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Original Research Article

Investigation of the Economic and Life Cycle Cost Benefits of Concrete Pavement over Asphalt Pavement: Case Study of Isieke Road, Ebonyi State

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Abstract

Comparative economic analysis using present net worth method was carried for 1 km of rigid and flexible pavement of Isieke Road, Ebonyi State. Information on the initial construction cost of the given length of the road, the maintenance cost, the rehabilitation cost, the salvage cost and the user cost which were obtained from the Ministry of Works, Ebonyi State, were used to assess the life cycle cost of the each alternative using the present net worth method. Comparisons between the various costs used to determine the life cycle cost for both rigid and flexible pavement showed that except the initial cost of construction where the rigid pavement is considerably higher than the flexible pavement, the other costs show the flexible pavement being on the high side. The summary cost showed that the for the period of 40 years which was the period of study in this work, the life cycle cost (LCC) of rigid pavement is 8.52% lower than that of the flexible pavement. Considering economy, this savings in LCC makes it a more viable alternative to flexible pavement.

Keywords: Annual Average Daily Traffic (AADT)**,** Flexible pavement, Life cycle cost analysis (LCCA), Present net worth**,** Rigid pavement.

1.0 INTRODUCTION

Access in the present age is facilitated predominantly by the use of paved roads called pavement which are travel surfaces made durable and serviceable to withstand the axle load of traffic commuting on it (Mohood and Kadam, 2016). Pavements are generally classified into two: rigid pavement and flexible pavement (Loijos, 2011). Each of these types of pavements has their unique structure, characteristics and performance under traffic loads. Generally, the structure consists of superimposed layers of processed materials that come over the foundation of the pavement which is the subgrade and whose purpose is to transfer the axle load to the subgrade of the pavement (Matthew and Rao, 2007). Rigid pavement usually consists of three layers: the foundation (subgrade), subbase and the concrete slab while the flexible pavement consists of up to five layers: foundation (subgrade), subbase, base course, wearing course and surfacing.

In pavement design and construction, the ultimate aim is to ensure that the stresses coming on the pavement due to axle loads do not cause early failure of the pavement. In rigid pavement, loads are transmitted by slab action whereas in flexible pavement loads are transferred by grain to grain transfer through points of contact in the granular structure (Mohod and Kadam, 2016). Due to the fact that rigid pavement often behave like elastic plate resting on a vicious medium during load transfer, it often performs better than flexible pavement in supporting loads. In spite of its load bearing capacity and longevity under load, it also has other demerits such as initial high cost of construction. Hence, in order to make the most construction choice among these two pavement as a results of increasing need for roads, and increasing cost of construction materials, it is necessary to carry out a life cycle cost analysis (LCCA) for both pavements before choosing the one to construct.

1.1 Life Cycle Cost Analysis (LCCA)

LCCA is a method based on the principles of economic analysis that is used for the investigation of long-term economic viability of different investment options (Taylor et al, 2016). LCCA as a tool for economic analysis replaced benefits-cost analysis (BCA) which was used prior to the 1970s. LCCA was introduced in the 'Red Book' of American Association of State Highway and Transportation Officials (AASHTO) in 1960 and defined as suitable principle of economic analysis to assess the long-term economic efficiency between competing alternative investments options (FHWA, 1998). In short, it is a tool to assess the best value for investment outlays by enabling the government or the organization identify the lowest or the best (Shatnawi, 2012). According to Pasetto *et al*., (n.d.), LCCA considers the cost due to material production, construction, use (excluding emission and delay due to traffic, maintenance/rehabilitation and end-of-life (pavement demolition and material removal). LCCA has been widely used in economic analysis in wide range of industries that include aerospace, automotive, defence, transportation, energy and civil infrastructures (Rahman and Vanier, 2004).

1.2 Methods of Life Cycle Cost Analysis

Public infrastructure usually has a common lifecycle as illustrated in Figure 1.

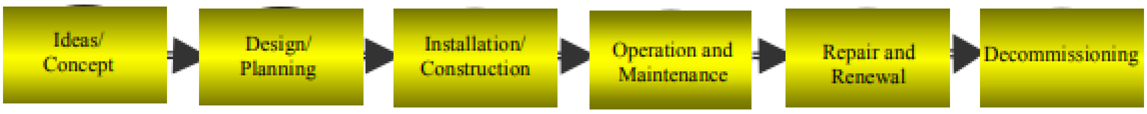

Figure 1: Lifecycle of public infrastructures (Rahman and Vanier, 2004)

These phases are the fundamentals on which LCCA analysis are based. According to Rahman and Vanier (2004) two common methods applicable in the LCCA analysis as described below:

a. Present value method or present net worth method: this method anticipates the effects of inflation on the present value (PV) of money and applies discount to the value over the service using a predicted rate.

Mathematically, $PV = FV \left[\frac{1}{(1+i)^n}\right]$ where, FV stands for future value; n = numbers of years between time of analysis and end of lifecycle while i = discount rate

b. Uniform annualized cost method: this method transforms present or future costs into uniform annual costs.

