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A LIFE CYCLE COST ANALYSIS OVER ALTERNATIVE MAINTENANCE INTERVENTIONS ON DOUBLE BITUMINOUS SURFACE TREATMENT ROAD SEGMENTS

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Abstract

This research aims to conduct a life-cycle cost analysis of different maintenance activities over DBST road segments undertaken by Ethiopian Roads Authority (ERA) Sodo Road Network and Safety Management Branch Directorate (RNSMBD) by considering the Maintenance District as a case study. Quantitative and qualitative data were collected to meet the study's objectives Road condition survey data were collected by conducting a road condition survey with the help of Sodo RNSMBD staff. After collecting the necessary data, all possible input data was arranged to feed HDM-4. The analysis used the Highway Development and Management Model (HDM-4) tool and the life-cycle cost analysis (LCCA) to determine the economic viability of different road maintenance intervention alternatives. The analysis was carried out by considering doing nothing, doing routine work, and doing periodic work scenarios. The economic indicator used for this study was Net Present Value (NPV). The results of this study indicate that most of the road conditions of the selected DBST road segments fall under poor conditions. The economic analysis results also depicted that implementing a preventive maintenance strategy on DBST road segments can significantly decrease the life cycle cost in terms of costs incurred by both the road agency and users under Sodo RNSMBD. The study concluded that road agencies should embrace the practices of applying more preventive activities at early signs of pavement deterioration to preserve of road assets.

Keywords: ***DBST, HDM-4, Life Cycle Cost Analysis, Road maintenance, ERA***

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I. INTRODUCTION

A. Background of the Study

The road is a fundamental infrastructure for the economic development of a country. Ethiopia is one of the developing nations that requires the expansion and preservation of road networks. According to the Ethiopian Roads Authority's 23-year assessment report of October 2021, the country's road network has increased from 26,550 km in 1997 to 144,027 km in 2020 (an average increase of 19.23 percent each year). As a result, the road density per 1000 sq. km has increased from 24.1 km in 1997 to 130.9 km in 2020. Also, substantial improvements are registered in the condition of the country's road network. The proportion of road networks in acceptable condition (good and fair) increased from 22% in 1997 to 58.6% in 2020. The average road density in Ethiopia is 130.9 km per 1000 square kilometers [1]. This is far lower than the average road density of 260 km per 1000 square kilometers for middle-income countries.

LCCA of road projects has been the subject of extensive research and study in developed countries. Nonetheless, in Ethiopia, the practice of using LCCA as the main component in decision-making on road project investment has received little attention. Many types of research have been conducted to develop methods and tools to assess and analyze the total cost of road projects throughout their life cycle. The Life Cycle Cost Analysis (LCCA) approach has been used to assess the viability of road projects throughout their life cycle and a set of Practice Standards and Interim Technical Reports have been produced to provide a common framework [2].

Fair distribution of the road network among regions is the result of two key factors: these are the ability of regions to allocate their own resources efficiently towards road network development which demonstrates initiative and the capacity for self-reliant growth and Equitable Regional Development Policy of Federal Governments. The latter is crucial in addressing disparities by constructing "missing links" and other critical roads in less developed or under-served regions [1]. Therefore, the fair distribution of the road network reflects a collaborative effort where regional commitment and federal support converge to promote inclusive growth and equitable development.

The major road asset management challenges in Ethiopia currently are rising costs of construction materials, lack of skilled manpower and machinery, and lack of integrated maintenance strategies.

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Annually, road authorities spend a significant amount of expense on maintenance and rehabilitation of road networks; yet, most of these efforts are wasted due to a lack of appropriate maintenance strategies [2]. Hence, this study will attempt to assess the problems associated with the cost-effectiveness of pavement maintenance strategies by conducting a life cycle cost analysis over different road maintenance interventions undertaken by Sodo RNSMBD which consists of long stretches of DBST road networks [3]. Therefore, the main aim of this research is to indicate a sustainable, cost-effective, and appropriate maintenance strategy to reduce the life cycle cost of double-bituminous surface treatment road networks by using the HDM-4 analysis tool.

