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Life Cycle Cost Analysis of Flexible Pavement with Geosynthetic Materials and Conventional Flexible Pavement

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ABSTRACT: *In this study; it was aimed to determine the overall cost of flexible pavement with geosynthetic material and conventional flexible pavement and evaluating its cost effectiveness. It was conducted on the road construction project under Addis Ababa city road authority. The true cost (LCCA) was adopted as it has the means to fulfill these requirements. This was achieved by determining the agency, user and environmental costs for the selected road segment. In this regard information like traffic data and pavement data was collected from concerned agencies. Travel speed on the road segment, discount rate, design period, analysis period and base year were selected based on the experience of Addis Ababa City Road Authority. An Indian department of transportation vehicle class were adopted and Percentages of Truck distribution were determined by conducting a sample of field survey. Accordingly, observation of sample field survey revealed that out of 100 vehicles on the road segment under study 65% were passenger cars, 20% were single unit trucks and 15% were combination trucks. Estimation of costs was done specific to each treatment activities. Two alternative methodologies were provided: one was using a per-lane length approach which incorporates updated market prices and contract data from design document and this was adopted in determining agency cost associated with maintenance and rehabilitation. The other approach was one that builds the costs from a developed model. This approach was adopted to determine the cost of construction at initial stage of the project for both alternatives.*

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Key words: Agency Costs, Discount rate, Economic Indicators, Environmental cost, Net Present Value,User Cost

1. INTRODUCTION

Budget adjustment, escalating prices for maintaining public services, and freshly emerged public commitment toward scrutinizing government-related expenditures have centered the eye of all segments of our socioeconomic system on the importance of effective management of resources and assets[1, 2]. Besides, an asset base of three trillion dollars is affected by various man-made and natural dynamics, many of which are uncontrollable or uncertain[2].

Transportation sector have to practice decision-making and management that based on informed and conversant support[1, 2, 3, 4].

One of the most techniques given the prominent concern that provide such informed support is “Life Cycle Cost Analysis” (LCCA) provided that it is applied properly. It is an economic evaluation technique that has been particularly valuable when there is a need to compare competing alternatives for projects with entailing costs and benefits that stretch over long spans of time [1, 5].

LCCA is a way of comparing design alternativesassessing economic concern of item,or facility by considering significant costs over the design life, expressed in terms of equivalent currency units [3, 2].

LCCA is employed to objectively underpin selections regarding ways and materials that influence the service lifetime of the plus, and thus the life cycle prices [6].

It was determined that about 20% by weight of the subgrade soil once mixed into the mixture can considerably cut back the bearing capability of the bottom [7, 8, 9, 10].

Geosynthetics are employed to either extend the service lifetime of the pavement by avoiding intermixture of mixture and subgrade soil or to scale back the overall thickness of the pavement[7, 9].

Based on the price of geosynthetic materials relative to the extra thickness of the bottom layer the employment of geosynthetic materials attributed to the construction cost savings up to fifty fifth [10, 8]. However, the attribution of this fabric on behave of complete life cycle cost has been not clearly addressed yet. This was because of that most studies overlooked it.

This document proposed a comprehensive life-cycle cost analysis of flexible pavement with and without geosynthetic materials.

1.1 Objective of the study

1.1.1 General objective

The general objective of this study was to identify the economical pavement option by making life cycle cost comparisons and economic analysis of flexible pavement with and without geosynthetic materials in Addis Ababa.

1.1.2 Specific objectives

- To estimate agency, user and environmental costs for both flexible pavement with geosynthetic materials and without geosynthetic materials.
- To carry out economic evaluation of the flexible pavement with geosynthetic materials and without geosynthetic materials on selected segments of roads in Addis Ababa and to determine which pavement option is more economical & sustainable.
- To draw conclusions and recommend the best and most effective alternative pavement option from economic point of view.

1.3 Study Area

This analysis was conducted within the capital town of Ethiopia; Addis Ababa which was founded in 1886 having a population of 3.38 million consistent with the 2014 population census with annual rate of around 4%. Addis Ababa is located in geographic coordinates between 9° 0' 19.44" *N* and 38° 45' 48.99" E and elevation of 2405 m above mean sea level[11]. The place where geomembrane as separation function applied was on the road around Ethiopian National theater center near Gandhi memorial Hospital which is located in Kirkos sub-city in Addis Ababa city administration as shown in the figure below.