Mathematically, $A = PV \left\{\frac{[i\,(1+i)^n]}{[(1+i)^n - 1]}\right\}$ where A = end of year expenses, n = number of years between time of analysis and end of lifecycle while i = discount rate.

2.0 METHODOLOGY

In the research, asphalt pavement was used as the base case while a concrete pavement was used as the project case. One (1) km length and 7.3 m width of asphalt pavement and concrete pavement in Isieke, Ebonyi State were used in the research (See Figures 1 and 2).

Figure 2: Concrete Pavement
(Source: Author)

Figure 3: Asphaltic Pavement
(Source: Author)

LCCA applied here includes all costs that are involved in the manufacture and use of the product during its lifetime; it was decided to compare alternatives by using the Present worth Method. The components of LCCA were divided into two categories: agencies' costs and user costs. Agencies' costs include initial construction costs, rehabilitation and maintenance costs. Others costs, such as engineering design and land acquisition, were not considered. User costs such as vehicles operating costs, accident costs, discomfort costs etc. were considered equal for both pavement types. The only user costs considered were fuel consumption costs and street light requirement costs because other data for user costs are difficult to collect and quantify.

2.1 Data Collection

Traffic data for the analysis were collected from Ebonyi State Ministry of Works historic data manual. The initial traffic annual average daily traffic (AADT) data were taken from the manual for each specific road segment. Construction material, labour and machinery unit costs were taken from market values during the time around November 2021 when the research was carried out.

2.2 Analysis Period

The Federal Highway Administration (FHWA) of the United States of America (USA) recommends an analysis period of at least 35 years. Nigerian highway manual recommends a design service life of 20 years for flexible pavement and 40 years for rigid pavement. For this research, an analysis period of 40 years was chosen so that it would include full design period for concrete pavement, depending on the traffic level.

2.3 Discount Rate

Discount rate is used to convert the future benefits and costs of projects to present value. The higher the discount rate, the lower the net present worth of future costs will be. Thus, higher rates render initially expensive projects less profitable while lower rates render them more so. A discount rate of 10% was used in this study as recommended by Ministry of Finance for evaluation of project feasibilities in Ebonyi State.

2.4 Traffic Analysis and Pavement Design

Traffic analysis and forecast were conducted using the applicable trend of traffic projection practices for Nigeria. Two different traffic classes were selected for equivalent pavement design works for the two alternative pavement types. Assessment was made on the existing pavement design type selection practices and conditions in Nigeria in relation to international practices. Equivalent pavement design works were carried out for the two pavement alternatives using different traffic volumes based on the traffic analysis data.

2.5 Traffic Data Analysis

It is the part and parcel of the main research to integrate and make analysis of the collected and computed data to come in to picture of this research. Hence, the following core tasks were carried out in the data analysis scheme.

i. The Present net worth method was used for cost comparison and economic analysis purpose.
ii. Initial cost estimates were carried out for each alternative pavement structure based on current market rates of each specific cost components.
iii. Life cycle maintenance and rehabilitation costs were adopted from international practices with some modifications to be suited for our specific country.
iv. User benefits and sustainability issues were assessed in this study.
v. Cost comparison and economic analysis of concrete and asphalt pavement roads were conducted.

2.6 Life cycle cost of concrete and flexible pavement

The data presented here represent the life cycle cost of rigid and flexible pavement for 1km of such road at Isieke, Ebonyi state as obtained from the Ministry of Works, Ebonyi State. The data were sourced, processed and analysed with the outcome used as basis for evaluating the economic and life cycle cost of concrete over asphalt pavement.

Table 1a: Summary of Initial Construction Cost of 1 km Concrete Pavement at Isieke Ebonyi State

Item No	Description	Total Cost (₦)
1	Sub-grade level	3,240,000.00
2	Sub-base level	4,724,000.00
3	Concrete pavement	48,728,000.00
4	Texturing and curing	640,740.00
5	Joints	80, 480.00
6	Reinforcement bars	4, 458, 380.00
7	Separation membrane	480, 855.40
8	Subtotal	62, 353, 455.40
9	Contingency allowance	6, 235, 245.54
10	Total cost per km	68,587,700.94

(Source: Ministry of Works, Ebonyi State)

Table 1b: Summary of Initial Construction Cost of 1 km Flexible Pavement at Isieke Ebonyi State (Source: Ministry of Works, Ebonyi State)

Item No	Description	Total Cost (₦)
1	Preparation of Subrade	2,940,000.00
2	Preparation of Subbase	3,120,000.00
3	Preparation of Base Course	4,620,000.00
4	Application of Bituminous Emulsion	3,750,000.00
5	Laying of Hot Rolled Asphalt (HRA)	33,280,000.00
6	Subtotal	47,710,000.00
7	Contingency Allowance	4,771,000.00
8	Total cost per km	52,481,000

Table 2a: Agency (Authority) cost of concrete pavement

S/No	Activity	Cost (₦)	Remark
1	Construction Cost	68,587,700.94	---------
2	Routine Maintenance Cost	2,346,740.00	Every ten years interval
3	Periodic Maintenance Cost	845,750.75	Every fourteen years interval
4	Rehabilitation Cost	950,780.50	After forty years
5	Salvage Cost	475,390.25	-----------