II. RESEARCH METHODS

A. Research Design

Research design encompasses the general guiding principles for conducting a study and the selection of a specific design depending on the purpose of the study under investigation [3]. This study adopted a mixed-methods approach, integrating both quantitative and qualitative data collection and analysis to address the research questions. To achieve the objective of this study, a case study was conducted by focusing on selected DBST road networks currently administered under Sodo RNSMBD of ERA. The case study design is suitable for a study that involves a thorough investigation of a specific case by collecting qualitative, quantitative, or mixed-methods data on the subject under investigation [4].

There are over 600 Km of double bituminous surface treatment road networks under Sodo RNSMBD's supervision. Out of this DBST road network, five road segments, which have an overall length of 211 km, were selected for this specific research study based on the availability of data, their functional classification, and the level of deterioration. These are presented in Table I that are in terms of name, length, and surface types, and they are stipulated as follows:

Table I: Sample DBST road segments selected for this study

Id No.	Section	Road Segment	Length (Km)	Wearing Course	Climate zone
1	Sodo	Areka – Sodo	36	DBST	Sub-Humid Tropical
2	Konso	Arba Minch - Wezeqa	33	DBST	Sub-Tropical Hot
3	Konso	Gato – Konso	27	DBST	Sub-Tropical Hot

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4	Konso	Konso – Woito	73	DBST	Tropical Arid Hot
5	Turmi	Woito - Keyafer	42	DBST	Tropical Arid Hot

B. Data Collection

For this research study, existing documents were thoroughly reviewed by accessing Sodo RNSMBD. These include road maintenance-related manuals, technical specifications, traffic count reports, condition surveys, and bills of quantities by considering the period of consecutive 5 years starting from 2016/2017 to 2020/2021. In addition to this, the observational data collection method was also applied by conducting road condition surveys jointly with Sodo RNSMBD engineers over the selected road segments in February 2021 [3].

The data collection consisted of three main stages; the very first stage was planning over the desk and identifying the necessary input data that could be used in the analysis of LCC. The second stage was communicating with Sodo RNSMBD road network administration team staff and scheduling to gather the needed data of the selected DBST road segments under Sodo RNSMBD that could be an input for the HDM-4 analysis tool. The last stage was collecting the raw data on road maintenance history, different maintenance manuals and specifications of road maintenance, annual performance reports, traffic volume AADT, and budget year summary reports. Afterward, condition surveys and road inventory works were conducted over the selected DBST road segments.

C. Required Input Data for HDM-4 Analysis Tool

In this study, the types of data that are required for project analysis are base year traffic data, existing road inventory data and current road condition data, vehicle fleet characteristics data, vehicle operating costs, and road maintenance work costs.

The principal outputs of the economic evaluation on the HDM-4 analysis tool are the economic indicators in financial feasibility which are Net Present Value (NPV), Economic Internal Rate of Return (EIRR), and Net Present Value per Cost Ratio (NPV/C) [5].

A project's minimum economic viability requirement is a positive net present value (NPV), indicating that total discounted cash inflows exceed total discounted cash outflows over the project's lifetime. This is coupled with an economic internal rate of return (EIRR) that represents the discount rate at which the net present value of costs equals the net present value of benefits. A

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positive NPV implies the project is expected to generate a surplus of value above the costs of investment and operation, aligning with the goal of value creation while a negative NPV would suggest that the project destroys value, making it economically unviable. Similarly, if the EIRR is higher than the discount rate, it demonstrates that the project provides returns greater than the opportunity cost of capital, which is the benchmark rate of return expected from alternative investments, and an EIRR lower than the discount rate indicates that the project does not compensate for the risk or cost of funds, deeming it not viable.

D Determination of Optimum Maintenance Standards

As the term maintenance standard indicates, it is the standard that fixes minimal requirements to a given maintenance operation and output. It comprises maintenance intervention type, maintenance activity type, material specification, economic and financial costs including preparatory works, and effects.

Generally, routine and periodic maintenance treatments (including preventive maintenance and rehabilitation) are thought to achieve maintenance standards and strategies at the network level. It means a road network needs to be maintained when it is good to fair, as it provides the best economic return on investment [6].

