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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 the 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 road assets.

Keywords: DBST, ERA, HDM-4, Life Cycle Cost Analysis, Road Maintenance, Bituminous

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.

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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 the Equitable Regional Development Policy of the Federal Government. The latter is crucial in addressing disparities by constructing "missing links" and other critical roads in less developed or underserved 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. 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-

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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 the 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 of 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
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.

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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 is the economic indicators in financial feasibility which is 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 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 like asphalt binder and crushed aggregate. The asphalt binder material is applied by an asphalt spreader

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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.

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

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winding and gently undulating	20	3	300	5	60	1.00
winding and severely undulating	40	4	500	7	50	1.00

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 Discussions

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.

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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 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
	Micro-surfacing	3 to 6 years

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	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 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

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mount up in the form of decreased travel time and the vehicle operating cost savings for 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 Work	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)
The 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.

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: -

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- Existing road conditions after construction in which the road segment is supposed to be in good condition are the 'do-nothing' scenario as it involves 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 like.
- The year afterwards 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 based budget of both routine and periodic road maintenance projects over the selected DBST road segments is estimated as per ERA's current practice of budget allocation based on the required activity specification and unit rate over the analysis period of 20 years indicating 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

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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 models 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 that the current maintenance interventions executed by Sodo RNSMBD are spending much higher life cycle costs. This denotes that the maintenance interventions practised under Sodo RNSMBD are more responsive activities and cost much.

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

S.N	Project Name	Road Segment	Paved (Km)	Estimated Allocated Need based 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 investments to increase access to transport infrastructure and transport service delivery. As depicted in Fig.1, the government has been implementing the Road Sector Development Program (RSDP) to address the development constraints caused by the poor condition of

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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 the 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.

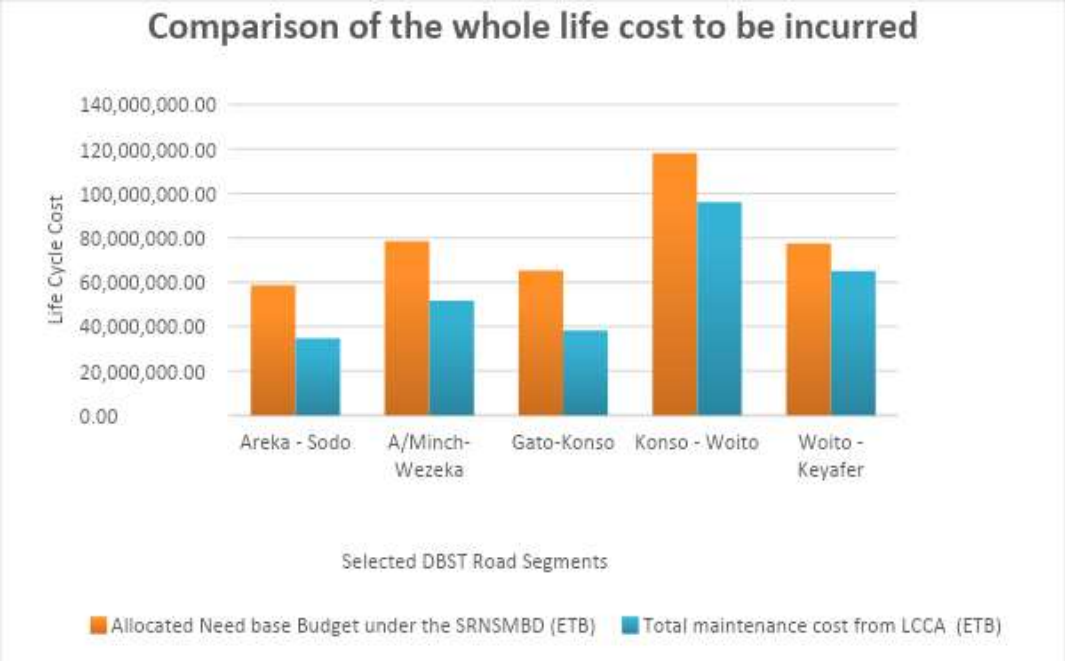

Fig. 1: Comparison of the life cycle cost to be incurred on the selected DBST road segments

In some cases, provisionally approved activities and unit rates have been used. These maintenance activities and rates fail to consider the prevailing technological advancements 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 the ERA 2003 road maintenance specifications. About this, items missing on the maintenance specifications can be adopted from the 2013 ERA technical specifications [5].