(Source: Ministry of Works, Ebonyi State)

Table 2b: Agency (Authority) cost of flexible pavement

S/No	Activity	Cost (Naira)	Remark
1	Construction Cost	52,481,000.00	--------------
2	Routine Maintenance Cost	5,608,350.00	Twice every five years
3	Periodic Maintenance Cost	2,378,000.00	Once every eight years
4	Rehabilitation Cost	3,330,304.97	At every ten years interval.
5	Salvage Cost	1,665,152.485	--------------

(Source: Ministry of Works, Ebonyi State)

Table 3: Summary of life cycle cost for concrete and flexible pavement

Description	Concrete (₦)	Asphalt (₦)	Difference (₦)
Initial Construction Cost	68,587,700.94	52,481,000.00	16,106,700.94
Routine Maintenance Cost	3,060,148.96	29,253,153.6	26,193,004.64
Periodic Maintenance Cost	827,144.23	3,876,140.00	3,048,995.77
Rehabilitation Cost	309,954.443	4,342,717.68	4,032,763.237
Salvage Value	-154,977.22	-542,839.71	387,862.49
Fuel Cost	132,214,779.00	131,849,105.7	365,673.3
Time Saving Cost	-1,494,675.00	-597,870.00	896,805.00
Total Cost in 40 years	203,350,075.353	220,661,407.27	17,311,331.917

3.0 RESULT AND DISCUSSION

3.1 Initial Construction Cost

Figure 4 shows the bar chart representation of the data sourced on the initial construction cost of concrete and flexible pavement. The data indicate that after thorough adjustment using the current inflationary rate, the concrete pavement was relatively higher than the flexible pavement with a cost difference of more than ₦16.1 million. This can be attributed to the cost of materials that constitute concrete pavement. It can also be deduced from the chart that there is a relative economy in the initial construction cost of flexible pavement than that of concrete pavement. This result mirrors the work of Yonas *et al*., (2016).

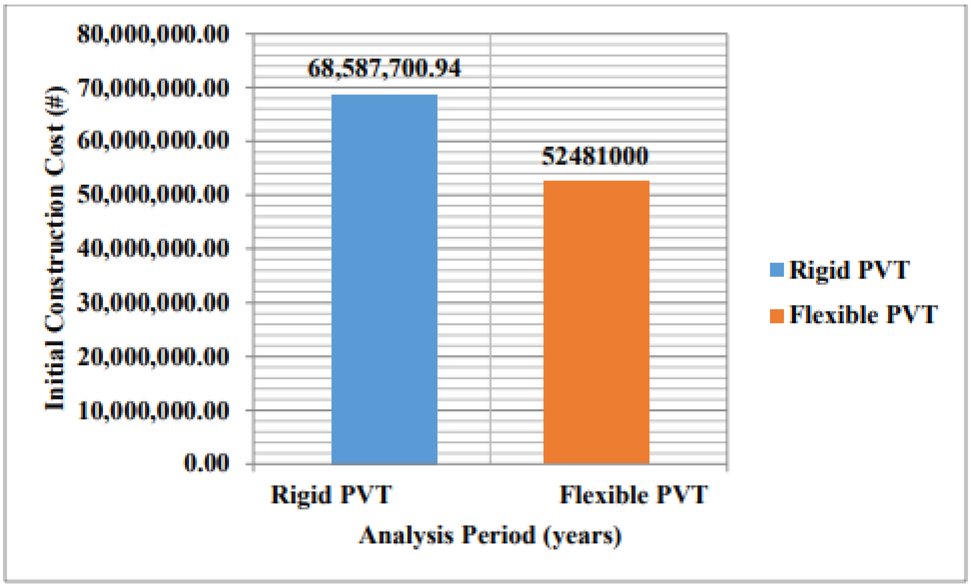

Figure 4: Chart showing the initial construction cost of concrete (rigid) and flexible pavement

3.2 Maintenance Cost

The life time maintenance of both concrete and flexible pavement was categorized into periodic and routine maintenance schedule. These are shown in Figures 5 and 6. The periodic and routine maintenance of concrete pavement was conducted at every 14 and 10 years interval while that of the flexible pavement was carried out every eight and five years respectively. This maintenance was conducted before and after the period of high rainfall intensity. Result obtained from the maintenance cost suggests that the periodic and routine maintenance cost of flexible pavement was considerably higher than that of concrete pavement. This is mainly due to the frequency at which this maintenance was conducted as flexible pavement are susceptible to distress even at the early stage of it service life. This result is in agreement with the works of Yonas *et al*., (2016) and Audu *et al*., (2015).