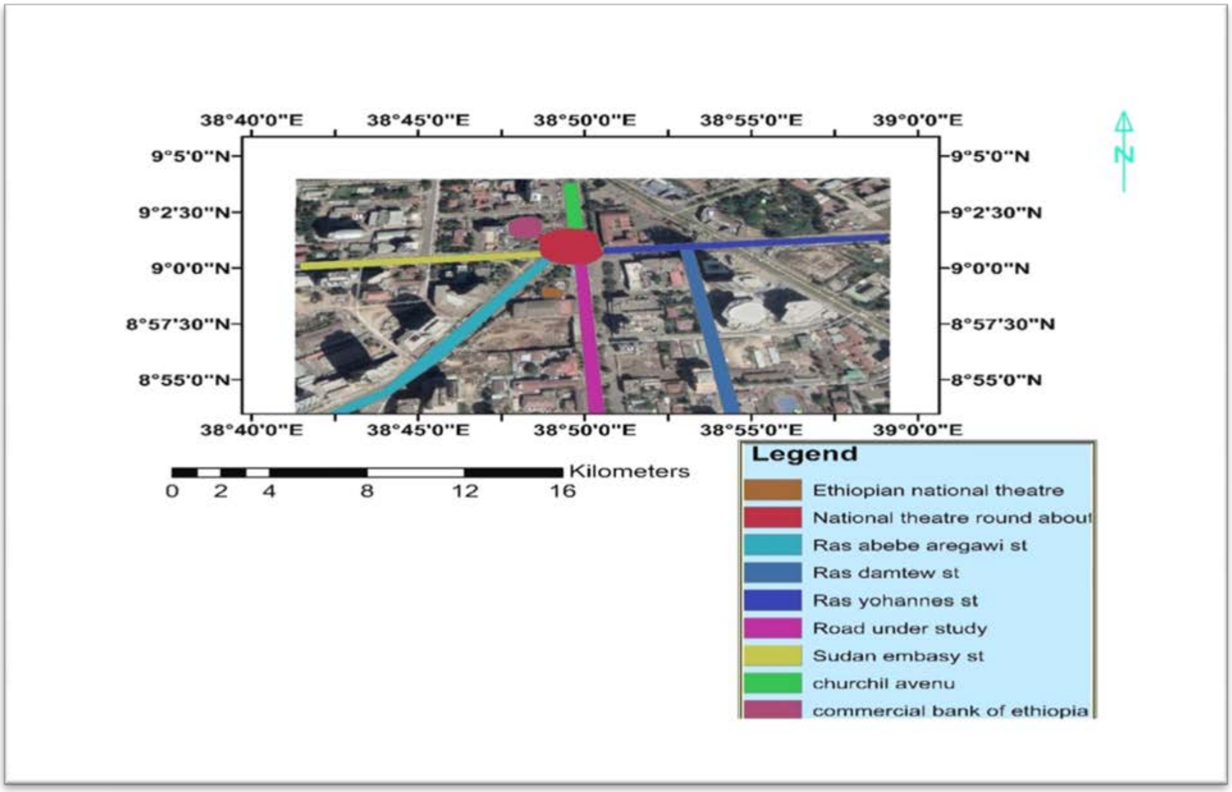

Figure 1: The study area

1.4 Study Variables

- **Dependent variables-**Life cycle cost of flexible pavement with and without geosynthetic materials.
- **Independent variables-**Initial construction cost, Maintenance/Rehabilitation cost, Vehicle operating cost, Travel time cost, Traffic volume/AADT, Design period, Analysis period, Road way capacity, Travel speed on the road segment.

1.5 Data, Sources of Data, Method of Data Gathering and Instruments.

The most important data for this study were design periods, analysis periods, pavement layers data, updated traffic data (AADT, traffic growth rate, percentage of vehicles, travel speed, travel speed on

Queue, market survey (unit rate), maintenance and rehabilitation strategies.Secondary data sources such as; pavement design documents, manuals, internet sites, reports, books, journals and other documents in governmental institutions were used.Methods used in the collection of data were document review, websites, field measurement, manual review and informal interview. internet and recommendation letter were instruments used collection of data.

