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Life cycle economic comparison between rigid and flexible pavement: a case study for the construction of wajen- garin barkamawa-dugurawa road in kano state nigeria

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HIGHLIGHTS

- Rigid pavement construction costs 64% more than flexible pavement construction.
- Rigid pavement exceeded flexibility in strength, deformation, and wheel loads.
- Rigid pavement increases sustainability via a longer lifespan and lower maintenance.
- Rigid pavement becomes financially efficient over time, highlighting longevity in choice.

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ABSTRACT

Flexible pavements may be strengthened and enhanced incrementally to meet traffic needs, making them preferable to cement concrete roadways. Due to the rise of poor-quality bituminous pavements, Nigeria is promoting concrete pavements. Concrete pavements are becoming more popular because of their durability and ability to withstand heavy traffic and harsh environmental conditions. The primary objective of this study is to provide a comprehensive comparative analysis of both flexible and rigid pavement suitability, considering various parameters such as material characteristics, load-bearing capacity, longevity, and cost-effectiveness. The pavement structure used for the project meets the Federal Ministry of Works Highway Manual Part 1, Design Volume III specifications, with a few compositional adjustments. The study contains cost estimates for numerous parts of flexible pavement design, such as using a concrete wearing course, a bitumen emulsion tack coat, a concrete binder course, and an MC 1 cutback bitumen prime coat. The expenditure associated with the construction of flexible pavement amounts to 1,760,293,155.18 N, while the anticipated cost for the construction of rigid pavement is projected at 2,725,765,337.00 N. In percentage terms, rigid pavement costs 64% more than flexible pavement. Flexible pavement costs are based on supply, construction, and finish unit rates. The projected flexible pavement cost includes labor, materials, and plant expenditures. Reinforcing and concrete costs are estimated in rigid pavement studies. The analysis examines plant, people, and permanent material expenses. The research gives detailed pavement structural design and construction cost estimates for the road project, enabling informed pavement structure decisions.

1. Introduction

In Nigeria, driving is the most popular and significant mode of transportation. People can travel freely, and commodities can be carried thanks to the nation's well-developed road network [1]. However, given the circumstances of this developing country, it is necessary to devote constant attention to three key areas: the construction and extension of transportation infrastructure, the continued upkeep of existing roads, and the compliance with internationally acknowledged standards for road and highway safety [2-5].Nigeria's responsibility for maintaining the vast road network is divided among the Federal Government, State Governments, and Local Governments. This division of labor promotes development and guarantees that even smaller cities and villages can profit from these technical breakthroughs [6]. In Nigeria, the road sub-sector grew significantly after the country gained independence in 1960. This was primarily caused by the significant capital expenditures that the federal, regional, and, subsequently, state governments made. The principal goal of these expenditures was to enable effective transportation to guarantee the prompt delivery and evacuation of agricultural products and supplies [7]. The 1970s

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oil boom prompted the adoption of bold development plans characterized by large investments in transportation infrastructure. The oil boom prompted the implementation of these tactics. The main goal of these initiatives was to achieve a maximum cost-per-kilometer reduction while simultaneously obtaining extensive road coverage [8,9]. Nigeria has a road network spanning around 200,000 km as of 1996. This comprised state roads totaling 30,500 kilometers, municipal government roads totaling 130,600 km, and federal highways measuring 32,097 km.

The choice of pavement type is critical in road infrastructure building since it significantly impacts long-term economic issues [10,11]. One of the most crucial choices that must be made in the road construction sector is between rigid and flexible pavements [12-14]. The two basic choices are classified as flexible pavements and rigid pavements. Rigid pavements are a popular choice for many applications due to their numerous advantages, which include strength, lifetime, cost-effectiveness, and durability [15]. Rigid pavements are more adaptable since they can be installed in various layouts. According to reports, flexible pavement is used in 99 percent of road construction projects in Nigeria. This is because flexible pavement is the most often used method of creating road surfaces throughout the country [16]. The phrases "deflection" and "flexure" are widely used to describe the behavior of stressed pavement systems. Pavements exhibit extremely low resistance to the wheel load-induced deformation [17,18]. When subjected to wheel loads, a material with poor flexural strength behaves pliantly and has a significantly lower capacity to withstand bending pressures. Rigid pavements, on the other hand, have a significant modulus of elasticity in their surface layer, resulting in minimum deflection under load. Their previously noted properties have earned them the moniker "rigid pavements." Furthermore, because of their high flexural strength and slab action, these pavements may effectively disperse wheel loads across a broader area beneath the pavement structure [19-21].

