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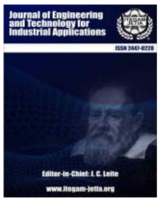

RESEARCH ARTICLE OPEN ACCESS

# LIFE-CYCLE COST ANALYSIS (LCCA) COMPARISON OF PAVEMENTS (FLEXIBLE, RIGID AND RIGID-ADMIXED WITH COW BONE ASH)

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**ABSTRACT**

Life Cycle Cost Analysis (LCCA) acts as a decision support tool in economic evaluation of cost (agency and user) during pavement type selection, maintenance and rehabilitation strategy. The Life cycle cost analysis was done using the Present worth of Cost method. Technical Recommendations for Highway (TRH) 12 (pavement rehabilitation investigation and design) analysis was used for calculating the agency cost which entailed the initial rehabilitation, maintenance, future and salvage cost. The LCCA analysis period for this study was taken as 40 years as the analysis period have to be sufficiently long to reflect long-term cost differences associated with reasonable design strategies. The result of the study shows that the present worth cost for the varying Pavement presents the options available for decision making. The result revealed that the initial cost of Rigid pavement is the highest followed by the initial cost of Rigid pavement with 15% CBA while flexible Pavement has the lowest initial cost. However, considering the result showing the present worth cost for the varying pavement types present worth cost of flexible pavement is the highest followed by Rigid pavement and Rigid pavement with 15% CBA has the lowest life cycle cost. The study recommended that Rigid pavement with 15% CBA should be considered because it gives the lowest life cycle cost and the initial cost is relatively low.



## I. INTRODUCTION

Road networks and transportation infrastructures play a significant role in the development of many countries across the globe. The increase in population growth and need for economic development had significantly contributed in the expansion of the road networks in particular highways road. Recently, road pavement construction, maintenance and rehabilitation costs are rising sporadically. As such, many highway agencies have employed tools and approaches that facilitate appropriate judgment making by applying economics and research like Life-Cycle Cost Analysis (LCCA) to attain economically reasonable long-run investments [1]. Accordingly, with respect to road construction, life-cycle cost analysis (LCCA) is seen to having a higher priority than merely investments. Sustainability of transportation infrastructure is vital in enriching economy of developing countries hence the need for roads with long service life which requires less maintenance and able to sustain the country's traffic demands [2]. LCCA acts as a decision support tool in economic evaluation of cost (agency and user) during pavement type selection, maintenance and rehabilitation strategy. LCCA further provides better understanding on factors that influences cost effectiveness in pavement construction.

A pavement is a structure that comprises of superimposed layers of processed materials over a characteristic soil sub-grade, with the basic purpose of appropriating vehicle loads to the sub-grade. There exists basically two types of pavements based on design considerations namely flexible and rigid pavements. Flexible pavements are pavements constructed from asphaltic or bituminous materials and aggregates while rigid pavements are pavement constructed from concrete or reinforced concrete slabs. Flexible pavements offers benefits such as low initial construction cost, absence of thermal stresses due to the pavements ability to expand and contract freely, does not require expansion joint, ability to be opened to traffic within a short time after construction, its surface can be milled and recycled for rehabilitation, it can be strengthened and improved in stages with the growth of traffic [3-6]. Construction of rigid pavements offer benefits such as reduction in greenhouse gas emissions (GHGs) due to use of pozzolanic materials such as cow bone ash (CBA), improves fuel saving [7-8], reduces accident due to less hydroplaning and enhanced night vision, and less traffic obstruction during frequent maintenance and rehabilitation works associated with flexible pavements [9]. [10] in their study considering vehicle type, annual average daily traffic, number and percentage vehicle composition stated that when a pavement condition is improved, an average of 124.41 minutes/day is saved annually by road users. [10] further revealed that for a 40 years pavement, 2.5 years is spent is spent on maintenance and rehabilitation when it is a rigid pavement while 14 years is spent on maintenance and rehabilitation when it is a flexible pavement. This makes the effective years for the rigid pavement to be 37.5 years while that of the flexible pavement becomes 26 years.

Rigid pavements regardless suffer from Alkali-Silica Reaction (ASR) which is an internal expansion in concrete that leads to concrete deterioration. However, several studies such as [11-15] have shown using CBA to replace cement even in aggressive soil environments is good. [16] in their study reveals that replacement of cement with 15% CBA in concrete (rigid) pavements influences the densification of the rigid pavement at the transition zone, resulting in a much lower porosity. This further results in the rigid pavement having a tightly bound layer that repels ingress of water and thereby inhibiting cracks and gel formation as water is a contributing factor to the ASR in pavement. It is on this basis that this study evaluates rigid pavement with 15% CBA.