2. Analysis, Result and Discussion

2.1. Selection of Analysis Period

As per the brief recommendation presented in chapter two of this document a period of 25 years was considered for the analysis assuming costs and benefits, discounted to present, become negligible.

2.2. Design Period

Some of the points to consider include Functional importance of the road, Traffic volume, Location and terrain of the project, Financial constraints, Difficulty in forecasting traffic. Bearing in mind the above considerations and Ethiopian road authority manual, 2013the design period of 20 years was chosen since the road under consideration is a link road as it connects different major roads.

2.3. Interest Rate (i)

In Ethiopia, interest rates decisions are taken by Monetary Committee of the National Bank of Ethiopia. The official rate is the bank's savings rate. The benchmark interest was 7% in the first quarter 2019, according to Trading Economics global macro models and analysts' expectations.

2.4. Inflation Rate (f)

Inflation Rate in Ethiopia is 19.10%at end of the first quarter of 2019, according to expectations of trading economics global macro models and analysts.

Assuming that goods have higher opportunity to continue as it is; Inflation rate f=19.10% and Inflation adjusted interest rate (I_f)is calculated to be (0.07+(0.07 * 0.191)+0.191) = 0.27437 = 27.44%

2.5. Selection of Discount Rate

The exact mathematical relationship between the discount rate, the interest rate, and the inflation rate presented by [5] was employed in selecting a discount rate for this particular case.

$d_r = \left[\frac{1+i}{1+f}\right] - 1$ Given; f = inflation rate in decimal = 0.191,i = interest rate in decimal = 0.070

d_r= [(1+ .07)/ (1+.191)] – 1 = - 0.102

A negative discount rate implies that current value of a future liability is higher these days than at the future date when that liability will have to be paid. The discount rate is a function of risk and return, there is no such thing as negative risk and it is illogical. Therefore, it was found good to use the maximum allowable value presented in [12]in such situation. Hence, a discount rate of 3.5% was adopted in this particular case.

2.6. Activity Parameters and Cost Schedules

As per the recommendation of ERA manual 2013, based on the number of ESALs, the following time-based pavement strategy was adopted[13].

Table 1: Activity Timing

Options	Remedial type	Activity Time
Flexible pavement with geosynthetic materials	Initial Construction	In 2019 G.C.
	Routine Maint.	Once Every Two Years
	Periodic Maint.	Once Every 4 Years
	Rehabilitation	Once Every 10 Years
	user cost	During Maint.& Rehabil
	salvage value	At 25th Year (2044 G.C.)
conventional pavement	Initial Construction	In 2019 G.C.
	Routine Maint.	once every year
	Periodic Maint.	Once Every Three Years
	Rehabilitation	Once Every 8 Years
	user cost	During Maint.& Rehabil.
	salvage value	At 25th Year (2044 G.C.)

2.7. Determinationof Agency Cost

Agency costs determined during this case were; theInitial construction cost, future rehabilitation cost, maintenance cost and salvage value. This cost is the arithmetic sum of initial construction cost and future maintenance/rehabilitation costs and its summary is going to be tabulated below. Analysis of this value reveals that saving of about 1.6 billion Ethiopian Birr per kilometer is possible when applying the geosynthetic material in road pavement project. This means that about 50.34% of project cost is wasted only for a reason of unwise decision making which based on the initial construction cost when selecting alternative options.

Table 2: Agency Cost Summary

№	Description	Cost (ETB)
1	Conventional Flexible Pavement	3,182,653,893
2	Flexible Pavement Geosynthetic Materials	1,580,443,895