This particular study adopted the current maintenance standards and technical specifications used to order maintenance interventions over the road networks in the Sodo road maintenance district of ERA. Hence all the road segments this study focuses on are DBST roads. The maintenance standards also comply with DBST road maintenance techniques.

DBST is a term used to describe a common type of pavement construction that includes two applications asphalt binder and crushed aggregate. The asphalt binder material is applied by an asphalt spreader immediately followed by the application of crushed aggregate and finished by rolling. The process is repeated for the second application of asphalt binder and crushed aggregate. The first application of aggregate is coarser than the aggregate used in the second application and normally determines the pavement thickness. The thickness of DBST can vary from 19mm to 30mm depending on the thickness of the coarser aggregate applied.

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E. Recommended HDM-4 Default Values

The HDM-4 model recommends default values for the different road characteristics. The recommended HDM-4 default values for roughness are given in Table II.

F. Alternative Maintenance Interventions for HDM-4 Analysis

For this study, three maintenance alternatives were identified and included in the comparison of LCCA. These are: - 'Do nothing', 'Do Routine works or preventive maintenance', and 'Do Periodic works or corrective maintenance' [1].

Table II: HDM-4 Default values for roughness [7]

Paved Roads Roughness (IRI, m/Km)			
Road Condition	Primary Roads	Secondary Roads	Tertiary Roads
Good	2	3	4
Fair	4	5	6
Poor	6	7	8
Bad	8	9	10

The recommended HDM-4 default values for road geometry parameters are given in Table III below.

Table III: HDM-4 default values for road geometry [7]

Road Geometry	Rise & Fall (m/Km)	No. of Rise & Fall	Horizontal Curvature (deg/Km)	Super elevation (%)	Speed limit (Km/hr)	Roadside Friction
Straight and level	1	1	3	2	110	1.00
Mostly Straight and gently undulating	10	2	15	2.5	100	1.00
Bendy and generally level	3	2	50	2.5	100	1.00
Bendy and gently undulating	15	2	75	3	80	1.00
Bendy and severely undulating	25	3	150	5	70	1.00
winding and gently undulating	20	3	300	5	60	1.00
winding and severely undulating	40	4	500	7	50	1.00

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G. Method of Data Analysis

In this particular study, the fundamental unit of analysis in HDM-4 was the homogeneous road section. Ethiopian Roads Authority Road maintenance specifications and work items were assigned to the selected road sections for analysis. Different vehicle types were used to determine traffic volume, which was specified in terms of annual average daily traffic (AADT) [8].

In this study, the researcher considered AADT for only motorized traffic which means (motorcycles, cars, buses, trucks, etc.) on the HDM-4 analysis tool. The HDM-4 analytical framework is based on the concept of pavement life-cycle analysis. This is applied to predict road deterioration, roadwork effects, and road user effects over the life cycle of road segments.

The data analysis was carried out for LCCA involving different road maintenance interventions by using the HDM-4 software package.

III. RESULTS AND DICUSSIONS

A. Selection of Road Maintenance Works to Counteract Defects on DBST Road Segments

To indicate the right maintenance works at the right time it is necessary to determine the condition and extent of defects on the road segments. Having this in mind, it is necessary to conduct a condition survey of the selected road segments to address the necessary maintenance work items to be implemented within different sets of time frames. In doing so, this particular study has investigated the condition status of the selected DBST road segments under Sodo RNSMBD of the Ethiopian Roads Authority based on the Road Condition Survey Manual.

The result of the road condition survey analysis indicated that the ride quality and the overall road condition of the segment Arba Minch – Wezeqa were in fair condition. The road segments Konso-Woito and Woito-Keyafer severely deteriorated, and the overall ride quality of the road segments was under poor condition. However, road segments Areka – Sodo and Gato - Konso were damaged to a lesser extent and the surface roughness was at fair condition. Based on the result from the road condition survey analysis, the corresponding maintenance activities were also identified for all the road sections along with their unit rate per ETB/Km.

The selection of the most appropriate maintenance treatment for a given pavement distress type should consider several factors including type and extent of distress, traffic level, climate, and

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existing pavement type. Treatments are rated effective, marginally effective, not effective, not recommended, or maintenance requiring a high level of expertise and quality control [9].

