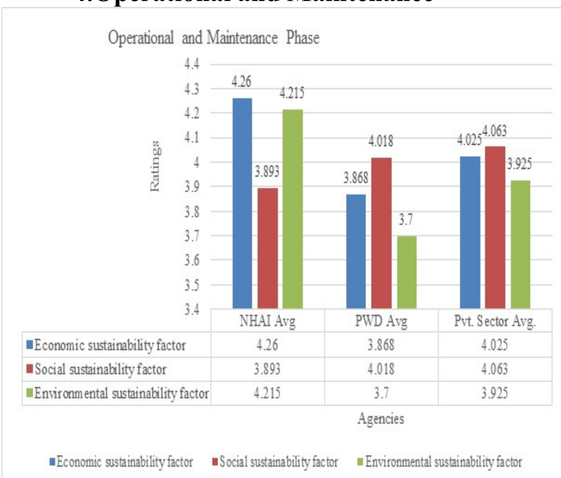
2.Design Phase



3.Construction Phase



4.Operational and Maintenance



5. Demolition Phase

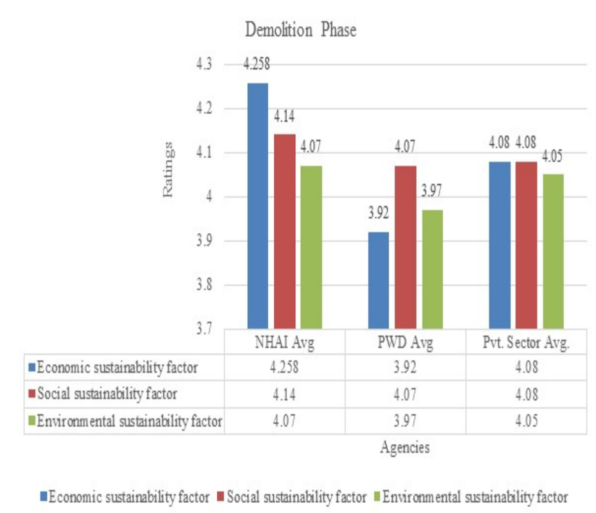


Table 1 Average Value of All agencies

Sr. No.	Agencies	Average Value
1	Overall Avg.	3.88
2	NHAI Avg.	4.08
3	PWD Avg.	3.74
4	Govt. Sector Avg. (NHAI + PWD)	3.85
5	Pvt. Sector Avg.	4.02

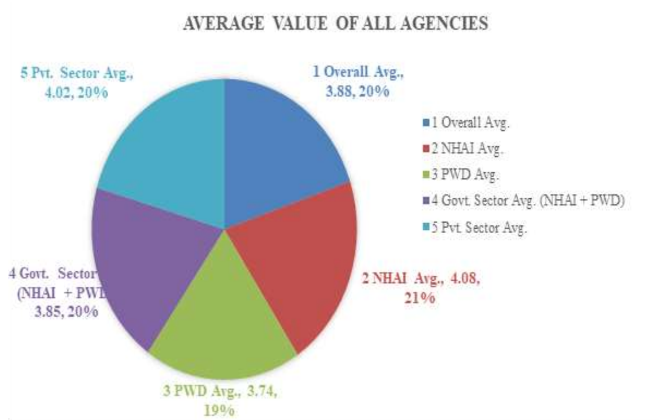
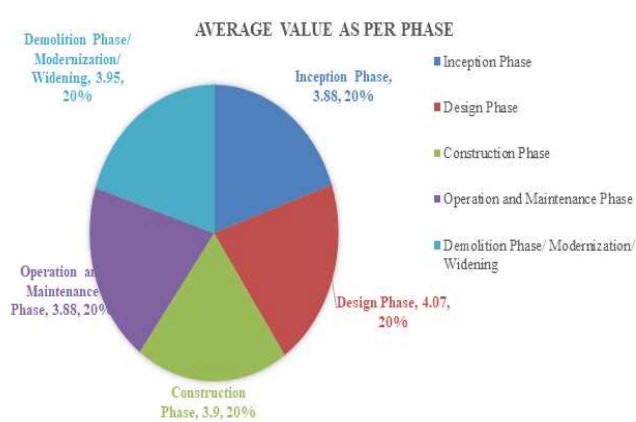