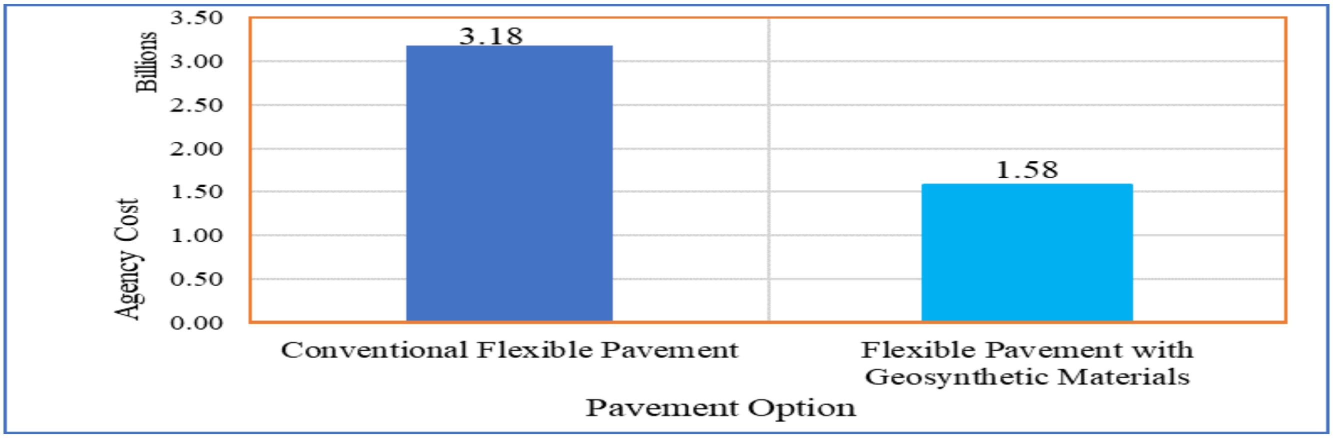

Figure 2: Agency Cost Summary Comparison

2.7.1. Initial Construction Cost

The initial construction cost was calculated bya developed model [14] and collected quantity data as well as the unit rate from recent market survey.

Therefore, Total initial project cost determined by the expression $45.7\ X_1 + 151.4X_2 + 195.24X_3$ was adopted where; X_1 = Earthwork; cut, fill, and topping quantities (m3)

X_2 = Sub base, Base and capping layer quantity (m3), X_3 = Asphalt quantity (m2)

The results obtained from this model reveal that only 64500 Ethiopian Birr per kilometer is saved from initial construction cost when avoiding the geosynthetic material from road pavement. As shown in the table below it is only 1.5% (64500 Birr) of cost saving that leads agencies to wrong direction and makes decision making subjective even by using as historical precedent.

Table3:Initial Construction Cost Summary

№	Description	Cost (ETB)
1	Conventional Flexible Pavement	4,248,120
2	Flexible Pavement with Geosynthetic Materials	4,312,620

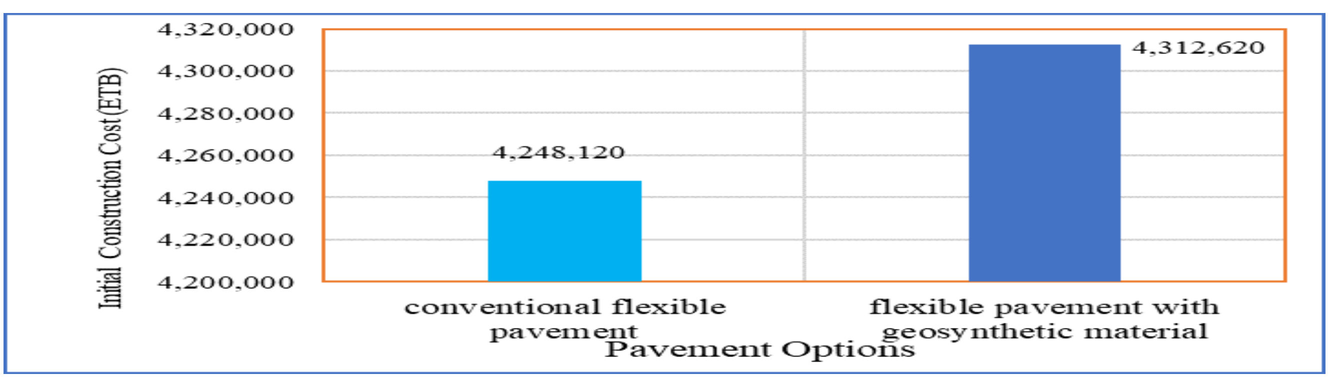

Figure 3: Initial Construction Cost Summary Comparison.