This paper examines the complicated road construction area using life cycle economic analysis and rigid and flexible pavement technology comparisons. Choosing between these two technologies could affect road construction costs, maintenance costs, and network efficiency. This study will examine the financial aspects of different paved surfaces, including original construction costs, ongoing maintenance costs, and lifespan. This study evaluates the pros and cons of various approaches to help road construction decision-makers and engineers make cost-effective choices. This study proposes a strategy to choose the most cost-effective pavement design method for a highway network part and to analyze the cost of several methods.

2. Study area

Dawakin Tofa Local Government Area, the research location, is located in the northern Nigerian state of Kano and around 20 km south of Kano's city center. Figure 1 shows Dawakin Tofa Local Government Area's approximate geographic coordinates, which are 11.9706° N latitude and 8.5051° E longitude. The principal sources of income for the people who live in the area are livestock farming and agriculture.

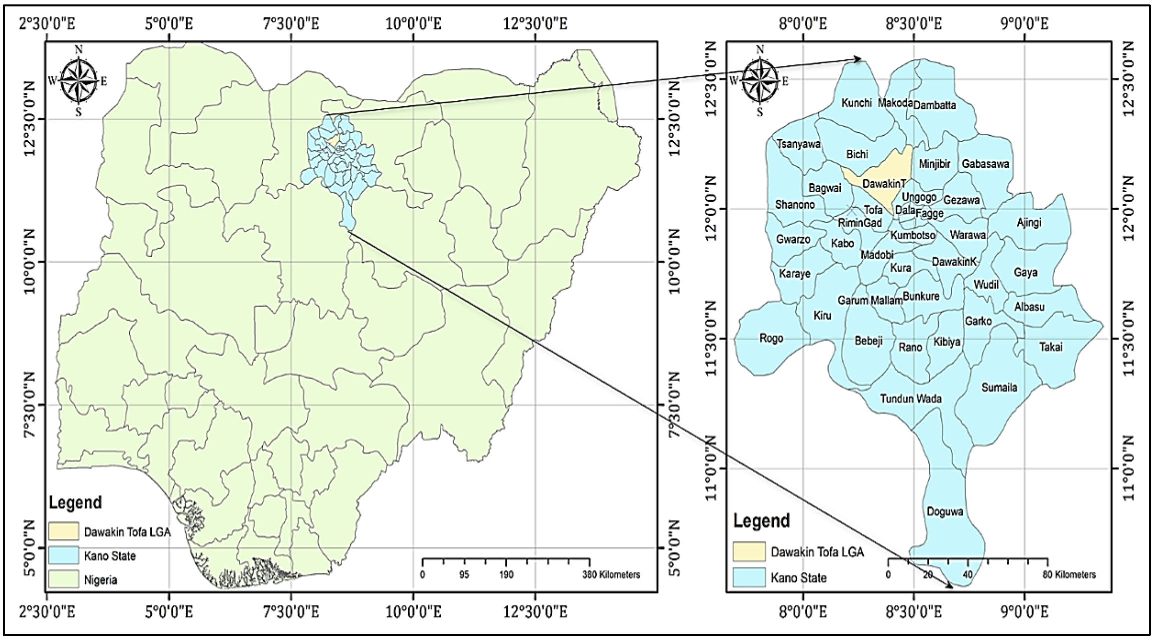

Figure 1: Map of Geographical coordinates of the study area

The main goal of this project is to construct the Wajen Garin Barkamawa-Dugurawa Road, which is located inside Kano State's borders. Barkamawa and Dugurawa are long-established communities with a sizable local population. The project begins at the Barkamawa intersection on the Kano-Gwarzo Road in Rimin Gado. The road then continues through other towns and farmlands before concluding at Dugurawa, acting as an important transportation route in the area.

The existing pavement consists of surface dressing over lateritic bases in poor condition. This road length is 5,300 m long and designed to Federal Ministry of Works (FMW) standards, consisting of a 7.3 m wide carriageway with 2.75 m wide shoulders on either side, as shown in Figure 2.

Figure 2: The project route alignment (by the researcher)

3. Methodology

3.1 Pavement structural design

The pavement structural design of the route of this study complies with the suggestions in the UK Overseas route Note 31 [22]. The technique detailed in this methodology for determining the optimal pavement cross section for the road includes calculating future traffic loads and evaluating the strength of the design subgrade.

An estimated 1.5 million Estimated Standard Axle Load (ESAL) was used for a 20-year projection. ESAL was calculated using Equation 1, which enables the calculation of ESAL, a critical metric in pavement design and analysis [23]:

$$T = 365 \times F \times Y \times G \times W \times P \times 10^6 \quad (1)$$

Where T represents the Estimate single-axle Load (ESAL), F stands for the Flow of Traffic (AADF) for each traffic class at the project's commencement, Y indicates the Design Period, which is typically 20 years, G is the Growth Factor, P represents the Percentage of vehicles in the heaviest loaded lane, W signifies the Wear Factor for each specific traffic class.