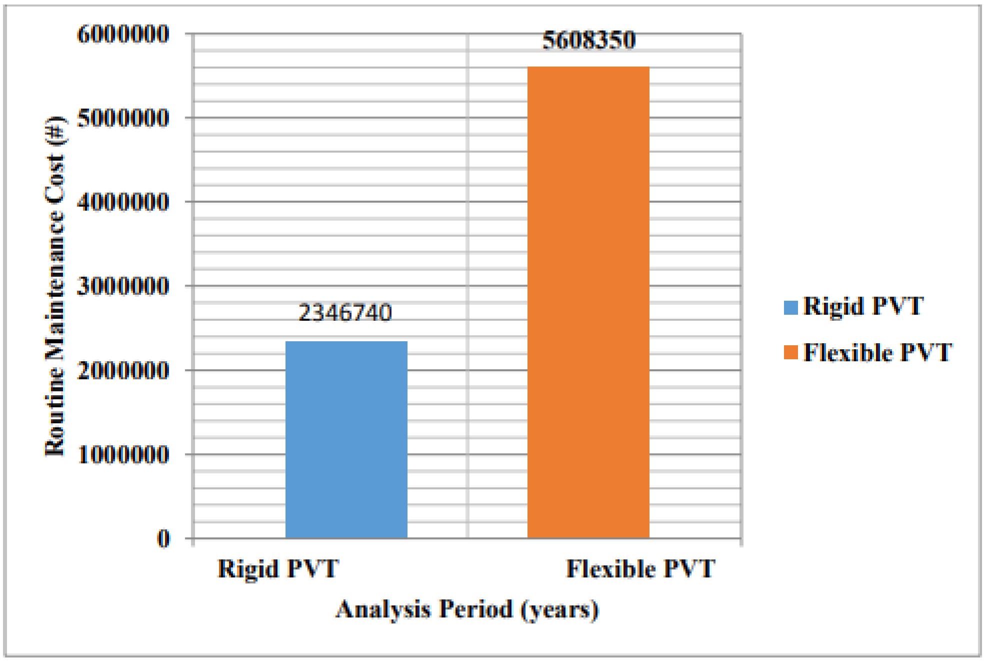

Figure 5: Chart showing the routine maintenance cost of concrete and flexible pavement

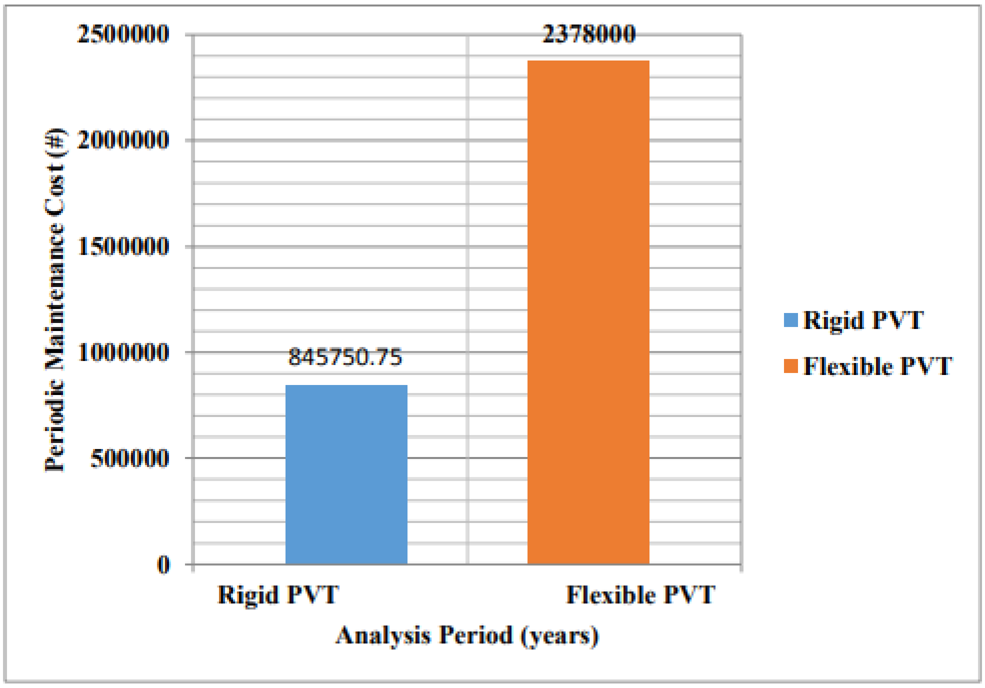

Figure 6: Chart showing the periodic maintenance cost of concrete and flexible pavement

3.3 Rehabilitation Cost

The rehabilitation cost is the cost of full depth repair in concrete pavement or removal and replacement of asphalt (resurfacing) in asphalt pavement (see Figure 7). According to the rehabilitation activities schedule specified in the work, the concrete pavement will be rehabilitated at the end of the analysis period (40 years) while the flexible pavement will be rehabilitated at every ten years intervals. Comparative deduction extracted from the rehabilitation cost of the competing alternatives suggests that the rehabilitation cost of flexible pavement was appreciably higher than that of concrete pavement with a substantial discrepancy in cost. This development can be attributed to the higher frequency in rehabilitation exercise for flexible pavement which cumulatively amount to higher cost. The results are also in agreement with the works of Yonas *et al*., (2016) and Audu *et al*., (2015).