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ERA has revised the maintenance works unit rate and ordered its 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.

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 follows:

- 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 a 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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Investigation of Road Asset Management Practices in South Road Authority (The Case of Sodo District)

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Abstract

Road asset management (RAM) is a critical function for ensuring the sustainability, safety, and efficiency of transportation infrastructure. In developing countries like Ethiopia, RAM practices face significant challenges due to the lack of appropriate tools, limited technical capacity, inadequate data systems, and insufficient coordination among stakeholders. This study investigates the existing status of road asset management practices in the Sodo District under the South Road Authority (SRA) of Ethiopia. A descriptive survey design incorporating both qualitative and quantitative approaches was employed. Primary data were collected through questionnaires administered to 15 professionals, including team leaders, data collectors, and supervisors, as well as interviews and field observations. The study revealed multiple deficiencies, including a lack of digitalized systems, poor data organization, inadequate maintenance planning, limited awareness, and poor integration of management components. Statistical analysis showed weak correlations between performance monitoring and overall asset system issues, indicating gaps in implementation. Based on the findings, the study recommends adopting a modern, digital road asset management system; enhancing technical capacity through training; improving inter-agency coordination; and implementing evidence-based, proactive maintenance strategies to optimize resource use and extend asset lifespan.

Keywords: Data Integration, Ethiopia, Infrastructure Maintenance, Road Asset Management, Rural Roads, Sodo District

I. Introduction

Road infrastructure is fundamental for fostering socio-economic development, especially in third-world countries where rural connectivity directly influences access to markets, healthcare, education, and other essential services. In Ethiopia, the expansion of rural road networks has contributed significantly to improving household income, reducing poverty, and enhancing resilience against environmental shocks [1]. For example, studies show that rural roads can reduce the risk of falling into poverty by up to 14.4%

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and increase household consumption by 16.1%, highlighting their strategic importance to national development [1].

Despite these benefits, road infrastructure management is still the topmost challenge. The Ethiopian Road sector is overseen by multiple institutions, including the Ethiopian Roads Authority (ERA), the Ethiopian Road Fund (ERF), Regional Roads Authorities (RRAs), and Woreda Roads Offices (WROs). However, these bodies often operate with limited coordination, inadequate technical capacity, and scarce financial resources[2]. Road maintenance in particular has been persistently underfunded and poorly managed, leading to the rapid deterioration of assets and significant financial losses. A World Bank report estimated that developing countries have lost road infrastructures that cost more than $45 billion in the twenty years because of poor reparations; these are preventable losses avoidable with just $12 billion in preventive interventions [3].

The South Roads Authority (SRA), responsible for road infrastructure in the Southern Nations, Nationalities, and Peoples' Region (SNNPR), exemplifies these challenges. In districts like Sodo, road asset management is hindered by outdated practices, manual data handling, limited use of digital systems, and a lack of strategic planning. Effective Road Asset Management Systems (RAMS)—which integrate engineering, economic, and technological principles—are either poorly implemented or absent. Moreover, there is minimal alignment between data collection, project selection, and long-term planning.

This study aims to examine existing road asset management practices in the Sodo District under the SRA, identify key gaps and challenges, and propose a practical framework for improvement. Through field observations, surveys, and interviews, the research explores how RAM components (asset inventory, condition assessment, performance monitoring, and program optimization) are currently applied in the study area and what measures are necessary for effective and sustainable infrastructure management.