## II. LITERATURE REVIEW

LCCA according to [17] is defined as the process of accessing the economic performance of a structure over its entire life. Life cycle cost analysis (LCCA) according to [18] is defined as an evaluation technique that builds on the principles of economic analysis to determine the overall long term economic efficiency of alternative investment opportunities by trying to identify the best cost value for investment expenses. [19] defined LCCA as an early stage economic feasibility tool used to select an alternative pavement design which will result in reduction of costs of construction and maintenance and will also offer sufficient serviceability over the entire design life of the road. [20] stated that LCCA is used to explore trade-offs between low initial costs and long-term cost savings, identify the most cost-effective system, and determine how long incremental costs for infrastructural developments will be paid back. Costs evaluated using LCCA consists of agency and user costs. Agency costs includes preliminary engineering, contract administration, initial construction, construction supervision, maintenance costs, rehabilitation costs, administrative costs, salvage value and sunk costs. User costs includes road user cost, vehicle operating costs and crash costs. Enhancing pavement condition offers various benefits for road users, socio-economic growth, vehicle time savings amongst several other benefits. [19] noted that economic assessment of alternatives that considers all of the significant costs of ownership over the useful life is essential. This includes; initial costs financing costs and maintenance costs.

LCCA is particularly necessary when project alternatives that fulfill the same performance requirements, but differ with respect to initial costs and operating costs. Life cycle cost analysis explains the economic assessment of highway upgrades during the initial stage and also for highway investment decisions overtime [1]. [21] states that LCCA includes all the phases, starting from materials procurement, through to design production, construction, maintenance, restoration, transportation, costs in the work zone, and ending with the recycling phase. The LCCA considered the costs related to raw materials, machinery, manpower, traffic management, and costs involved in lane closure. LCCA utilizes recycled asphalt which is economical and has eco-friendly benefits [22]. However, the cycle of cash flow is not restricted to the production of material and the materials' transportation, but it includes all life recycling and rehabilitation phases during the construction of pavements.

According to [23], the cost of road construction consists of design expenses, material extraction, construction equipment, maintenance and rehabilitation strategies, and operations over the entire service life. An economic analysis process known as Life-Cycle Cost Analysis (LCCA) is used to evaluate the cost-efficiency of alternatives based on the Net Present Value (NPV) concept. It is essential to evaluate the above-mentioned cost aspects in order to obtain optimum pavement life-cycle costs. However, pavement managers are often unable to consider each important element that may be required for performing future maintenance tasks. Over the last few decades, several approaches have been developed by agencies and institutions for pavement Life-Cycle Cost Analysis (LCCA). Findings from the study of [24] indicate that the estimation of initial bid prices is the major source of uncertainty, despite the regression analysis to reduce it. This can be a function of JPCP pavement which traditionally comes at a larger up-front cost, although it is expected to have significantly less rehabilitation costs than other pavement alternatives.

Posit that in order to determine the managerial consequences of the increase in operational and maintenance costs, the costs must be assessed using an asset management perspective [25]. Also, [26] posits that a life cycle costing system should include major variables that drive future costs in order to provide a framework for reducing the risk of under or overestimating the future costs for maintenance and rehabilitation aspects. In the same vein, [27] explained the economic aspects of Slovakia's pavement management system (PMS) - Road Network Management System (RNMS). The study revealed that economic efficiency is the criterion that enables the creation of insightful outputs like strategy for allocation of limited funds between particular road sections or the total funding amount is necessary.

## III. MATERIALS AND METHODS

The Life cycle cost analysis was done using the Present worth of Cost method. Technical Recommendations for Highway (TRH) 12 (pavement rehabilitation investigation and design) analysis was used for calculating the agency cost which entailed the initial rehabilitation, maintenance, future and salvage cost. Table 1 show the parameters used in the study.

Table 1: Parameters considered for the LCCA.

| S/N | Pavement Parameters | Dimension |
|---|---|---|
| 1 | Road length | 1000 m |
| 2 | Road width | 7.3 m |
| 3 | Wearing course | 40 mm (thick) |
| 4 | Binder course | 60 mm (thick) |
| 5 | Base course | 200 mm (thick) |
| 6 | Sub-base course | 200 mm (thick) |
| 7 | Concrete surface course | 225 mm (thick) |

Source: Authors, (2021).