2.7.2. Maintenance and rehabilitation Cost

Roadway Data:

Mainline: Length = 1000m, Width = 10.5m, inner shoulder = 1.22m, outside shoulder = 2.44m

Total width = 10.5+1.22+2.44 = 14.16m

Total Area = Total width * Mainline Length = 14.16 m * 1000 m = 14160 m^2

Using the total area calculated above, the entire lane quantities during each maintenance activities were determined and costs associated with routine maintenance, periodic maintenance and rehabilitation were determined. The results tabulated in the following table reveal that an agency can save a maintenance cost associated with routine and periodic maintenance when avoid the geosynthetic material in the selected analysis period. That is, about 258,836,903 Ethiopian Birr is saved from routine and periodic maintenance when avoid the geosynthetic material. But trying to avoid geosynthetic material to save this money can toss an agency to a loss of 1,339,577,146 Ethiopian Birr. This is because of the fact that adopting geosynthetic material in road pavement can save a total of 1,339,577,146 Ethiopian Birr per kilometer during rehabilitation. In general, an agency can save a total money of 1,080,740,241 Ethiopian Birr per kilometer during maintenance activities when adopting geosynthetic materials.

Table4: Maintenance Cost Summary

Description		Cost (ETB)	Total (ETB)
Conventional Flexible Pav't	Routine Maintenance	662050152	3,178,405,773
	Periodic Maintenance	441293636	
	Rehabilitation	2075061985	
Flexible Pav't with Geosynthetic	Routine Maintenance	779,553,308	2,097,665,532
	Periodic Maintenance	582627383	
	Rehabilitation	735484839	

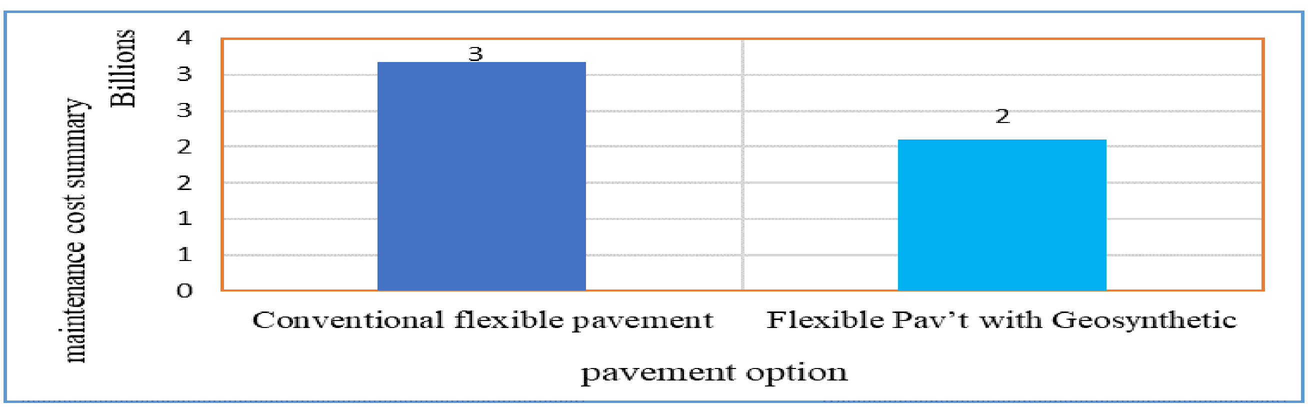

Figure 4: maintenance cost summary

2.7.3. Salvage values

Considering the last rehabilitation cost, expected remaining time of last rehabilitation and total expected life of last rehabilitation salvage value of each alternative was calculated and summarized in the following table. When agencies adopt the geosynthetic material in pavement, there will be a gain of some re-usable materials that can become increasingly important in the future at the end of the design period. Quantifying the value of these materials when reprocessed and to be used in a new pavement results in 222,755,902 and 337,836,878 Ethiopian Birr respectively for conventional pavement and the one that incorporates the geosynthetic material. This results in a benefit of 115,080,975 Ethiopian Birr per kilometer when incorporating the geosynthetic material in pavement option.