II. Research Methodology

A. Description of the Study Area

This research was done in the Wolayta zone of Ethiopia, as shown in Fig. 1 and the Sodo district was one of the twelve (12) districts under the South Roads Authority. Although, Sodo District was administered 33 road construction sites. The study areas of both Road Construction Sites were namely, Areka-Bombe, 19.6km, and Boditi- Badessa, 17 km. The zone is found at 300 km south road distance from the capital Addis Ababa and about 155 km southwest of Hawassa. Geographically, it is found at 6°54' N latitude and 37°45' E longitude altitudes ranging from 1600 and 2100 meters above sea level. The study area's climate is moderate midland climate locally known as Weyina Dega with mean annual rainfall ranging between

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800 to 1200mm and mean annual temperature ranging between 24°c and 30°c at daytime and 16°c to 20°c at night. Based on the national census 2007 the population of the zone is 5,473,190 while its total area is 4,208.64 km^2. Wolayta Sodo town has an overall populace of 356,670. Of these, 172,514 (11.49%) are urban inhabitants, and an additional 1,196 (0.08%) are pastoralists [4]. Wolayta has 562 kilometres of roads administered by the South Roads Authority and 669 kilometres of URRAP roads administered by the Wereda Roads Authority. It has a mean road concentration of 292 per 1000 square kilometres.

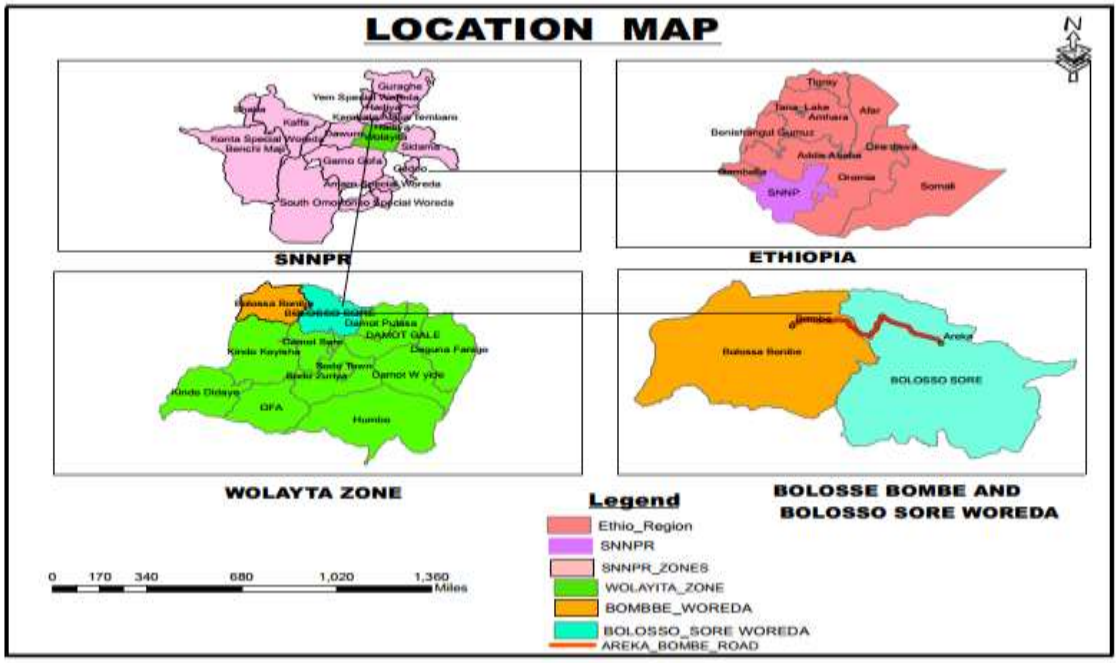
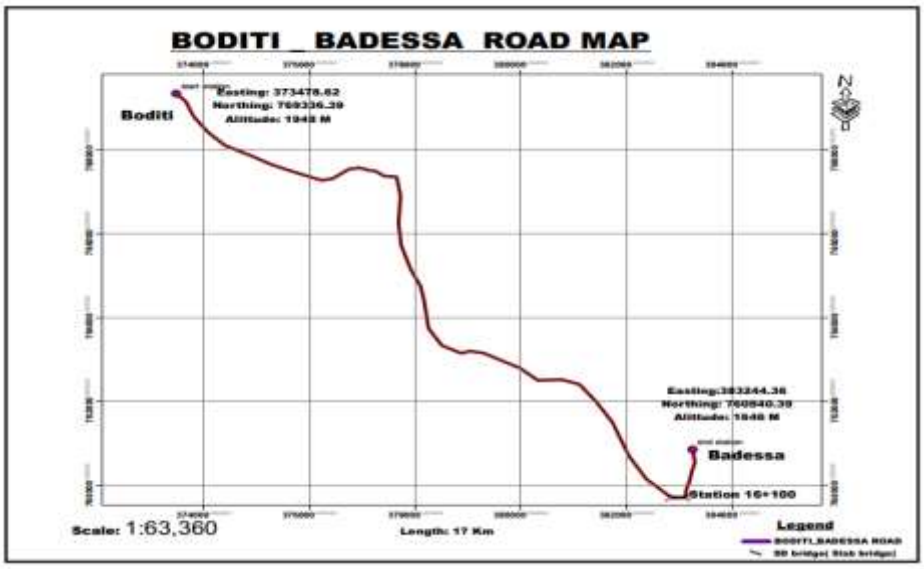