In this study, the researcher attempted to review AASHTO and ERA road maintenance manuals to identify the appropriate maintenance activities to counteract the defects on the surface of the road segments. These maintenance activities as presented in Table IV are asphalt patching, pothole reinstatement, pothole base failure, chip seal coating, single surface treatment, and mix-in-place overlay. Consequently, additional effort is required to determine the best and final solution.

B. Life Cycle Cost Analysis of Maintenance interventions by HDM-4

The principal outputs of the economic analysis of the alternative maintenance interventions were in terms of Net Present Value (NPV), Economic Internal Rate of Return (EIRR), and Net Present Value per Cost Ratio (NPV/C). Detailed results of the economic analysis are provided in the appendix. The summary of the results for the life cycle cost analysis of the alternative maintenance interventions in terms of these economic evaluation indices is presented in Table V. The results of the economic analysis presented in Table V above indicate that routine preventive maintenance on all road segments, excluding the Gato-Konso segment, yielded a positive net present value (NPV) averaging 1,690.60 million ETB and an economic internal rate of return (EIRR) exceeding the opportunity cost of capital. This implies that these routine works are economically viable.

Table IV: Typical pavement maintenance treatments and expected life [6]

Treatment category	Candidate maintenance treatments	Extended Service Life
Patching	Partial Depth	6 months to 1 year
	Full Depth	6 months to 1 year
Sealing Micro surfacing	Crack Sealing	up to 3 years
	Rout and seal	1 to 2 years
	Saw and seal	1 to 2 years
	Micro milling	
Surface Treatment	Chip Seal	3 to 7 years
	Fog Seal	2 to 5 years
	Slurry Seal	3 to 7 years

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	Micro-surfacing	3 to 6 years
	Sand Seal	1 to 2 years
	Scrub Seal	
	Bonded Wearing Course	

Periodic works have an average NPV of 2,191.88 million ETB compared to do nothing, and it has an EIRR that is greater than the discount rate applied in the analysis. This means periodic maintenance works applied over all the road segments are economically viable.

According to the recent figures of the road sector development program's 23-year performance assessment report by the Ethiopian Roads Authority, the overall budget for road asset management is over 6 billion ETB annually [1]. However, due to a lack of proper preventive maintenance strategies, most of the road networks are in poor and highly deteriorated condition. It can be seen from this that the maintenance strategies should be restructured and reassessed for their life cycle cost and benefits.

Table V: Summarized result of the economic analysis

Section	Road segment	NPV (discounted in millions ETB)					
		NPV Routine Works Vs. Do nothing	EIRR (%)	No of solutions	NPV Periodic works Vs. Do nothing	EIRR (%)	No of solutions
Sodo	Areka – Sodo	1353.4	95.6	2	4052.74	46	1
Konso	Arba Minch - Wezeqa	640.13	62.5	2	677.89	19.4	1
	Gato - Konso	-7.58	No	No	1419.56	35.6	1
Turmi	Konso - Woito	2403.14	84.7	1	2369.58	23.6	1
	Woito - Keyafer	2321.74	80.1	1	2439.63	30	1
Average		1679.60			2191.88		

C. Comparison of the Life Cycle Cost and Benefit of Alternative Maintenance Interventions

The economic cost-benefit analysis of the alternative road maintenance interventions has been performed using the HDM 4 (Version 1.1) model. HDM-4 is designed to make comparative cost estimates and economic analyses of different investment options. It estimates the costs for several alternatives' year-by-year for a predetermined analysis period by discounting future costs to the base year. Rates of return, net present values, and first-year benefits are also determined. To make

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these comparisons, maintenance standards and maintenance alternatives are needed together with unit costs.

The Cost-Benefit analysis of the alternative maintenance interventions determines the project investment cost acquired in financial terms over the next 20 years in which the road agency spent and the benefits that mount up in the form of decreased travel time and the vehicle operating cost savings on the road user. The main considerations in the measurement of costs and benefits for the economic viability of these alternative maintenance interventions are the discounted travel time cost that will be incurred on the road users which comprise of cost savings from the reduced travel time, ride quality of the road segment after the intervention, and vehicle operating costs related with the fuel consumption, tire replacement, regular maintenance, and depreciation at the end of serviceable period.