Table5: salvage value

Description	Cost (ETB)
ConventionalFlexible Pav't	222,755,902.90
Flexible Pav't with Geosynthetic	337,836,878.78

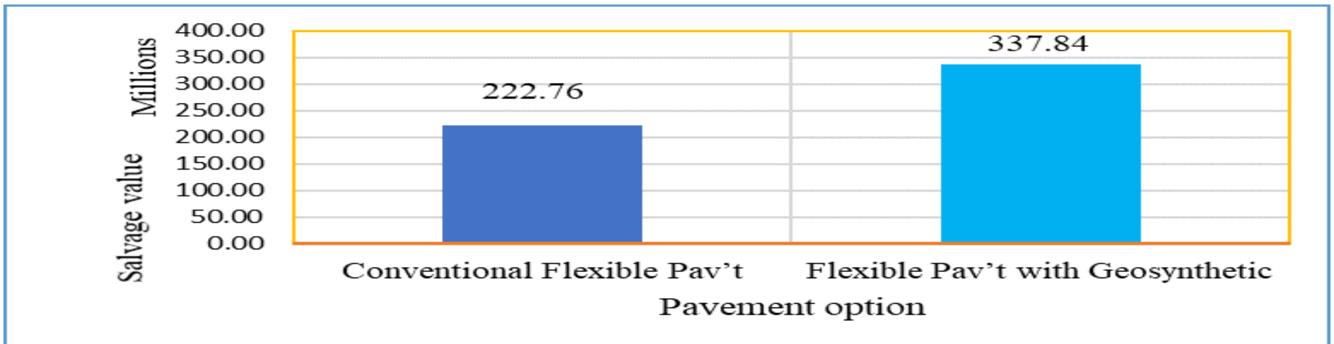

Figure 5: salvage value

2.8. User Cost

Summarized in the following table was all user costs and their distribution during each maintenance activities. They were determined to be 14.18 and 4.12 billion Ethiopian Birr respectively for conventional flexible pavement and flexible pavement with geosynthetic materials. The result reveals that about 70.9% of road user cost can be avoided if agencies adopt the practice of using the geosynthetic materials in road pavement provided that repetitive maintenance can be eliminated.

Table6: User Cost Summary

Description		Cost (mil ETB/day)	Days WZ in place	Total cost (mil.)	Total Cost (Bil.)
Conventional Flexible Pavement	RM	22.02	10	220.2	14.18
	PM	11.25	60	675.09	
	R	110.69	120	13,283	
Flexible Pav't with Geosynthetic Material	RM	31.21	10	312.1	4.12
	PM	59.71	60	3,582.7	
	R	1.88	120	225.34	
RM, PM = Routine & periodic maintenance respectively. R= Rehabilitation					

2.8.1. Vehicle Operating Cost

Examination of the following table immediately reveals that the higher user costs are not the problem of life cycle cost analysis rather a traffic control problem. Further inspection reveals that more than 52 percent of user cost resulted from vehicle operating cost and less than 48 percent from travel delay cost.

Table7: Work Zone Vehicle Operating Cost Summary

№	Description	Activity	VOC Bil.(ETB)	Total VOC (Bil.)
1	Conventional Flexible Pavement	RM	0.162	**7.39**
		PM	0.558	
		R	6.66	
2	Flexible Pavement with Geosynthetic Materials	RM	0.243	**3.71**
		PM	3.34	
		R	0.129	
RM, PM = Routine & periodic maintenance respectively R= Rehabilitation				

2.8.2. Travel Delay Costs (TDC)

Four types of delay costs were considered in quantifying travel delays for work-zone operations. These were, Speed Change Delay Costs (TDC), Reduced Speed Delay Costs (TDC), Stopping Delay Costs (TDC), and Queue Reduced Speed Delay Costs (TDC).Summarized in the following table were a travel delay user costs and their distribution during each maintenance activities. Their totals were determined to be 6,793,689,443 and 407,852,679 Ethiopian Birr respectively for conventional flexible pavement and flexible pavement with geosynthetic materials. The result reveals that travel delay cost in conventional flexible pavement is 93% more than that in flexible pavement with geosynthetic material. Therefore about 93% of travel delay cost can be avoided if agencies adopt the practice of using the geosynthetic materials in road pavement provided that repetitive maintenance can be eliminated.