The route's subgrade strength was calculated using California Bearing Ratio (CBR) data. The CBR Test analyzes the load-bearing capacity of subgrade soils, which is important when building pavements. The ASTM D1883:2021 test employs compacted soils in a moist environment [24,25]. The test findings are then compared to standard curves to determine the mechanical properties of the subgrade soil. This study evaluates the appropriateness of soil for pavement structures. The examination resulted in the road being classified as Subgrade Strength Class S3 and Traffic Class T3 by UK Overseas Road Note 31 standards.

The pavement structure chosen for this project meets the requirements of the Federal Ministry of Works Highway Manual Part 1, Design Volume III (Pavement and Material Design). The decision was based on the data in Table 1 of the manual. Following that, changes were made to the pavement construction composition, as shown in Table 1, to suit the project's requirements.

Table 1: Pavement Structure and Adjusted Pavement Structure Comparison

Pavement Structure	Thickness (mm)	Adjusted Pavement Structure	Thickness (mm)
Flexible bituminous surface	50	Asphaltic Concrete Wearing Course	50
Granular road base	175	Crushed Stone Base	150
Granular sub-base	225	Granular sub-base	250
Total	450	Total	450

Table 2: Standard Specifications for rigid pavement by the Federal Ministry of Works in the BEME (Bill of Engineering Measurement and Evaluation) [26,27]

S/No.	Road Category	Description
1	Major Roads – With Batching plant + Paver	Provide and place Concrete Grade 30 pavement, 200 mm thick, in CRCP (Continuously Reinforced Concrete Pavement), including formwork, water-based curing compound for quick curing reinforced with 20mm main bars @ 200 mm spacing and distribution bars of 16 mm @ 1000 mm spacing, cut wet concrete pavement 100 mm deep at every 100m length of road and fill with S125 bitumen on carriageway and shoulders, surface finished with friction gap.
2	Minor Roads – With Batching plant + Paver	Provide and place Concrete Grade 30 pavement, 200 mm thick, in CRCP (Continuously Reinforced Concrete Pavement), including formwork, water-based curing Compound for quick curing, reinforced with 16mm main bars @ 250 mm spacing and distribution bars of 10 mm @ 250 mm spacing, cut wet concrete pavement 100 mm deep at every 100m length of road and fill with S125 bitumen on carriageway and shoulders, surface finished with friction gap.
3	Minor Roads – With Makeshift mixer	Provide and place Concrete Grade 30 pavement, 200 mm thick, in CRCP (Continuously Reinforced Concrete Pavement), including formwork, water-based curing compound for quick curing, reinforced with 16mm main bars @ 250 mm spacing and distribution bars of 10 mm @ 250 mmn spacing, cut wet concrete pavement 100mm deep at every 100m length of road and fill with S125 bitumen on carriageway and shoulders, surface finished with friction gap.

The existing soil subgrade material is predominately sandy clay/silt of A-4 and A-6, AASHTO classification with low CBR values between 5 to 30% and poor engineering properties. Table 2, shows the standard specification for rigid pavement by Fededral Ministry of Works [27]. The lateritic base and sub-base course materials are predominantly silty clayey sand of A-2-4 AASHTO classification and, therefore, of good engineering properties.

From the foregoing, the proposed, approved pavement thickness of 700 mm was implemented as follows: (a) Carry out scarification and pulverization of any existing bituminous surfacing, mix it with the available lateritic base and sub-base course materials, and compact them to form a capping layer with a thickness of 200 mm for both the carriageway and shoulders; (b) Implement a compacted lateritic sub-base course with a minimum thickness of 200 mm on the carriageway and shoulders, utilizing materials sourced from identified and approved borrow pits; (c) Establish a compacted crushed stone base course with a minimum thickness of 200 mm exclusively on the carriageway; (d) Install a compacted 60mm thick asphaltic concrete binder course on both the carriageway and shoulders; and (e) Apply a compacted 40mm thick asphaltic concrete wearing course on the carriageway and shoulders. It is also recommended to consider an alternative pavement structure using a Rigid pavement design, which utilizes 200 mm thick concrete. This concrete should be reinforced with main bars of 20 mm diameter spaced at intervals of 200 mm, supplemented by distribution bars of 16 mm diameter spaced at 1000 mm intervals for enhanced durability and longevity. This alternative structure offers improved strength and performance for the project.