Fig. 1: Study area location map



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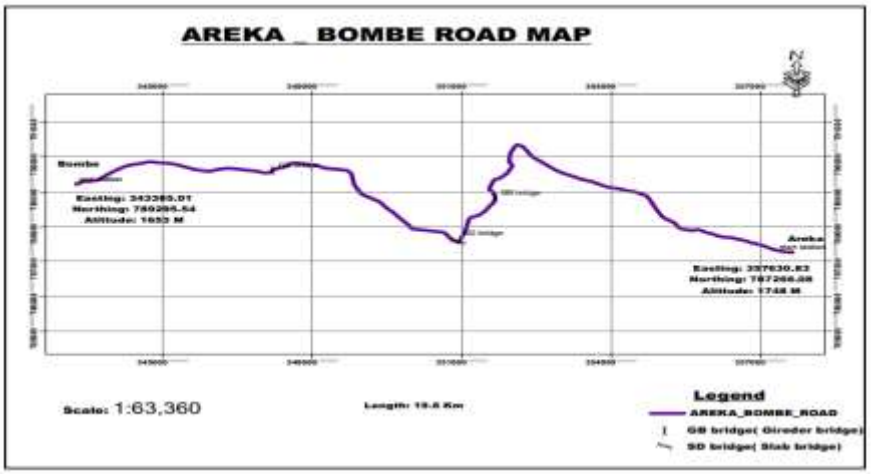

Fig. 2: Study area road alignment map

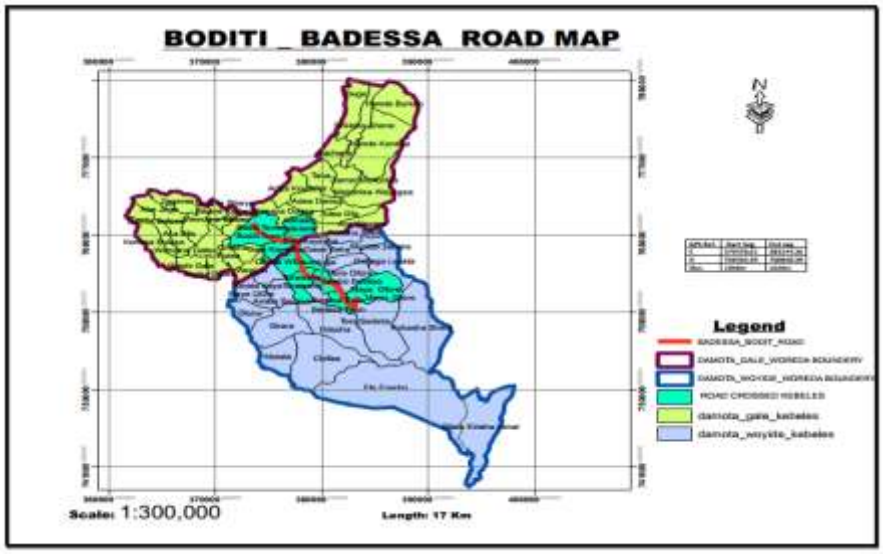

Fig. 3: Study Area's Crossing Kebles Network Map

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B. Research Design

Asto Creswell (2008), research designs are of three types: descriptive, exploratory, and explanatory. The research design used for this research is descriptive since it provides an accurate and valid representation of variables that are relevant to achieving the main goal of this research and answering the research questions.

C. Target Population

The targeted populations were relevant government organizations in the road sector in Ethiopia, like the South Roads Authority (SRA), Sodo District.