Table8: Work Zone Travel Delay Cost Summary

Description	Activity	Travel Delay Cost	Total TDC (ETB)
Conventional Flexible Pavement	Routine mainte.	58,576,715	6,793,689,443
	Periodic mainte.	116,964,161	
	Rehabilitation	6,618,148,567	
Flexible Pavement with Geosynthetic Material	Routine mainte.	69536246	407,852,679
	Periodic mainte.	242065735	
	Rehabilitation	96,250,697	

2.9. Net present value calculation

The following equation was used in this particular case to determine the net present value of each alternatives.

$$NPV = IC + \sum_{k}^{N} \mathbf{MC}\left[\frac{1}{1+d_r}\right]^{nk} + \sum_{k}^{N} \mathbf{RC}\left[\frac{1}{1+d_r}\right]^{nk} + \sum_{k}^{N} \mathbf{UC}\left[\frac{1}{1+d_r}\right]^{nk} - \mathbf{SV}\left[\frac{1}{1+d_r}\right]^{n}$$

Where;

IC = initial construction cost; MC= maintenance cost; RC= rehabilitation cost; UC= user cost; SV = salvage value; n= analysis period in years; n_k = number of years from the initial construction to the k^{th} expenditure; N= number of future costs incurred over the analysis period; d_r = discount rate.

Examination of table 10 and 11 below reveals that the discount amount of user cost to base year (2019) takes a large percentage from all other cost components. In addition, it conveys a message that how a huge money that agencies are excluding by relying on an initial construction cost only.

Table9: Discounted Sum for Conventional Pavement in the Analysis Period

Cost Components	IC Cost (ETB)	Maintenance Cost (ETB)	Rehabilitation Cost (ETB)	User Cost (ETB)	Salvage Value (ETB)
Discounted Sum	4,248,120.00	571,024,920	956,172,516	3,609,374,568	94,258,489

Table10: Discounted Sum for Conventional Pavement in the Analysis Period

Cost Components	IC Cost (ETB)	Maintenance Cost (ETB)	Rehabilitation Cost (ETB)	User Cost (ETB)	Salvage Value (ETB)
Discounted Sum	4,312,620	934,202,945	381,971,780	1,937,802,270	142,954,658

Using the values in above tables, net present values of each alternative were determined and summarized in the following table considering salvage value as a negative cost.

NPV for conventional FP = 4,248,120.00 + 571024920.4 + 956172516.1 + 3609374568- 94258489.65 = 5,042,313,514.84

NPV of FP with geosynthetic materials = 4,312,620 +934,202,945 + 381,971,780+ 1,937,802,270- 142,954,658 = 3,111,022,338.85 ETB

Table11 : Net Present Values of the Two Alternatives.

Serial №	Alternatives	Net Present Value (NPV)
1	Conventional Flexible Pavement	5,042,313,514.84 ETB
2	Flexible Pavement with Geosynthetic Materials	3,111,022,338.85 ETB

The core purpose of the life cycle cost analysis to compare the agency and user cots to draw a wise decision on investment selection. The following table summarizes the Discounted cost components of the two alternatives. The result of analysis reveals that the both agency and user cost of conventional flexible pavement greater than that of flexible pavement with geosynthetic material.

Table12: Discounted Cost Components

Option	conventional flexible pavement		flexible pavement with geosynthetic materials	
Cost component	Agency Cost (ETB)	User Cost (ETB)	Agency Cost (ETB)	User Cost (ETB)
NPV	1,437,187,066.81	3,609,374,568.03	1,177,532,688.72	1,937,802,270.13

3. CONCLUSION AND RECOMMENDATION FOR FURTHER STUDIES

3.1. Conclusion

Presented in this paper was a brief over view of sustainable and economical pavement option by making life cycle cost comparisons and economic evaluation of flexible pavement with and without geosynthetic materials in Addis Ababa.