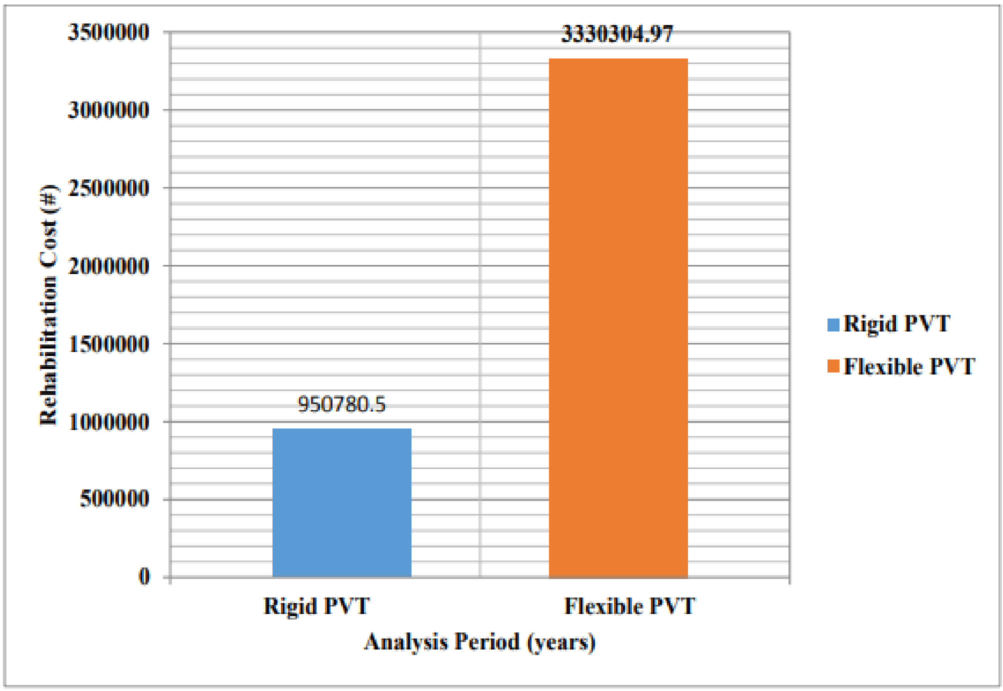

Figure 7: Chart showing the rehabilitation cost of concrete and flexible pavement

3.4 Salvage Cost

Salvage cost is the cost recovered from expenses incurred due to the rehabilitation of the competing alternatives (see Figure 8). It is expressed mathematically as rehabilitation cost multiplied by expected remaining life of the rehabilitation cost divided by total expected life of the rehabilitation cost. This cost is deducted from the total cost incurred due to the agency and user cost of both pavements. Result obtained indicates that the salvage cost of asphalt pavement was appreciably higher than that of concrete pavement implying higher recovery from rehabilitation cost for the concrete pavement option.

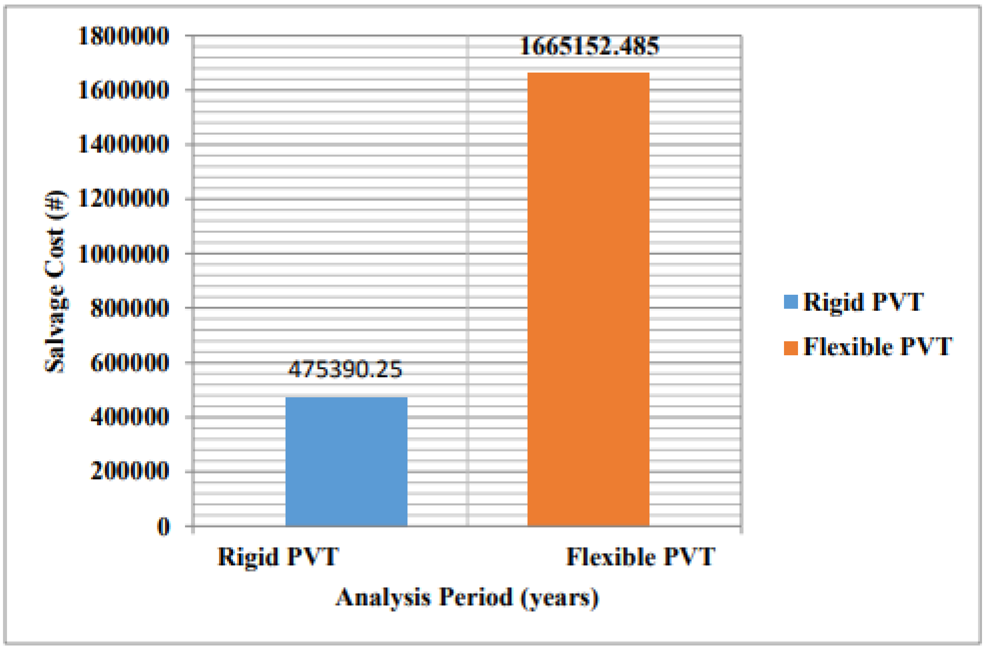

Figure 8: Chart showing the salvage cost of both concrete and flexible pavement

3.5 User Cost

The user cost comprises of both vehicle time saving and delay cost and also fuel cost for the two pavement options. The user cost was computed from the annual average daily traffic data collected from the Ministry of Works, Ebonyi state. Results obtained as shown in Figure 9 (a, b & c) indicate that the time saving and delay cost of concrete pavement were comparatively higher than that of flexible pavement while the fuel cost of flexible pavement is higher than that of concrete pavement. This result implies that there is higher energy consumption (fuel usage) and less delay cost in flexible pavement than that of concrete pavement.