Table 2 Average Value as per Phase

Sr. No.	Phases	Average Value
1	Inception Phase	3.88
2	Design Phase	4.07
3	Construction Phase	3.90
4	Operation and Maintenance Phase	3.88
5	Demolition Phase/ Modernization/ Widening	3.95



Appendix 1 Shows the responses received for sample questions during expert opinion semi structured interview. Where overall rating is given to a question by 51 experts. The graphs show the overall importance of specific factor for attaining the sustainability in the roads.

The survey's results, presented in a bar graph format, revealed varying degrees of importance attributed to the different phases and sustainability factors by different stakeholders:

NHAI Perspective:

The average scores for NHAI stakeholders' responses were consistently high, ranging between 4 to 5 on the scale of 1 to 5. This suggests that NHAI exhibits a strong commitment to all phases of road infrastructure development and maintenance, as well as the economic, social, and environmental sustainability factors associated with them. NHAI's focus on sustainability and life cycle cost analysis is evident from their high rating for all phases, indicating a comprehensive and proactive approach to decision-making in road projects.

PWD Perspective:

The average scores from PWD respondents were around 3 to 3.5 on the scale. While PWD acknowledged the importance of all phases and sustainability factors, their responses indicated a slightly lower emphasis compared to NHAI.

The survey findings highlight potential areas where PWD could further enhance their focus on sustainability and life cycle cost analysis to align more closely with NHAI's exemplary commitment.

Private Sector Perspective:

The private sector's responses displayed a consistently high rating, similar to NHAI, with an average score in the range of 4. This indicates a substantial emphasis on all phases and sustainability factors in their practices. The private sector's alignment with NHAI's perspective suggests a positive correlation between sustainable practices and successful road infrastructure projects.

Overall, the survey's outcomes demonstrate that different stakeholders have varying degrees of emphasis on the phases and sustainability factors in road development and maintenance. NHAI stands out as a leader in prioritizing sustainable practices and life cycle cost analysis across all phases, while the private sector also exhibits a strong commitment to these principles. For PWD, the survey findings present an opportunity to further enhance their focus on sustainability and life cycle cost analysis to achieve alignment with leading industry practices.

The valuable insights obtained from this survey can guide policymakers and decision-makers in fostering greater collaboration between government sectors and the private sector, encouraging the adoption of best practices, and promoting a more sustainable, economically viable, and socially beneficial road infrastructure network in India. Furthermore, from Table 1, In economic sustainability factors from Inception phase of road the experts average rating is in between 4 to 5 expect for seconds rating is almost 4, which shows that the economic sustainability factor is very important in inception phase of roads. Similarly, for social & environmental sustainability factors in inception phase, the rating the most of the rating is in between 3.5 to 4, indicates average to important factors for attaining sustainability in Indian roads with help of LCCA.

Similarly, In Design Phase, economic & social sustainability factors rating is in between 4-4.5, indicates these factors are very important for achieving sustainability in Indian roads. In case of environmental sustainability factors, most of average rating is in between 3.8 to 4, indicates relative importance from the Likert scale.

In Construction Phase, social sustainability factors held more rating which is in between 4 to 4.5, shows these factors shows more importance than economic & environmental sustainability factors (most of the rating is in between 3.5 to 4) for achieving sustainability in roads with help of LCCA.

In Operation & maintenance phase, most of economic and social sustainability factors rating is in between 4 to 4.5, shows these parameters held more importance (important to very important) compared to the environmental sustainability factors which has experts rating is in between 3.5 to 4.