D. Sampling Techniques

Purposive and snowball sampling were employed to choose representatives of the population. Snowballing focused on asking participants of the survey to suggest others people that are relevant and willing to participate.

Accordingly, the questionnaires were purposively disseminated to the entire asset management professionals (Team Leaders) and data collectors employed in the Road Asset Management Directorate in Sodo District. On the other hand, the interviews were done through the snowball sampling method with team leaders and construction supervisors only. Since the populace is very few, this sampling techniques make the sample free from prejudice.

E. Data collection tools

Based on the focus of the study, the primary data was collected using instruments such as semi-structured interviews, questionnaires, and different tools such as GPS and Tape meters on the field for manual observation.

1) **Questionnaire Design**: The survey questionnaire was the result of a deep dive into all the existing literature on Road Asset Management. We used all the information and best practices we found to design questions that would help us meet our specific research goals. The survey uses closed-ended questions to make the whole process much quicker and easier to record and analyse the answers. We also included a cover letter to explain the survey when we sent it out. They are also easier and quicker for the respondents to fill (Yes/No) responses. The survey questionnaire is categorized into two sections. The first section is the Organization and Respondent's position about overall agency data on asset management decision stages, and decision procedures. The second section is about Self-Assessment Performance Evaluation (District Level) and seeks info about data collection, management, and integration and their association with the project assortment decision level of Roadway Assets, and the questionnaire focused on factors

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affecting the implementation of asset management. In addition to close-ended questions, a small number of open-ended questions were included to give chance for the respondents to express their actual feelings, attitudes, and full understanding of the topic in their own words. Essentially, they allow the person filling out the survey to bring up new issues and give us extra, valuable information—which is the best way to tap into their true perspective on the subject under study.

2) **Interview**: Data that help answer the research questions and meet the objectives were asked from key informants through interview in order to expand understanding of the data gathered through the survey. The whole point of these interviews was to figure out their current practices and opinions regarding the Asset Management System. Specifically, we were trying to do two things: identify any extra problems that didn't come up in the written survey, and generally double-check the accuracy and make the challenges we got from the questionnaire much more reliable and accurate.

3) ***Data Sources:*** In order to get enough data about the investigation of road asset management practices in Sodo District, primary and secondary sources were consulted. The primary sources were used to obtain direct and immediate information through interviews with the manager of the road district, professionals/ team leaders, and experts at the district, and survey questionnaires filled by those that are directly involved in the work.

In addition to the ese primary sources, secondary sources were used to support and reinforce the findings. These secondary sources are various official documents from the Wolayta Zone and Woredas, periodicals, articles, records, files, books, and other sources. These were consulted to supplement possible gaps or limitations of the primary source data and guarantee the accuracy and reliability of the entire study.

F. Data Analysis Techniques

We analysed the information we gathered using a mix of descriptive and inferential statistics. First, all the quantitative data collected from the questionnaires was categorized, classified, tabulated, and coded. This data was then entered into SPSS version 20 for the statistical analysis. To start the analysis, we performed descriptive statistics, mainly using cross-tabulation to compute frequencies and percentages. This helped us paint a clear picture of the initial findings. Then, we moved on to correlation analysis. We used this technique to test for significant relationships between different factors. For instance, we checked if certain independent variables (like Performance Monitoring) had a measurable influence on the dependent variables (like the overall Asset System problem). In this regard, a correlation analysis model was employed to analyze the overall effects of the variables. The results from these statistical analyses were then used to support and give more depth to all the findings from our structured questionnaires.

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III. Results and Discussions

A. Response Return Rate

Overall, 18 questionnaires were distributed to purposively selected respondents of this study, including professionals, team leaders, and employees from the district Road Authority's engineering office. Of the 18 distributed questionnaires, 15 (83.33%) were completed and returned, as shown in Table I. This indicates the importance of thoroughly cross-checking the gaps in the current Asset Management Practices within the Sodo Road District Office.