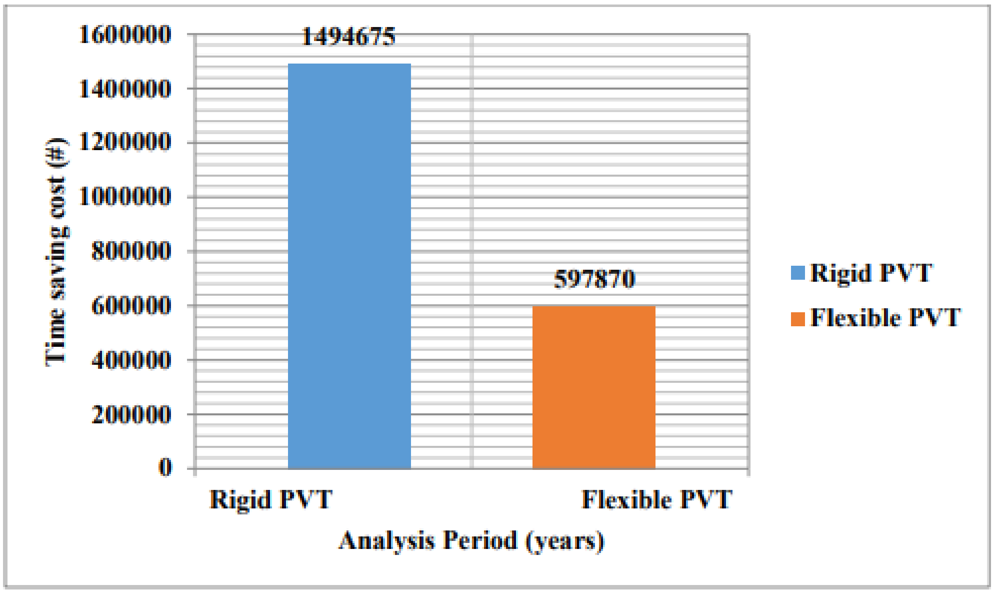

Figure 9a: Chart showing the time saving cost of concrete and flexible pavement

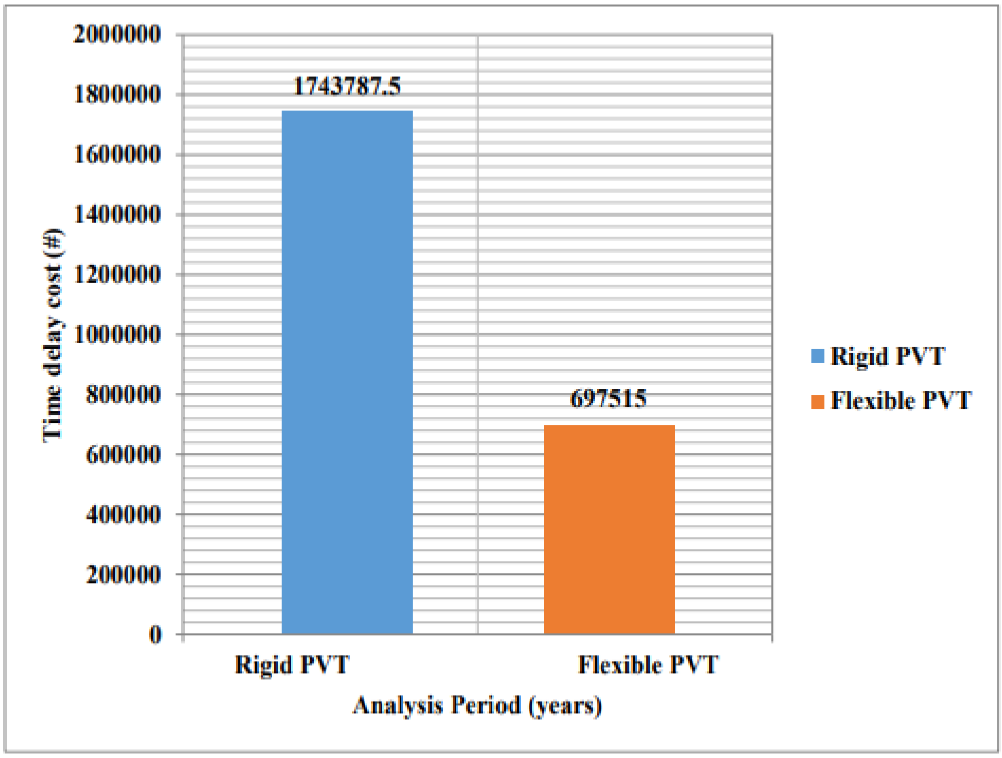

Figure 9b: Chart showing the time delay cost of both concrete and flexible pavement