3.1.1 Cost analysis: rigid and flexible pavement

The construction cost analysis of the Rigid Pavement of Wajen Garin Barkamawa Dugurawa Road in Kano State was estimated by applying typical supply, construction, and finish unit rates to each material. Overheads, mobilization, and other fixed costs were ignored. The rates used for this analysis were current contract rates by the Federal Ministry of Works of Nigeria [27].

This project alignment's total road length is 5,300 m. The road's design specifications dictate a width of 12.8 m and a thickness of 0.2 m, resulting in a total volume of 13,568 m^3 cubic meters see Equation 2 below:

$$\mathrm{Area} = \mathrm{L} \times \mathrm{W} \tag{2}$$

$$\mathrm{Volume} = \mathrm{L} \times \mathrm{W} \times \mathrm{T} \tag{3}$$

where L= Length of the road, W=Width of the road, and T=Thickness of the road

3.1.2 Life cycle cost determination: rigid pavement

The reference is based on the scope of work prescribed by the Federal Ministry of Works [27] Bill of Engineering Measurement and Evaluation (BEME) standard to ascertain the cost associated with rigid pavement construction. The defined scope encompasses the following tasks: the provision, mixing, and placement of Concrete Grade 30 pavement, 200 mm in thickness, designed in a Continuously Reinforced Concrete Pavement (CRCP) configuration. This work includes the erection of formwork, applying water-based curing compounds to expedite the curing process, reinforcement using 20 mm main bars spaced at 200 mm intervals, and distribution bars measuring 16 mm at 1000 mm intervals. Furthermore, it involves strategically cutting wet concrete pavement to a depth of 100 mm at 100 m intervals along the road, followed by filling these incisions with S125 material on both the carriageway and shoulder sections. The surface finish is accomplished with the incorporation of a friction gap.

3.1.3 Rigid Pavement: 200 mm Continuously Reinforced Concrete Pavement (CRCP)

Based on the computed specifications of the road infrastructure, it is determined that the total volume of concrete required for the entire road, given its dimensions (5.3 km in length, 12.8 m in width, and 0.2 m in thickness), amounts to 13,568 m^3. HZS60 Stationary Type Concrete Batching Plants are preferred for projects with substantial concrete production demands, especially those with extended durations at a fixed location [28]. These batching plants are distinguished by their maximum productivity of 60m^3/hr and a discharging height of 4.2 m.

It is anticipated that the batching plant will be proficient in producing 50 m^3 of concrete per hour, encompassing both the batching and mixing procedures. However, it is important to emphasize that this calculation does not encompass the subsequent processes of concrete transportation and application at the construction site [28]. The comprehensive project entails batching, mixing, transporting, and placing a total of 13,568 m^3 of concrete within 285 days. To account for potential contingencies such as unforeseen events and climatic conditions during the construction process, an additional margin of 1.05 days has been incorporated, as represented in Equation 4:

$$G = \frac{V \times 1.05}{O} \quad (4)$$

$$M = V \times 1.54 \quad (5)$$

where; V= Volume (m^3), O=Batching plant Output (m^3), G=Time frame for the work, M= Volume @ dry mix (m^3)

The ensuing sections, specifically Tables 3,4and 5, provide a detailed breakdown of the expenses associated with machinery, labor, and the permanent materials that are concurrently requisite for the concrete-related activities of the project. The labor cost for concrete works can vary depending on several factors, including the region, the project's complexity, the workers' skill level, and prevailing wage rates.

Table 3: Plant cost for concrete works

Description	Quantity	Duration (days)	Rate ₦	Amount ₦
Mobile Conc. Mixer	5	285	300,000	427,500,000
No. Batching plant	1	285	450,000	128,250,000
No. Conc Paver	1	285	250,000	71,250,000
No. Poker Vibrator	2	570	25,000	28,500,000
No. Small Tools	1	285	25,000	7,125,000
Water bowser	1	28.5	300,000	8,550,000
Water tank + Water	1	142.5	25,000	3,562,500
Hiab + Skip / Crane	1	285	300,000	85,500,000

*Rates are determined through a market survey and Zephyrgold's prior practical experience in construction projects. Nigeria Currency Naria (N)

Table 4: Labour cost for concrete works

Description	Quantity	Duration (days)	Rate ₦	Amount ₦
No. Foreman	1	285	8,400.00	2,394,000.00
No. Mason	2	285	8,200.00	4,674,000.00
No. Carpenter	4	285	8,200.00	9,348,000.00
No. U/Labour	5	285	5,056.00	7,204,800.00
Total				23,620,800.00