Cost calculations were based on the pavement layers and their dimensions. After cost determination of pavement initial, maintenance, rehabilitation, and salvage value costs for one kilometer, the present worth costs of the rigid and flexible pavements is calculated. The Net Present Worth formula which was used is shown in equation 1 and as used by [5].

$$PWC = I_C + [\sum_n^N M_c]\left[\frac{1}{(1+i)^n}\right] + [\sum_n^N R_c]\left[\frac{1}{(1+i)^n}\right] + [\sum_n^N F_c]\left[\frac{1}{(1+i)^n}\right] - S_V\left[\frac{1}{(1+i)^n}\right] \quad (1)$$

Where: $I_c$ = Initial construction cost; $M_c$ = Maintenance cost; $R_c$ = Rehabilitation cost; $F_c$ = Future cost; n = Number of years; N = Analysis period in years (40); i = Interest rate (5%).

The Life Cycle Cost Analysis (LCCA) analysis period for this study was taken as 40 years as the analysis period have to be sufficiently long to reflect long-term cost differences associated with reasonable design strategies. Furthermore, the analysis period should always be longer than the pavement design period which is usually 20 years for flexible pavements and 30 years for rigid pavements [28-29]. The FHWA's September 1996 Final LCCA Policy statement recommends an analysis period of at least 35 years for all pavement projects, including new or total reconstruction projects as well as rehabilitation, restoration, and resurfacing projects [30].

Discounting factor $\frac{1}{(1+i)^n}$obtained at the end of the 40 years analysis period is 17.2.

Salvage cost was estimated based on the results of rehabilitation, maintenance, and future cost. Salvage cost was calculated using formula:

$$\text{Salvage Cost} = S_V = \left[1 - \left(\frac{A}{B}\right)\right] \times \text{Cost of overlay}$$

$S_v$ = Salvage value; A = Age of the overlay; B = Expected life of overlay

## IV. RESULTS AND DISCUSSIONS

### IV.1 DETERMINATION OF AGENCY COSTS

The initial construction cost of pavements was calculated after determining the materials quantity and cost breakdown for a 1km and 7.3 meter width road based on the typical road section of both pavement types. Summary of initial construction costs for the Flexible, Rigid and Rigid with 15% CBA replacement pavements is as shown in Table 2 and Figure 1.

Table 2: Summary of Initial Cost for Pavements for road length of 9.413 KM.

| Bill Nos. | Description | Total Cost (₦) | | |
|---|---|---|---|---|
| | | **Flexible Pavement** | **Rigid Pavement** | **Rigid Pavement (with 15% CBA)** |
| 1 | Preliminaries | 110,000,000.00 | 110,000,000.00 | 110,000,000.00 |
| 2 | Clearing and Earthworks | 193,269,951.60 | 193,269,951.60 | 193,269,951.60 |
| 3 | Pavement and Surfacing | 802,173,086.00 | 1,286,803,426.08 | 1,177,659,690.08 |
| | **Total** | **1,105,443,037.60** | **1,590,073,377.68** | **1,480,929,640.08** |
| | **Cost per km** | **117,437,909.91** | **168,923,125.22** | **157,328,125.00** |

Source: Authors, (2021).

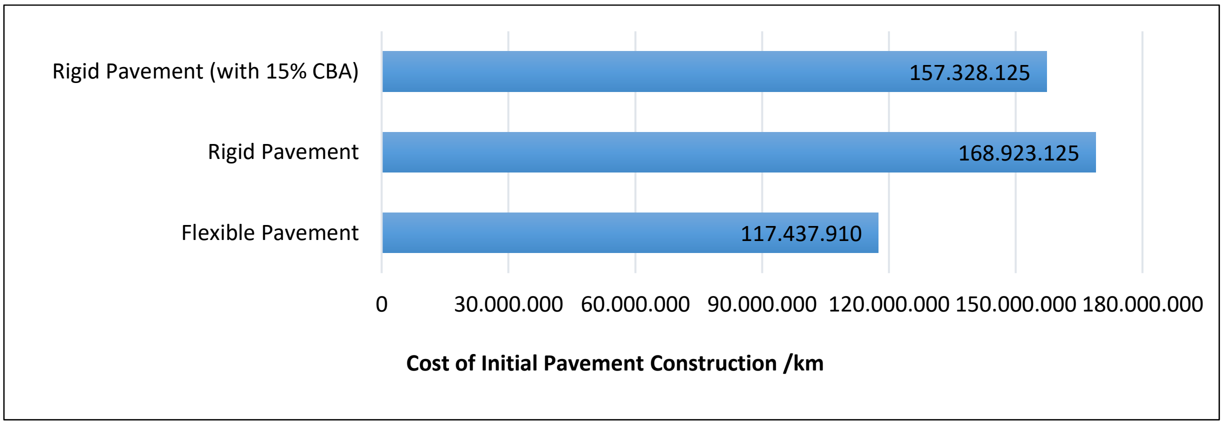


Figure 1: Initial cost comparison between Flexible and Rigid Pavement for a 1KM road section.
Source: Authors, (2021).