Table VI: Benefit-cost ratio of alternative maintenance intervention for the Arba Minch – Wezeqa road segment

H D M – 4				Benefit-Cost Ratios Study Name: My research study project Run Date: 08-03-2022 Currency: Ethiopian Birr (millions)		
Highway development & management				Discount Rate: 10.23%.		
Section: Arba Minch - Wezeqa						
Alternative	Increase in Agency Costs	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E- C)	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
Do Routine Works	60.73	700.86	0.00	640.13	10.540	62.5 (2)
Do Periodic Works	1,016.09	1,693.98	0.00	677.89	0.667	19.4 (1)
Figure in brackets is the number of IRR solutions in the range -90 to +900						

The researcher attempted to compare the overall costs and benefits associated with the alternative maintenance interventions on the selected road segments under Sodo RNSMBD and the total cost of the planned maintenance intervention costs currently used by ERA over the analysis period of 20 years.

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As can be seen in Table VI, the ratio of Net Present Value per Cost of agency (NPV/C) for the 'do routine works' alternative is much higher than that of the 'do periodic works' alternative for the road segment Arba Minch – Wezeqa. This implies that doing routine work at the right time has more road user benefits than doing periodic work [10].

D. The Practice of Road Maintenance under Sodo RNSMBD

To compare the practices of budget allocation under Sodo RNSMBD with the alternative road maintenance interventions, this research has considered four scenarios, and they are described as follows: -

- Existing road conditions after construction in which the road segment is supposed to be in good condition are the 'do-nothing' scenario as it involve minor routine maintenance activities like shoulder blading, bush clearing, etc.
- After three to five years the road segments begin to show some significant distress; therefore, it is necessary to do minimum preventive routine maintenance activities like crack sealing, asphalt patching, and the like each consecutive year.
- After Five to eight years, the extent and severity of the defects on the surface of the road significantly alter the travel time and the VOC, so it is compulsive to do some labor-intensive major routine maintenance activities like pothole reinstatement, repairing of base failure, and the likes.
- The year afterward the road segment needs to be improved in a way that may enhance the capacity and ride quality by doing periodic maintenance intervention activities that may require capital expense.

Therefore, Table VII below shows the suggested road maintenance intervention alternatives, their expected period the alternative intervention lasts, and related expenses over the analysis period of 20 years in the case of the Arba Minch-Wezeqa road segment. The cost estimate was done based on the expected damage due to the increasing traffic volume and deterioration model from HDM-4 [1].

As per the data shown in table VIII, the overall discounted need base budget of both routine and periodic road maintenance projects over the selected DBST road segments is estimated as per

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ERA's current practice of budget allocation based on the required activity specification and unit rate over the analysis period of 20 years indicate that it is 397,981,803.03 ETB.

Table VII: Estimated total discounted life cycle cost of Arba Minch – Wezeqa road segment

Road Segment: Arba Minch - Wezeqa					
Length 33 Km					
Discount Rate applied 10.23%					
No.	Maintenance Intervention	expected life in years	Financial expense in ETB		Total discounted cost
			Routine Works	Periodic Works	
1	Opening year	1	-	-	-
2	Do Nothing	1	185,591.28	-	152,741.82
3	Do minimum	3 to 5	7,562,502.42		5,646,328.02
4	Do Some	6 to 9	8,137,827.38		4,536,382.11
5	Do Major	10 to 11		53,989,135.2	20,384,886.46
6	Do Nothing	12	197,394.78		61,339.18
7	Do minimum	13 to 15	4,125,001.32		1,162,857.76
8	Do Some	16 to 19	9,444,466.25		1,987,835.77
9	Do Major	20 to21		124,933,380.0	17,810,755.48
Total Discounted Cost					51,743,126.59

However, the total road maintenance cost of the alternative maintenance interventions is estimated to be 285,771,304.63 ETB. This depicts that the overall cost for both routine and periodic road maintenance projects under the current Sodo RNSMBD's budget allocation trend seems exceedingly high with over 28% higher than the total cost estimated on the LCCA for the alternative maintenance interventions. This arithmetic data might entail that Sodo RNSMBD has to do further economic assessment and evaluation to adopt cost-effective and preventive modes of road maintenance interventions by minimizing the whole life cost of the road segment and maximizing the benefits from the maintenance intervention investments.