Table 5: Permanent Materials cost for concrete works

Description	Quantity	Unit	Rate ₦	Amount ₦
Cement	5385	Tons	110,000	592,350,000
Fine aggregate	26922	Tons	14,500	390,369,000
Coarse aggregate	13461	Tons	10,000	134,610,000
Admixture	53850	Kg	1,000	53,850,000
S125 Joints	53	Nos	45,500	2,411,500
Allow for shuttering				3,500,000
Total				1,177,090,50

For the permanent materials Concrete grade 30 (1:1.5:3) was chosen as the permanent material for calculating and manufacturing reinforced concrete pavement. The combined volume of the materials amounted to 13,568 m^3 in its wet mix state, while the dry mix volume equated to 20,894.72 m^3, incorporating a safety factor of 1.54 (K). The dry mix yielded the following material quantities: 5,385 tons of cement, 13,461 tons of fine aggregate, and 26,922 tons of coarse aggregate.

Admixture is multiplying the cement tonnage by 1000 and dividing the total by 100, resulting in 53,850 kg. The count of concrete cuts and fills with S125 was determined by dividing the total road length by 100 m, as specified in the description in section 5.1.1, yielding 53 units.

The success of rigid pavement construction relies heavily on accurate estimation and careful management of material quantities as shown in Table 6. Concrete (Cement, Fine, and Coarse Aggregate), Admixture, and joint sealants are all integral components that must be meticulously calculated to ensure the structural integrity and longevity of the road.

Table 6: Overall Quantities for Materials

Materials	Volume Dry Mix	Mass (kg)	Mass (ton)	No.
Cement	3,799.04	5,470,617.60	5,385.00	
Fine aggregate	5,698.56	13,676,544.00	13,461.00	
Coarse aggregate	11,397.12	27,353,088.00	26,922.00	
Admixture			53,850.00	
S125 Joints				53

The total cost for the concrete work is calculated to be N 1,960,948,800.00. This figure represents the comprehensive financial estimation associated with all aspects of concrete-related activities within the project, including but not limited to materials, labor, and equipment expenses directly related to the concrete work on the construction of the road project.

According to the specifications, 20 mm diameter reinforcement bars were designated for the main bars, and 16 mm diameter bars were specified for the distribution bars. The main bars, measuring 20 mm in diameter, extend continuously over 5200 meters. In contrast, the distribution bars span a width of 12.8 m and are 16 mm in diameter. The spacing between the 20 mm diameter main bars is set at 0.2 m, whereas the distribution bars, with a diameter of 16 mm, are spaced at intervals of 1.0 m. Additionally, it has been specified that a 1-m lapping should be employed for both the main and distribution bars.

Based on these characteristics, the total reinforcement required for the main bars is 916 tons, with 128 tons required for the distribution bars. To summarize, the project requires 1044 tons of reinforcement. Tables 7 and 8 show a full analysis of the required components, amounts, and extra information.

Table 7: Reinforcement Quantities for the Longitudinal Bar

Parameter	Value	Unit
Length of the road	5200	m
Length of reinforcement	12	m
V1: Length per stretch covering 5200 m	442	Nos
Width of the road	12.8	m
Spacing	0.2	m
V2: Total number of longitudinal bars	65	Nos
Total number of bars for longitudinal reinforcement	28,708	Nos
	845	Tons
Length of lapping	1.0	m
Length per stretch of the road covering 5200 m	441.7	m
Length of lapping bar per stretch of the road	441.7	m
V3: Number of lapping bars per stretch of the road	36.806	Nos
V4: Total number of lapping bars for the road	2,392.361	Nos
	71	Tons
Total Tonnage of Longitudinal Reinforcement	916	Tons

Table 8: Reinforcement Quantities for the Distribution Bar

Parameter	Value	Unit
Length of the road	5200	m
Spacing	1	m
V5: Length per stretch covering 5200 m	5200	m
Width of the road	12.8	m
Length of reinforcement	10	m
V6: Total number of longitudinal bars (W/L)	1.280	Nos
Total number of bars (V5 - V6)	6784	Nos
Total Tonnage - Distribution Reinforcement	128	Tons
Total Tonnage of Main & Distribution Reinforcement	1044	Tons

Nos = numbers

Understanding that several insightful elements have resulted in the reinforcement's length being fully adjusted to 10 m is critical. This alteration is meant to fit a 1.2 m lapping requirement, with a 0.8 m piece set aside for the transverse portion. Additionally, this adjustment minimizes the wastage of valuable reinforcement material at the construction site, thereby promoting resource efficiency. Furthermore, the overarching aim is to ensure that the project is adequately supplied with a substantial reinforcement material to meet its specific requirements.