Estimation of construction, maintenance and rehabilitation costs was done specific to each construction, maintenance and rehabilitation treatment. Two alternative methodologies were providedindeterminingagency cost associated with maintenance and rehabilitation fixing the costs to 2019 dollars and the initial construction cost of both alternatives. The Agency costs determined for conventional flexible pavement and that with geosynthetic material was to be 3,182,653,893 and 1,580,443,895 ETB respectively. This conveys a message that using geosynthetic material in flexible pavement can reduce an Agency cost by 50.34 % which can outweigh the applicability of using lower initial construction cost as standard. The seven user cost components associated to work zone operations were determined.Only work zone user costs were given prominent coverage in this paper and costs associated with noise, and pollution were not be a formidable concern as they are not expected to vary significantly by LCCA alternative. Accordingly, Inspection of analysis part in this paper reveals that, user cost was determined to be 14,178,855,923 & 4,120,182,985 ETB for conventional and flexible pavement with geosynthetic materials respectively. This implies that about 70.9% of user cost can be avoided when using a geosynthetic materials.

Economic evaluation of flexible pavement with geosynthetic materials and conventional one on selected road segment was carried out using the NPV as economic indicator. As such incorporating geosynthetic material in pavement was found more economical and most effective alternative pavement option.

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Finally; Overlooking life cycle cost analysis or wasting a budget on trying to avoiding it leads to managing asset cost reactively adopting the minimum construction cost as standard. Regardless to the policy of avoiding future economic surprise, decisions made in any area of construction industry has been failed to avoid it. To do right from the beginning, decision makers need to consider the comprehensive LCCA of pavements options including initial construction, future maintenance, rehabilitation, environmental, and user costs.

3.2. Recommendationfor Further Studies

1. Due to the absence of some important data in Ethiopia, data such as directional factor was adopted from abroad in this study. This may have a significant effect on queue length calculation. Therefore, more research needs to be done using an hour-by-hour roadway capacity, directional factor consistent to Ethiopia and traffic demand in Addis Ababa.
2. A formidable concern for detour was not given in this study. When work zone is in place, there is additional mileage that users travel, either voluntarily or involuntarily. This additional mileage is described by circuity. Therefore, circuity costs should be determined in future study If traffic is forced to detour (formal detour is established).

4. Acknowledgement

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References

[1] Dr. Kaan Ozbay, Dr. Neville A. Parker, Dima Jawad,, "Guidelines for life cycle cost analysis," FHWA, USDOT, Washington, D.C., 2003.

[2] FHWA, ""Economic Analysis Primer, Office of Asset Management"," FHWA, US departement of transportation, washington, DC, August, 2003.

[3] A. Zoeteman, ""Life cycle cost analysis for managing rail infrastructure"," EJTIR, pp. 391-413, 2001.

[4] K. L. Wubbenhorst, ""Life cycle costing for construction projects"," ScienceDirect, vol. 19, no. 4, pp. 87-97, August, 1986.

[5] Demos, George Paul, ""LCCA and Dr of Pavements for Colorado DOT"," US Department of Transportation, Federal Highway Administration, washington D.C., 2006.

[6] Ugwu, O.O; Et-al, "Durability assessment and life cycle costing framework," automation in construction, vol. 14, no. 5, pp. 611-632, actober, 2005.

[7] Pokharel, Snat Kumar, ""Exeprememental Study on Geocell-Reinforced Bases Under Static and

Dynamic Loading"," university of kansas, Kansas, 1997.

[8] M. Tencate, ""Application of the Groud-Han Design Method for Geosynthetic Reinforced Unpaved Roads"," 2014.

[9] E. yoder and M. witczcak, principle of pavement design, john wiley and sons, 1975.

[10] D.K. Kipto & D. Kalumba, ""Investigation of Dynamic and Static Loading Effect to Geosynthetic Reinforced Pavements Overlaying a Soft Subgrade"," UCT, cape town, 2016.

[11] "("Addis Ababa," n.d.)".

[12] Michael R.Smith, JamesWalls III, "LCCA in Pavement Design , Pavement Division Interim Technical Bulletin," Federal Highway Administration, US DOT, Washington, D.C., 1998.

[13] E. R. A. ERA, "Road Maintenance work technical Specification," Ethiopian road authority, Addis Ababa, 2013.

[14] S. Alemayehu, "Test of Regression Models to Estimate project costs," Addis Ababa University, Addis Ababa, 2014.

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