Figure 1 shows that the initial construction cost for flexible pavement (₦117,437,909.91) was lower than that of the rigid pavement without CBA replacement (₦168,923,125.22) by 30.5%. Also, the initial construction cost of the flexible pavement is lower than that of the rigid pavement with 15% CBA replacement (₦157,328,125.00) by 25.4%.

## IV.2 FLEXIBLE PAVEMENT - AGENCY COST

### IV.2.1 Rehabilitation Cost

Rehabilitation Cost = Base + Sub-base + Binder + Wearing Cost
= 8,679,349.60 + 5,621,700.80 + 18,490,244.46 + 15,987,584.00
= ₦ 48,778,878.90

### IV.2.2 Maintenance Costs

Asphalt Resurfacing (Once every decade = 4times) = ₦ 63,950,336.00

### IV.2.3 Future Cost

Asphalt Resurfacing (After 1st decade, 2nd decade, 3rd decade and on the 35th year)
Total Future Cost= Rehabilitation Cost + Resurfacing(s)
= ₦ (48,778,878.90 + 63,950,336) = ₦ 112,729,215.00

### IV.2.4 Salvage Cost

Total salvage cost = Conventional Rehabilitation + Conventional Maintenance Cost + Conventional Future Cost
Total Salvage Cost = ₦ (12,194,719.70 +15,987,584+28,182,303.8) = ₦ 56,364,607.50

$$PWC = I_C + [\sum_n^N M_c]\left[\frac{1}{(1+i)^n}\right] + [\sum_n^N R_c]\left[\frac{1}{(1+i)^n}\right] + [\sum_n^N F_c]\left[\frac{1}{(1+i)^n}\right] - S_V\left[\frac{1}{(1+i)^n}\right] \quad (2)$$

Flexible Pavement Initial Construction Cost = ₦117,437,909.91
PWC = 117,437,909.91 + [(48,778,878.90 + 63,950,336+112,729,215)(17.2)]-(56,364,607.5×17.2)
PWC = 117,437,909.91 + [(225, 458,430 ×17.2]-(56,364,607.5×17.2)
PWC = 117,437,909.91 + 3,877,885,000-969,471,249
PWC = 3,995,322,909.91-969,471,249
PWC = ₦3,025,851,660.91

## IV.3 RIGID PAVEMENT - AGENCY COST

### IV.3.1 Rehabilitation Cost

Rehabilitation Cost = Base + Surface course costs
= ₦ (8,679,349.60 + 31,332,330.00) = ₦ 40,011,679.60

### IV.3.2 Maintenance Costs

Concrete resurfacing (After 15th, 30th and on the 40th year) = ₦ 16,710,576.00

### IV.3.3 Future Cost

Concrete resurfacing (After 15th, 30th and on the 40th year)
Total future cost = Rehabilitation cost + Resurfacings
= ₦ (40,011,679.60 + 16,710,576.00) = ₦ 56,722,255.60

### IV.3.4 Salvage Cost

Total salvage cost = Conventional Rehabilitation + Conventional Maintenance Cost + Conventional Future Cost
Total Salvage Cost = ₦ (10,002,919.90 + 4,177,644.00 + 14,180,563.90) = ₦ 28,361,127.80

Rigid Pavement Initial Construction Cost = ₦ 168,923,125.22k
PWC = ₦[168,923,125.22+ [(40,011,679.60 + 16,710,576.00 + 56,722,255.60)(17.2)] – (28,361,127.80) (17.2)]
PWC = ₦ [168,923,125.22+ (113,444,511)(17.2) – (28,361,127.80) (17.2)]
PWC = ₦ [168,923,125.22+ 1,951,245,590 – 487,811,398]
PWC = ₦ [2,120,168,720 – 487,811,398]
PWC = ₦ 1,632,357,320