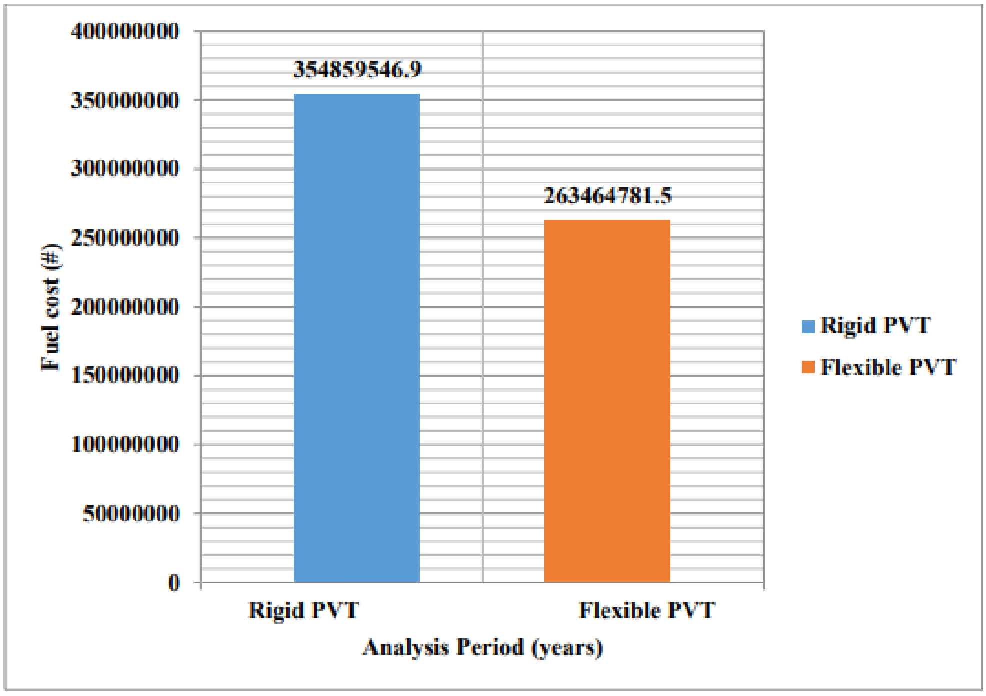

Figure 9c: Chart showing the fuel cost of both concrete and flexible pavement

3.6 Life Cycle Cost

The comparison of the economic worth of the competing alternatives was done from the findings obtained from the life cycle cost of both pavement types over an analysis period of 40 years. This result is employed as a supporting tool for investment decision on economic viable alternatives. Result obtained from the life cycle cost of both alternatives (Figure 10) indicate that the concrete pavement has longer service life than flexible pavement and for 1km (kilometer) road length, the life cycle cost of the concrete pavement is lower by a value of ₦17.3 million than that of the asphalt pavement over the 40 years analysis period. This result suggests that the concrete pavement is an economically viable alternative than the asphalt pavement due to it lower life cycle cost and longer service life. Life cycle cost comparison in currency suggests that 1 km (kilometer) road length in USD (United State Dollar) for both asphalt and concrete pavement requires 537267 and 495129 USD respectively (Figure 11). The summary cost correlates closely to that obtainable in the work of Yonas *et al*., (2016) and Audu *et al*., (2015).