Based on the calculations mentioned earlier, 1044 tons of reinforcement is needed for the entire road construction project. It is anticipated that 20 tons of iron will be produced daily, and this production rate will be sustained for 55 days to complete the project. This time frame includes an additional 1.05 days as a safety margin to account for various unforeseen events and climatic conditions during construction. Tables 9,10 and 11 below furnish a detailed overview of the expenses linked to machinery, workforce, and permanent materials required concurrently for the reinforcement work.

Table 9: Plant Cost for Reinforcement Works

Description	Quantity	Duration (days)	Rate ₦	Amount ₦
Cutting Machine	1	55	50,000.00	2,750,000.00
Bending Equipment	1	55	50,000.00	2,750,000.00
Small Tools	1	55	25,000.00	1,375,000.00
Generator	1	55	150,000.00	8,250,000.00
Crane	1	22	400,000.00	8,800,000.00
Lowbed	1	16.5	350,000.00	5,775,000.00
Total				29,700,000.00

Table 10: Labor Cost for Reinforcement Works

Description	Quantity	Duration (days)	Rate ₦	Amount ₦
No. Foreman	2	55	8,400.00	924,000.00
No. Iron Benders	5	55	8,200.00	2,255,000.00
No. Steel fixers	5	55	8,200.00	2,255,000.00
No. U/Labour	7	55	5,056.00	1,946,560.00
Total				7,380,560.00

The labor cost for reinforcement work can vary depending on several factors, including the region, the specific type of reinforcement work, the laborers' skill level, and the project's complexity. Generally, labor costs for construction activities, including reinforcement work, are influenced by local market conditions, labor supply and demand, and the overall economic environment.

As delineated in Table 11, the total reinforcement volume employed was computed to be 1044 tons. To factor in the possibility of incomplete materials, a safety margin of 1.05 was judiciously applied. As a result, 1100 tons of reinforcement were provisioned, thus ensuring an adequate buffer to accommodate potential material inadequacies and fortify structural integrity.

Table 11: Permanent Materials Cost for Reinforcement Works

S/N	Description	Quantity	Unit	Rate ₦	Amount ₦
i	Reinforcement	1,100	Ton	650,000.00	714,867,777.00
ii	Binding wire	14298	Kg	900.00	12,868,200.00
	Sub Total Permanent Materials =				727,735,977.00
Sub Total HT Steel Reinforcement =					₦ 764,816,537.00
Total for Concrete and Reinforcement =					₦ 2,725,765,337.00

4. Results and discussion

Determining the life cycle cost (LCC) for flexible payment methods involves identifying and quantifying all relevant costs, including initial setup expenses, ongoing operating costs, maintenance and replacement costs, training expenses, and any opportunity costs over a defined timeframe [29,30]. However, for the study area, the construction cost analysis of flexible pavement for Wajen Garin Barkamawa Dugurawa Road was estimated by applying typical supply, construction, and finish unit rates to each material. Overheads, mobilization, and other fixed costs were ignored. The rates used for this analysis were the current contract rate by the Federal Ministry of Works of Nigeria [27].

4.1 Prime coat using MC 1 cutback bitumen

As per the guidelines set forth by the Federal Ministry of Work's BEME, for the application of a prime coat using MC 1 cutback bitumen, as shown in Table 12, the specified procedure entails the provision and application of MC 1 cutback bitumen 100/150 STV at a temperature of 40 ºC, at a rate of 0.9 l/m^2 (0.25 gallons per square yard), inclusive of blinding with sand or quarry dust on the carriageway. Based on the previously calculated figures, the collective surface area requiring the application of MC1 Cutback Bitumen is determined to be 67,840 m^2. Employing a spraying rate of 0.9 kg/m^2, the overall necessity for MC1 amounts to 61,056 kg, equivalent to 61.056 metric tons, encompassing the entire road length. With an anticipated operational output of 3,200 m/hour, the comprehensive timeline for the project is estimated to be 23 days. This duration incorporates an additional safety margin of 1.05 days to accommodate unforeseen contingencies and adverse climatic conditions throughout the construction process.

Table 12: Plant, Labour, and Permanent Materials Cost for MC1 Cutback Bitumen

			Plant			
S/N	**Description**	**Quantity**	**Duration**	**Unit**	**Rate N**	**Amount N**
i	Tar Boiler	1	23	Days	300,000.00	6,900,000.00
ii	Water bowser	1	23	Days	300,000.00	6,900,000.00
Sub Total						13,800,000.00
			Labor			
iii	No. Foreman	1	23	Days	8,400.00	193,200.00
iv	No. U/Labour	4	92	Days	5,056.00	465,152.00
Sub Total						658,352.00
			Permanent Materials			
v	MC 1	67,840	m²		3,200.00	217,088,000.00
vi	Granite Sand	62	Kg/m²		6,000.00	372,000.00
Sub Total						217,460,000.00

The aggregate total for MC1, which represents the cost or value associated with MC1 in the project context, is calculated to be 231,918,352.00. This figure reflects all expenditures for plant, labor, and Permanent Materials.