## IV.4 RIGID PAVEMENT WITH CEMENT AND 15% CBA - AGENCY COST

### IV.4.1 Rehabilitation Cost

Rehabilitation Cost = Base + Surface course costs
= ₦ (8,679,349.60 + 24,992,280.00) = ₦ 33,671,629.60

### IV.4.2 Maintenance Costs

Concrete resurfacing (After 15th, 30th and on the 40th year) = ₦ 13,329,216.00

### IV.4.3 Future Cost

Concrete resurfacing (After 15th, 30th and on the 40th year)
Total future cost = Rehabilitation cost + Resurfacings
= ₦(33,671,629.60 + 13,329,216.00)= ₦ 47,000,845.60

### IV.4.4 Salvage Cost

Total salvage cost = Conventional Rehabilitation + Conventional Maintenance Cost + Conventional Future Cost
Total Salvage Cost = ₦ (8,417,907.40 + 3,332,304.00 + 11,750,211.40)
= ₦ 23,500,422.80

Rigid Pavement Initial Construction Cost = ₦ 157,328,125.00k
PWC = ₦ [157,328,125.00 + [(33,671,629.60 + 13,329,216.00 + 47,000,845.60)(17.2)] – (23,500,422.80) (17.2)]
PWC = ₦ [157,328,125.00 + (94,001,691.20)(17.2) – (23,500,422.80) (17.2)]
PWC = ₦ [157,328,125.00 + 1,616,829,090 – 404,207,272]
PWC = ₦ [1,774,157,220 – 404,207,272]
PWC = ₦ 1,369,949,950.00

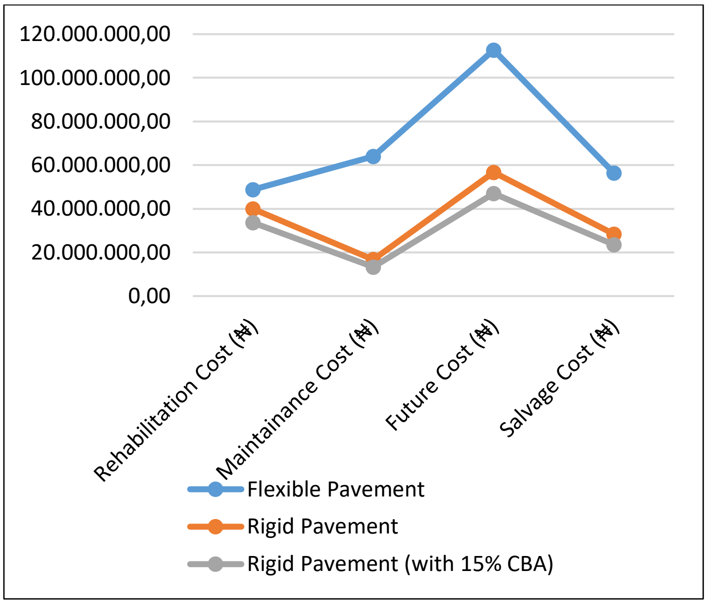


Figure 2: Agency costs for varying pavement types.
Source: Authors, (2021).

Figure 2 show that the rehabilitation cost for flexible pavement was higher than that of the rigid pavement without CBA replacement and with 15% CBA replacement by 18.0% and 31.0% respectively. The maintenance cost for the flexible pavement was also higher by 73.9% and 79.2% for the rigid pavement without CBA replacement and with 15% CBA replacement respectively. The future and salvage costs also show an increase of 49.7% and 58.3% when comparing the flexible pavement and rigid pavement without CBA replacement and with 15% CBA replacement respectively. This shows that maintenance cost is the main factor contributing to the cost difference between flexible and rigid pavements.

Figure 3 reveals that the present worth cost of the flexible pavement (₦3,025,851,660.91) is 46.05% higher than the cost of the rigid pavement without CBA (₦ 1,632,357,320.00). The flexible pavement present worth cost is also 54.73% higher than the cost of the rigid pavement with 15% CBA (₦ 1,369,949,950.00).