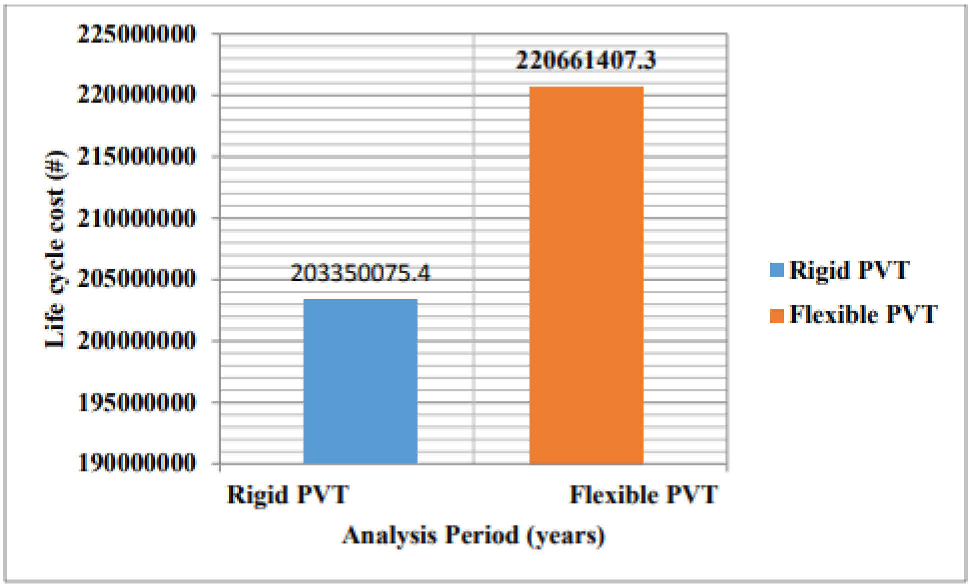

Figure 10: Chart showing the life cycle cost of both concrete and rigid pavement

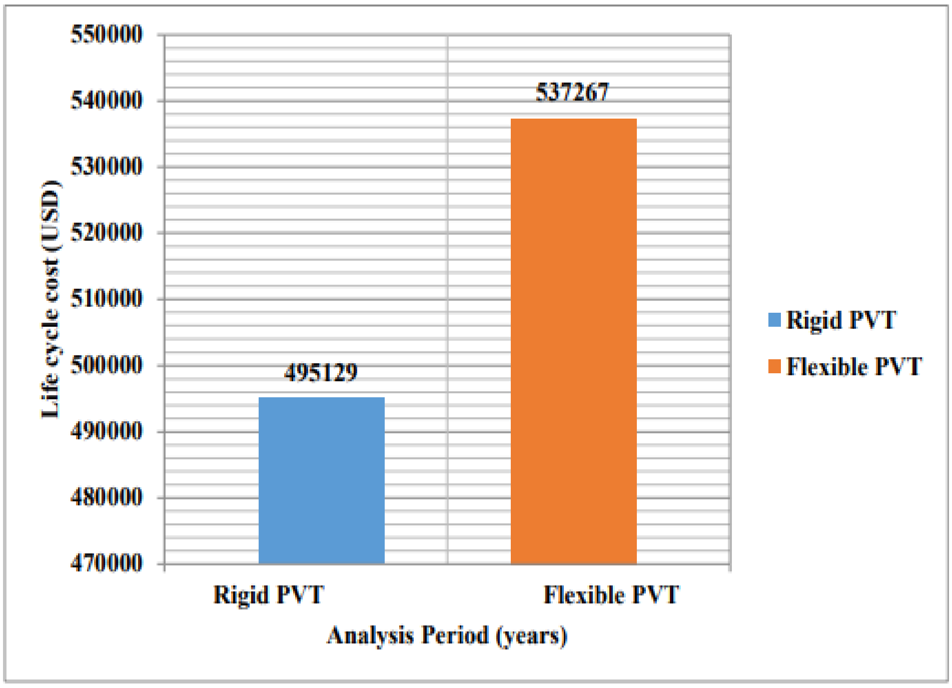

Figure 11: Chart showing the life cycle cost of both concrete and rigid pavement in USD

4.0 CONCLUSION AND RECOMMENDATION

The following conclusion and recommendations can be drawn from the work.

4.1 CONCLUSION

From the findings obtained the following conclusion can be drawn:

1. The data sourced on the initial construction cost of concrete and asphalt pavement, indicate that after thorough adjustment using the current inflationary rate, the concrete pavement was relatively higher than the flexible pavement with a cost difference of about 16.1 million.
2. This maintenance conducted before and after the period of high rainfall intensity suggests that the periodic and routine maintenance cost of asphalt pavement was considerably higher than that of concrete pavement. This is mainly due to the frequency at which this maintenance was conducted as asphalt pavement are susceptible to distress even at the early stage of it service life.
3. Comparative deduction extracted from the rehabilitation cost of the competing alternatives suggests that the rehabilitation cost of flexible pavement was appreciably higher than that of concrete pavement with a substantial discrepancy in cost.
4. The salvage cost derived from the rehabilitation cost indicates that the salvage cost of asphalt pavement was appreciably higher than that of concrete pavement implying higher recovery from rehabilitation cost.
5. Results obtained from the user cost indicate that the time saving and delay cost of concrete pavement were comparatively higher than that of asphalt pavement while the fuel cost of asphalt pavement is higher than that of concrete pavement.
6. Result obtained from the life cycle cost of both alternatives indicate that the concrete pavement has longer service life than asphalt pavement and for 1 km (kilometer) road length, the life cycle cost of the concrete pavement is lower by a value of about ₦17.3 million than that of the asphalt pavement over the 40 years analysis period.
7. The 1 km (kilometer) concrete pavement is therefore adjudged as an economically viable alternative over asphalt pavement due to its relatively lower life cycle cost and higher service life and as a result of that, it ought to be given due consideration by prospective investors.

4.2 Recommendations

The following recommendation can be made from the research findings obtained:

1. Concrete pavement is adjudged as a more economically feasible alternative over asphalt pavement due to its relatively lower life cycle cost and higher service life.
2. For widespread construction of concrete pavement over asphalt pavement, this study recommends that consulting and contracting firms must convince their client over the

economic and life cycle benefit of concrete pavement over flexible pavement.

3. Academic institutions must promote the economic and life cycle benefit of concrete pavement over asphalt pavement through robust tutelage. Professional engineering bodies such as Nigeria Society of Engineers (NSE), Nigeria Institution of Civil Engineers (NICE) etc. must raise awareness on the economic and serviceability values of concrete pavement over asphalt pavement.

Conflicts of Interest: There is no conflict of interest associated with this work.

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