4.2 Bitumen emulsion tack coat

In accordance with the prescribed procedures, the preparation of surfaces involves the provision and application of bitumen emulsion tack coat at a specified rate of 0.9 l/m^2 on the carriageway. As per the prior calculations, it is determined that a surface area of 67,840 m^2 necessitates the application of Bitumen Emulsion Tack Coat at the stipulated rate of 0.9 kg/m^2, resulting in a cumulative requirement of 61,056 kg, equivalent to 61.056 metric tons, to cover the entire expanse of the road. Considering a projected operational efficiency of 3,200 m/hour, the project's overall duration is estimated to be 23 days, as shown in Table 13. This time frame encompasses a supplementary safety margin of 1.05 days, which has been incorporated to accommodate unforeseen circumstances and adverse weather conditions during the project.

Table 13: Plant, Labour, and Permanent Materials Cost for Bitumen Emulsion Tack Coat

			Plant			
S/N	**Description**	**Quantity**	**Duration**	**Unit**	**Rate ₦**	**Amount ₦**
i	Tar Boiler	1	23	Days	300,000.00	6,900,000.00
ii	Wet Can	4	92	Days	5,000.00	460,000.00
Sub Total						7,360,000.00
			Labor			
iii	No. Foreman	1	23	Days	8,400.00	193,200.00
iv	No. U/Labour	4	92	Days	5,056.00	465,152.00
Sub Total						658,352.00
			Permanent Materials			
v	Tack Coat	67,840	m²		2,900.00	196,736,000.00
Sub Total						196,736,000.00
Total for Tack Coat						204,754,352.00

4.3 Binder course application

The task entails the provision, spreading, shaping, and compaction of asphaltic concrete onto the carriageway to achieve a compacted thickness of 60 mm, as stipulated for the concrete binder course on the carriageway. Considering the extent of the area to be covered, which spans 67,840 m^2 and requires a 60 mm thick concrete binder course, a comprehensive logistical plan has been devised. This plan involves the utilization of 12 tippers, each boasting a 20-ton carrying capacity and making two trips per day, resulting in a combined daily output of 480 tons. In terms of specific application, this configuration translates to an average of 0.15 tons/m^2, considering the 60mm thickness, enabling coverage of 3,200 m^2 daily. By this calculation, as shown in Table 14, the estimated quantity of asphalt required for the entire road length is projected to be 9,769 tons, equivalent to 9,769,600 kg. Considering this analysis, it is anticipated that the project will encompass a total duration of 23 days, including an additional 1.05 days reserved for safety contingencies.

4.4 Wearing course

A logistical plan has been devised to facilitate the application of asphaltic concrete to the carriageway at a specified compacted thickness of 40 mm for a total area of 67,840 m^2, particularly for the wearing/overlay course. This plan involves the utilization of 12 tippers, each with a carrying capacity of 20 tons, undertaking two trips daily, thus resulting in a daily aggregate of 480 tons of asphalt material. This operational arrangement translates to an average coverage of 0.10 tons/m^2 for the prescribed 40mm thickness, allowing for the treatment of 4,800 m^2 daily, as shown in Table 15. Consequently, the cumulative calculation estimates the requirement of 6,513 tons (equivalent to 6,512,640 kg) of asphalt for the entire road project. The envisioned timeline for the project's completion spans over 15 days, with an additional 1.05 days allocated for safety considerations and measures.