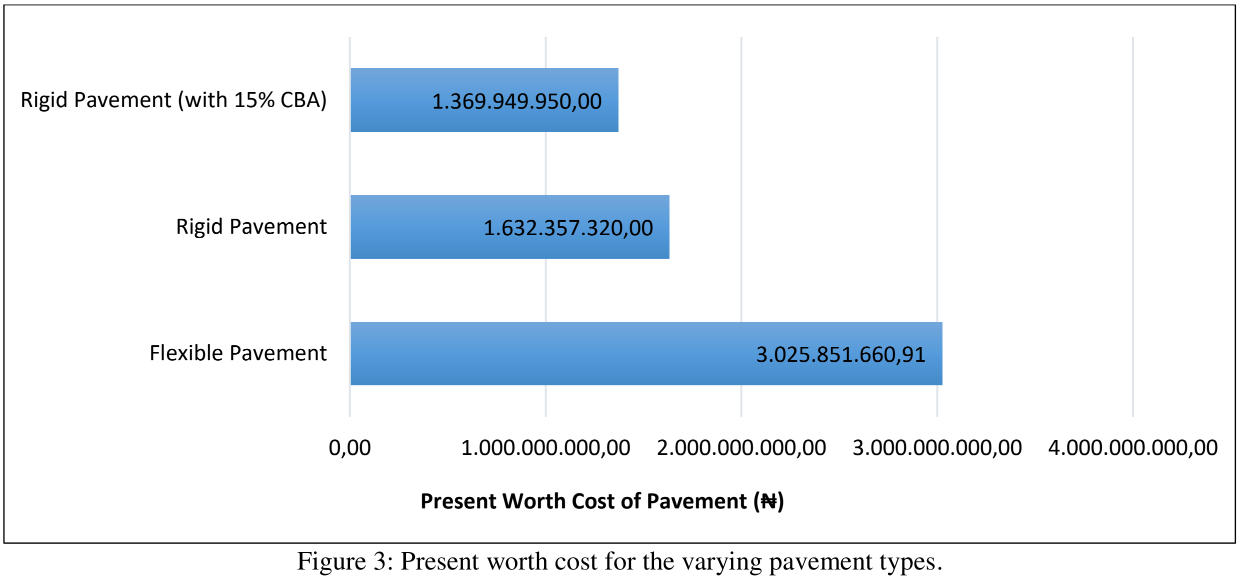


Figure 3: Present worth cost for the varying pavement types.
Source: Authors, (2021).

The study reveals that the frequent periodic maintenance of flexible pavement causes its life cycle cost to increase significantly whereas rigid pavements do not need costly periodic maintenance. Furthermore, according to [2] rigid pavements follow the build and forget concept which eventually make it economically viable and sustainable type of pavement especially for developing countries such as Nigeria. The findings of this study supports the findings of [4] that posit that flexible pavements have lower initial construction cost, they require higher maintenance cost and lower life span when compared to rigid pavement. The findings of this study negates the findings of [31] whose economic analysis slightly shows higher lifecycle costs for rigid pavement when compared with flexible pavements.

## V. CONCLUSIONS

The study evaluated the life cycle costs analysis (LCCA) of three different pavements (flexible, rigid and rigid with 15% replacement of cement CBA). The result of the study shows that the present worth cost for the varying Pavement presents the options available for decision making. The result revealed that the initial cost of Rigid pavement is the highest followed by the initial cost of Rigid pavement with 15% CBA while flexible Pavement has the lowest initial cost. However, considering the result form Figure 3 present worth cost of flexible pavement is the highest followed by Rigid pavement and Rigid pavement with 15% CBA has the lowest life cycle cost. The reason for the high cost of flexible pavement is due to the fact that the frequent periodic maintenance of flexible pavement causes its life cycle cost to increase significantly whereas rigid pavements do not need costly periodic maintenance. Furthermore, rigid pavements follow the build and forget concept which eventually make it economically viable and sustainable type of pavement especially for developing countries such as Nigeria. Therefore the study recommends rigid pavement with 15% CBA because it gives the lowest life cycle cost. Further studies should be extended to the life cycle assessment analysis (LCAA) by considering fuel consumption, $CO_2$ emissions, and pavement condition ratings for both flexible and rigid pavements.

## VI. AUTHOR'S CONTRIBUTION

**Conceptualization:** Adanikin Ariyo and Falade Funsho.
**Methodology:** Ajibade Temi and Adewale Olutaiwo.
**Investigation:** Adanikin Ariyo and Adeoye Itunuoluwa.
**Discussion of results:** Adanikin Ariyo and Adeoye Itunuoluwa.
**Writing – Original Draft:** Adanikin Ariyo.
**Writing – Review and Editing:** Ajibade Temi and Adeoye Itunuoluwa.
**Resources:** Adanikin Ariyo and Falade Funsho.
**Supervision:** Falade Funsho and Adewale Olutaiwo.
**Approval of the final text:** Adanikin Ariyo and Falade Funsho.

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