Table I: Distribution of questionnaires and response rate

Respondents	Total Distributed Questionnaires	Returned Questionnaires	% of valid/ returned questionnaires
Asset Management professionals/ team leaders	15	12	66.67
Data Collectors	3	3	16.67
Total	18	15	83.33

B. Demographic Characteristics of Respondents

Table II: Educational background of respondents

Educational Status	Frequency	Percent	Valid Percent	Cumulative Percent
Diploma	1	6.7	6.7	6.7
Degree	13	86.7	86.7	93.3
Master's	1	6.7	6.7	100.0
Total	15	100.0	100.0	

As shown in Table II, the educational qualifications of the respondents were as follows: 6.7% held a diploma, 86.7% held a bachelor's degree, and 6.7% had a master's degree. Based on the data gathered, it is evident that the current workforce is neither sufficient in number nor adequately qualified to effectively manage the district's road assets systematically. Academic qualification is a key criterion for establishing a proper and standardized digital asset management system, and the existing manpower falls short of meeting this requirement.

Here, we have seen that degree-level employee professionals in the district were not upgrading their educational statuses to master's and above levels. Practically, there was no best framework-based standard and digitalized asset management system practices as compared to regional, national, and international levels on the road network asset management practice in the Sodo district. Therefore, the educational background of professionals affected the road asset management system practices.

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C. Field of Specialization of Respondents

The introduction of Road Asset Management Systems (RAMS) in third-world countries presents unique challenges that need to be addressed along with possible approaches to resolve them. RAMS is not encompassed in the undergraduate civil engineering curriculum in the universities and technical institutes of these countries, except for some postgraduate programs. One reason for this is that RAMS involves not only civil engineering, but also other disciplines such as Information Technology (for Programming and Database Management Systems), Geographic Information Systems (GIS), and Mathematical Modeling. This article selected the respondents from this field to discuss the concepts and components of a modern RAMS, as well as its use and application by road agencies. It can help in exploring the challenges and solutions in implementing RAMS in these countries. Several authors have covered various dimensions of the multidisciplinary aspects of RAMS, which is expected to become an essential component of road agencies shortly [4].

Table III: Educational background of professional respondents

Educational Background	Frequency	Percent	Valid Percent	Cumulative Percent
Surveyor	2	13.3	13.3	13.3
Civil Engineer	13	86.7	86.7	100.0
Total	15	100.0	100.0	

As shown in the above table, 13.3% of the respondents were surveyors and 86.7% were civil engineers. Therefore, condition surveys of the road assets from the field were not proper and not sufficient. Because there was a lack of surveyors in the district, i.e.13.3% of the total respondents, it negatively influenced the district's current practices of the road asset management system.

D. Experience of the Respondents

Table IV: Respondents' experience

Respondents' experience	Frequency	Percent	Valid Percent	Cumulative Percent
3-5 years	6	40.0	40.0	40.0
5-10 years	8	53.3	53.3	93.3
above 10 years	1	6.7	6.7	100.0
Total	15	100.0	100.0	

The research responses show that 40% of the respondents were employed for 3 to 5 years; 53.3% for 5 to 10 years; and 6.7% for over 10 years. So, in the district, the professionals were not well experienced.

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E. The Respondents' Position

Table V: The respondents' position

Respondent's Position	Frequency	Percent	Valid Percent	Cumulative Percent
Road asset management project manager	1	6.7	6.7	6.7
Asset management professionals/team leaders	11	73.3	73.3	80.0
Data collectors	3	20.0	20.0	100.0
Total	15	100.0	100.0	

Regarding positions of staff professionals on the district level, 6.7% were Road Asset Management Project Managers while 73.3 % were Asset Management Professionals/Team Leaders. The remaining 20.0% were Data Collectors. Although the educational background is good status in the district with one Master's degree holder and the professionals having degree level qualification in civil engineering, there were problems or gaps currently because road asset management practices and asset management systems were not modernized technologically. For practically managing the road assets well, the basic method was collecting the road assets data from the field properly. However, this did not happen sufficiently in the Sodo district.

F. Assessment of Current Road Asset Management Practice

This section discusses the current practice of road asset management practice in the south region's Sodo district as shown in the table below.