Table 14: Plant, Labour, and Permanent Materials Cost for Concrete Binder Course

S/N	Description	Quantity	Duration	Unit	Rate	Amount N
			Plant			
i	Asphalt Plant	1	1	Days	450,000.00	10,350,000.00
ii	Gen Set-350KVA	1	1	Days	60,000.00	1,380,000.00
iii	Pay Loader Cat 966E	2	2	Days	122,390.60	5,629,967.60
iv	Tipper 20T	12	12	Days	250,000.00	69,000,000.00
v	Paver	2	2	Days	124,178.20	5,712,197.20
vi	Vibrating Roller 16 T	2	2	Days	66,569.00	3,062,174.00
vii	Smooth Roller 6.3 T	2	2	Days	32,588.50	1,499,071.00
viii	Roller - Pneumatic	1	1	Days	27,198.40	1,251,126.40
ix	Water Tanker 15T	1	1	Days	48,939.45	1,125,607.35
x	Water Pump 80MM	1	1	Days	1,451.30	33,379.90
xi	Diesel Tanker 7T	4	4	Days	11,417.18	262,595.14
xii	Sky Light 14KVA	2	2	Days	8,784.30	808,155.60
xiii	Level + Tripod + Stave				538.04	24,749.84
Sub Total for Plant						100,139,024.03
			Labor			
xiv	Foreman	1	23	Days	8,400.00	193,200.00
xv	Operators	27	23	Days	8,400.00	5,216,400.00
xvi	General Labour	6	23	Days	5,056.00	697,728.00
xvii	Checkers	2	23	Days	5,500.00	253,000.00
xviii	Survey Team	4	23	Days	9,000.00	828,000.00
xix	Material Testing Team	2	23	Days	10,000.00	460,000.00
xx	Security	6	23	Days	4,000.00	552,000.00
Sub Total for Labour						8,200,328.00
			Permanent Materials			
xxi	Asphalt Binder Concrete	9769		Tons	69,500.00	678,945,500.00
Sub Total for Permanent Materials						678,945,500.00

Table 15: Plant, Labour and Permanent Materials Cost for Concrete Wearing Course

S/N	Description	Quantity	Duration	Unit	Rate N	Amount N
			Plant			
i	Asphalt Plant	1	15	Days	450,000.00	6,750,000.00
ii	Gen Set-350KVA	1	15	Days	60,000.00	900,000.00
iii	Pay Loader Cat 966E	2	15	Days	122,390.60	3,671,718.00
iv	Tipper 20T	12	15	Days	250,000.00	45,000,000.00
v	Paver	2	15	Days	124,178.20	3,725,346.00
vi	Vibrating Roller 16 T	2	15	Days	66,569.00	1,997,070.00
vii	Smooth Roller 6.3 T	2	15	Days	32,588.50	977,655.00
viii	Roller - Pneumatic	2	15	Days	27,198.40	815,952.00
ix	Water Tanker 15T	1	15	Days	48,939.45	734,091.75
x	Water Pump 80MM	1	15	Days	1,451.30	21,769.50
xi	Diesel Tanker 7T	1	15	Days	11,417.18	171,257.70
xii	Sky Light 14KVA	4	15	Days	8,784.30	527,058.00
xiii	Level/ Tripod/Staff	2	15	Days	538.04	16,141.20
Sub Total for Plant=						65,308,059.15
			Labor			
xiv	Foreman	1	15	Days	8,400.00	126,000.00
xv	Operators	27	15	"	8,400.00	3,402,000.00
xvi	General Labour	6	15	"	5,056.00	455,040.00
xvii	Checkers	2	15	"	5,500.00	165,000.00
xviii	Survey Team	4	15	"	9,000.00	540,000.00
xix	Material Test Pers	2	15	"	10,000.00	300,000.00
xx	Security	6	15	"	4,000.00	360,000.00
Sub Total for Labour						5,348,040.00
			Permanent Materials			
xxi	Asphalt Wearing Concrete	6,513	Tons		71,500.00	465,679,500.00
Sub Total for Permanent Materials =						465,679,500.00

5. Conclusion

This study thoroughly assessed several pavement types' life cycle costs (LCC) by examining pavement construction, materials, labor, and equipment. This study gives comprehensive cost estimates for flexible and rigid pavement designs, considering various criteria such as materials, labor, equipment, and permanent materials. The major findings are:

- Evaluating reinforcement bars, batching facilities, labor and equipment expenses, and Federal Ministry of Works Highway Manual Part 1, Design Volume III specifications.

- Pavement structure meets specifications with compositional adjustments.
- Initial cost for flexible pavement: 1,760,293,155.18 Nigerian Naira, anticipated cost: 2,725,765,337.00 Nigerian Naira.
- Rigid pavement has superior flexural strength, higher longevity, lower maintenance costs, and economic superiority.
- Budgetary constraints and long-term durability should be considered when choosing between the two.

Author contributions

Conceptualization, R. Adewumi, W. Sulaiman and A. Shola .; methodology, R. Adewumi and W. Sulaiman.; software, W. Sulaiman.; validation, R. Adewumi, W. Sulaiman and A. Shola.; formal analysis, R. Adewumi and W. Sulaiman.; investigation, R. Adewumi and W. Sulaiman.; resources, R. Adewumi.; data curation, R. Adewumi.; writing—original draft preparation, R. Adewumi.; writing—review and editing, R. Adewumi.; visualization, A. Shola.; supervision, R. Adewumi.; project administration, R. Adewumi. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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