The economic comparison in Table VIII illustrates the current maintenance interventions executed by Sodo RNSMBD are spending much higher life cycle costs. This denotes that the maintenance interventions practiced under Sodo RNSMBD are more responsive activities and cost much.

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TABLE VIII: Total summary of costs currently estimated under Sodo RNSMBD road maintenance projects

Total Summary of costs currently estimated under Sodo RNSMBD road maintenance projects					
S.N	Project Name	Road Segment	Paved (Km)	Estimated Allocated Need base Budget under the Sodo RNSMBD (ETB)	Total maintenance cost from LCCA (ETB)
1	Sodo Section Maintenance	Areka – Sodo	36	58,689,472.44	34,742,832.51
2	Konso Section Maintenance	A/Minch-Wezeqa	33	78,385,495.24	51,743,041.04
3		Gato-Konso	27	65,271,176.86	38,205,698.31
4	Turmi Section Maintenance	Konso – Woito	73	118,194,881.98	96,080,750.44
5		Woito – Keyafer	42	77,440,776.50	64,998,982.33
	Total discounted cost			397,981,803.03	285,771,304.63
	Total difference in the discounted cost			112,210,498.39	
	Total discounted difference in %			28.26	

This results in deterioration of the road segments before their road maintenance policies. serviceable period.

The FDRE government has been dispensing huge investment to increase the access of transport infrastructure and transport service delivery. The government has been implementing the Road Sector Development Program (RSDP) to address the development constraints caused by the poor condition of roads and lack of access. One of the main objectives of RSDP is to maintain and preserve existing road assets to an acceptable level besides increasing the road network through expansion of new road infrastructures with adoption of improved. However, the effort on preserving and maintaining road assets in Ethiopia is very low and is given less attention which the amount of allocated budget for over the last two decades was lower than what was required for proper preventive maintenance intervention. Because of the scarcity of resources for proper road maintenance in the country, it is recommended to utilize the available budget appropriately and cost-effectively. Ethiopian Roads Authority has been using road maintenance activities specifications and corresponding unit rates established since 2003.

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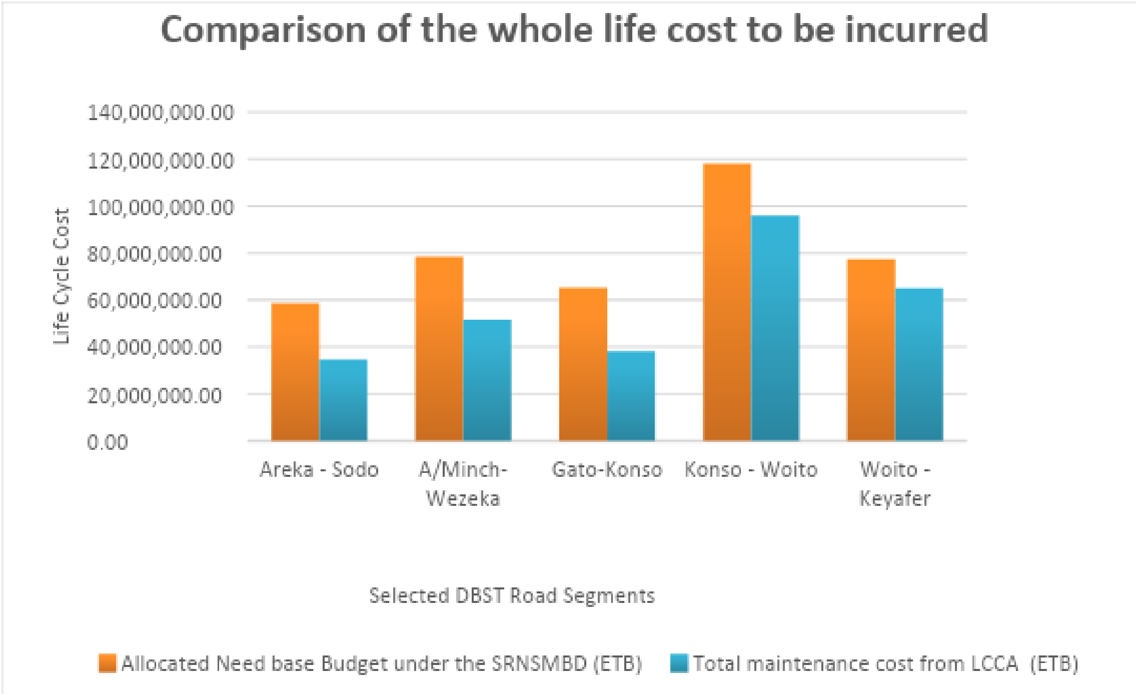