Table VI: Asset implementation in Sodo district

Yes	2
At planning phase	8
Don't know	5
Total	15

For the question asked to describe road asset management implementation in the Sodo district, 2 responding professionals, team leaders, and data collectors responded that there is implementation of road asset management in the Sodo district. 8 professionals, team leaders, and data collectors responded that the road asset management implementation is still adopted at the planning phase. About 5 respondents don't know about road asset management implementation in the Sodo district. Based on the responses obtained about road asset management adoption, most of the responses show that road asset management is not well adopted in the Sodo district. It can be noted that road asset management teams in road asset management

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systems have not been used, the principal ones among them being: - pavement, bridge, and maintenance management systems. Further systems comprise safety (SMS), and congestion (CMS) management systems. Moreover, majority of the replying professionals exposed that the level of incorporation of these separate systems within a whole asset management framework is non-existent.

In addition to road asset management implementation in the Sodo district, respondents were requested to rate the components of the asset management system. After an extensive literature review, the constituents of asset management systems like goals and policies, asset inventory, condition assessment, performance monitoring, alternatives analysis/program optimization, short/long-range plans, and program implementation of Asset Management Systems were identified. The respondents were asked about their awareness of these and whether they have adopted them in the Sodo district.

Table VII: Asset management component rating

Components of Asset Management	Percentage of rating			
	Low	medium	High	Very high
Goals and policies	63.5	20.32	9.68	6.5
Asset inventory	60.5	23.32	9.68	7.5
Condition assessment	62.5	21.32	9.68	6.5
Performance monitoring	61.5	19.32	11.68	7.5
Alternatives analysis/program optimization	62.5	20.32	10.68	6.5
Program implementation of asset management systems	61.4	22.32	9.68	6.6

As can be noted from the above table respondents rate the goals and policies component 63.5% as low, 20.32% as medium, 9.68 as high, and 6.5 as very high. For asset inventory respondents rated it 60.5% as low, 23.32% as medium, 9.68 as high, and 7.5 as very high. The condition assessment component is rated 62.5% as low, 21.32% as medium, 9.68 as high, and 6.5 as very high. Performance monitoring is rated 61.5% as low, 19.32% as medium, 11.68 as high, and 7.5 as very high while program optimization is rated 62.5% as low, 20.32% as medium, 10.68 as high, and 6.5 as very high. The program implementation of the asset management system is rated 61.4% as low, 22.32% as medium, 9.68 as high, and 6.6 as very high.

In addition to rating the components of asset management, respondents are asked to define their decision-making level in road asset management of the Sodo district. It indicates they have not clearly demarcated stages according to the standards as well-defined in the literature. The chief recognized levels were programming and budgeting. This proves that the organization had primarily concentrated its attention on the middle stages- mainly programming and budgeting- which serve as a bridge between the broad strategic decisions made at the strategic level and their execution at the project implementation level.

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G. Correlations between Overall Asset System Problems and Performance Monitoring

Taking care of roads is important to make sure they stay in good shape. Road asset management is all about keeping track of the roads and making decisions about what needs to be fixed or replaced. Right now, most of the data about the condition of the roads is collected and analyzed by people, which can take a long time. Researchers look at three main things when they collect this data: what kind of information they collect, what parts of the road they look at, and how much information they get. Then, they evaluate these categories based on how accurate the information is, how efficient it is to collect, how much it costs, and how much it improves the current way of doing things. But even with all these methods, they found that monitoring the condition of the roads is not very efficient, and none of the methods looked at solving the problem completely i.e., the mentioned problem in this study was overlooked [5].

Table VIII: Correlations b/n overall asset system problem vs. performance monitoring

		Overall asset system problem	performance monitoring
Overall asset system problem	Pearson Correlation	1	-0.055
	Sig. (2-tailed)		.845
	N	15	15
performance monitoring	Pearson Correlation	-0.055	1
	Sig. (2-tailed)	.845	
	N	15	15

As shown in the above Table VIII, correlations between overall asset system problems and performance monitoring of road assets management system responses were gathered from respondents' questionnaires and computed. However, both variables were negatively correlated with a -0.055 value. These results showed the existence of great disparity in the overall asset management system and performance monitoring of the road assets management system in the Sodo District.