In Demolition/ Modernization/ Widening phase, social and environmental sustainability factors held more rating (almost 4 to 4.5) compared to economic sustainability factors for achieving sustainability in roads.

5. Results:

To evaluate the sustainability and life cycle cost analysis of Indian roads, data was gathered from multiple field experts. Their thoughts helped us understand what makes roads last longer, how important it is to look at the whole life cycle cost, and what we can do to make India's roads better. A thorough effort was made to collect data from experts on the factors that affect the sustainability of Indian road projects. We made a list of 56 questions and asked experts to rate them from 1 to 5. The questions asked about different parts of sustainability that could be used in road projects. The data we gathered shows what a group of experts thinks about the most important sustainability factors in Indian road projects. Experts stressed the importance of using eco-friendly materials and methods, especially when it comes to lowering the carbon emissions that come from building and maintaining roads.This includes using eco-friendly building methods and materials, like recycled materials, and using building methods that are good for the environment. The study shows that experts see renewable energy sources as another important factor. They said that adding renewable energy sources like solar panels to roads is important because it will reduce our reliance on non-renewable energy and encourage the use of renewable energy sources. All experts agree that sustainability should be the most important thing to think about when building and maintaining roads.

They stress how important it is to use eco-friendly materials and methods to cut down on the carbon footprint of road projects. Experts also stress the need to use renewable energy sources, like solar panels, to power road infrastructure and cut down on the use of non-renewable energy. LCCA is an important tool for making decisions about road projects. Experts emphasise the importance of performing comprehensive Life Cycle Cost Analysis (LCCA) to assess the long-term expenses related to the construction, maintenance, and rehabilitation of roads. By looking at the total life cycle costs, which include the initial investment, maintenance, and future rehabilitation costs, decision-makers can make smart choices that are good for the economy and the environment.

Experts have come up with a number of ways to make things more sustainable and cost-effective. First, they stress the importance of planning and coordinating between all the people who are working on road projects. This all-encompassing approach would make it easier to make decisions and use resources more effectively. Secondly, experts say that new building methods should be used, like using recycled materials or following sustainable design principles. These practices not only help the environment, but they also make roads last longer and stay in better shape. Experts also say that regular maintenance and evaluations are important for making Indian roads last longer. They stress how important it is to use preventive maintenance methods, such as fixing things on time and rehabilitating them, to keep costs down in the future and make sure roads are safe. Experts also stress the importance of keeping an eye on things all the time and making decisions based on data to find possible problems and take action quickly.

6. Conclusion

Through an exhaustive literature review spanning three decades, 56 life cycle cost analysis parameters were identified as integral elements in achieving overall sustainability (economic, social, and environmental) in Indian roads. The research ingeniously established robust correlations between these parameters and the overarching sustainability of Indian roads, revealing the pivotal role of life cycle cost analysis in fostering a resilient road network for the future.

Expert opinion surveys involving 51 stakeholders from government sectors, private contractors, and consultants further bolstered the research, providing a quantitative assessment of each parameter's importance through the Likert Scale. This valuable input equips policymakers with powerful tools for strategic decision-making in sustainable road development. As the research concludes, its profound implications are evident for policymakers, urban planners, and infrastructure visionaries. Armed with the knowledge of essential life cycle cost analysis parameters, the roadmap to sustainable Indian roads becomes lucid and attainable, inspiring a greener, more inclusive, and economically vibrant future. This comprehensive research serves as a beacon of insight, guiding stakeholders towards a harmonious convergence of life cycle cost analysis and sustainability in Indian roads. The quest for a resilient and sustainable road network is underway, and this study ignites the torch of knowledge, inspiring the collective will to pave the way for a brighter, more prosperous future. As the nation strides forward, the research encourages ongoing exploration, fostering an environment of continuous improvement in the relentless pursuit of sustainable road infrastructure.

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