Fig.1.: Comparison of the life cycle cost to be incurred on the selected DBST road segments

In some cases, provisionally approved activities and unit rates have been used. These maintenance activities and rates fail to consider the prevailing technological advancement in maintenance techniques and fluctuations in the market price.

Accordingly, the Ethiopian Roads Authority revised the procedures and specifications of the maintenance activities and the market price in terms of labor, equipment, and material to accommodate the prevailing variation in maintenance projects to be carried out by road maintenance districts. The maintenance activities and classifications of the activities are mainly based on ERA 2003 road maintenance specifications. About this, items missing on the maintenance specifications can be adopted from 2013 ERA technical specifications [5].

ERA has revised the maintenance works unit rate and ordered the own force maintenance districts to use the revised maintenance activities unit rates for both routine and periodic maintenance projects along with the respective unit price in ETB. As it has been figured out during the data collection stage, most of the maintenance interventions at the Sodo RNSMBD road project are carried out by ERA's force wing which is the road maintenance district.

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Most of the road maintenance activities are responsive in which the maintenance works are executed to mitigate the damage on the road surface rather than focusing on preserving the road asset. These results resulted in low ride quality of the road surface and increased user and agency costs. Therefore, ERA needs to follow preventive maintenance strategies to advance and ensure effective utilization of the federal road networks. In general, the results of this study imply the practice of preventive maintenance intervention in a pragmatic method at the right time will effectively preserve the road asset, and it also has significant savings on the life cycle costs incurred on the road segments.

IV. CONCLUSION

The major findings of this study are:

- As the results of the road condition survey analysis showed, the overall road condition of Arba Minch – Wezeqa is in fair condition from the selected DBST road segments under Sodo RNSMBD. This segment only needs preservative maintenance activities like crack sealing, shoulder repair, asphalt patching (seal coat), and the like. On the other hand, the overall road condition of the road segments Areka – Sodo, Gato – Konso, and Konso - Woito is poor condition which implies the road segments need to be maintained through corrective maintenance activities like pothole reinstatement (DBST), pothole base failure repair, shoulder rehabilitation, etc. Finally, the overall road condition of the road segment Woito – Keyafer is in bad condition, which means the road segment is severely damaged requiring reconstruction and rehabilitation to improve the structural capacity.
- While performing the comparison between alternative maintenance interventions, the values of NPV and IRR from economic analysis on HDM-4 software were the basic economic indicators. The results of the life cycle cost analysis imply that the preventive maintenance activities in both periodic and routine maintenance interventions over all the road segments have the highest NPV and IRR. This means the preventive maintenance mechanism is way too advantageous in terms of life cycle cost and preserving the road networks. Therefore, preventive maintenance activities executed on road networks like crack sealing, thin overlay, seal coating, and the like can impede water infiltration and reduce the pavement’s exposure to high radiation.

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- One of the major findings of this study was related to the assessment of the practice of road maintenance under Sodo RNSMBD. The allocated need-based budget for road maintenance projects executed by Sodo RMD is mainly focused on responsive way of maintenance activities. This maintenance strategy results in high user and agency costs. As a result of this, the serviceable period of the road asset becomes low. However, the life cycle cost of alternative maintenance interventions over the selected DBST road segments appears to be much lower than the current practice of a need-based budget which is 285,771,304.63 ETB.

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