H. Planning to Implement an Asset Management System for the Respondents

In recent years, there has been increasing attention on the investment and performance of highway infrastructure. The present financial hurdles and higher community needs have led local highway authorities to reconsider how they manage their infrastructure. Both central and local governments have to find ways to improve the management of main road infrastructure assets through long-term planning. Our people and economy rely on various infrastructure assets, such as water supply, waste disposal, energy,

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telecommunications, and transportation. These assets are crucial in modern society and require substantial capital spending for construction and maintenance. By adopting an asset management method, resources can be used more efficiently and effectively. This approach also ensures compliance with legal responsibilities, meets stakeholder requirements, and safeguards the structural reliability of the road network.

Table IX: Respondents' plan to implement an asset management system

	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	8	53.3	53.3	53.3
No				
Not sure	6	40.0	40.0	93.3
Total	1	6.7	6.7	100.0
	15	100.0	100.0	

53.3% of the respondents were planning to apply an asset management system, 40% were not planning to implement and 6.7% were not sure to implement a road asset management system. This shows that there was not enough asset management system implementation due to the plan in the road district.

I. Causes of Problems Arising in Asset Management Implementation

As a systemic process, road asset management involves maintaining, upgrading, and operating assets. It combines solid engineering with smart financial management and economic reasoning, as defined by the OECD. This activity is carried out by road authorities and involves balancing costs, risks, and performance. It includes tasks such as data gathering, data analysis, and planning the allocation of resource and budget. Pavement managers today face the trial of meeting transportation requirements with inadequate resources. Additionally, legislative organs have put higher requirements on highway agencies, demanding more answerability for the use of taxpayers' money. Due to this, the significance of management systems has become all the weightier. Several studies have highlighted the necessity to contemplate the environmental impact of road maintenance and operation in the asset management process. This includes factors such as congestion, noise, and pollution. Furthermore, when choosing between different maintenance stratagems, road operators must also consider the effects on socio-economic life. In recent years, new measurement systems have been advanced to deliver more accurate information about the state of road assets at traffic speed. These advancements advance the accuracy of measurements and provide additional data for decision-making [6].

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1) Organizational Challenges:

Table X: Organizational challenges

	Frequency	Percent	Valid Percent	Cumulative Percent
Very low	2	13.3	13.3	13.3
Medium	7	46.7	46.7	60.0
High	6	40.0	40.0	100.0
Total	15	100.0	100.0	

Of the causes of problems arising in asset management implementation, 13.3% are very low, 46.7% are medium, and 40% are high challenges in the organization or district. Therefore, this result shows that the asset management implementation in the road district was poor and below the standard qualified level.

2) Financial challenges:

Table XI: Financial challenges

S	Frequency	Percent	Valid Percent	Cumulative Percent
Medium	3	20.0	20.0	20.0
High	7	46.7	46.7	66.7
Very high	5	33.3	33.3	100.0
Total	15	100.0	100.0	

Indeed, from the respondents' responses to returned questionnaires, financial challenges were 46.7% high and 33.3% very high respectively. This shows that there was an insufficient budget allocation for the maintenance of the road asset management system. So, the road asset valuation management practice in the Sodo district was not good or very poor**.**

3) Political awareness:

Table XII: Political awareness

	Frequency	Percent	Valid Percent	Cumulative Percent
Very low	1	6.7	6.7	6.7
Low	2	13.3	13.3	20.0
Medium	5	33.3	33.3	53.3
High	6	40.0	40.0	93.3
Very High	1	6.7	6.7	100.0
Total	15	100.0	100.0	

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In the Sodo district, the employers in different administration and technical professions departments were not awarded politically. This was why they did not care about politics depending on the interrelation between the road asset management practice performance goal and political awareness.

4) Integration problem:

Table XIII: Integration problem

Frequency	Percent	Valid Percent	Cumulative Percent
1	6.7	6.7	6.7
5	33.3	33.3	40.0
3	20.0	20.0	60.0
5	33.3	33.3	93.3
1	6.7	6.7	100.0
15	100.0	100.0	

As shown in the above result, there was a high integration problem in the Sodo district. Different employees in the district did not do their activities together in an integrated manner.

5) Overall asset system problem:

Table XIV: Overall asset system problem

	Frequency	Percent	Valid Percent	Cumulative Percent
Low	1	6.7	6.7	6.7
Medium	9	60.0	60.0	66.7
High	4	26.7	26.7	93.3
Very high	1	6.7	6.7	100.0
Total	15	100.0	100.0	

Overall asset system problems in the road district were medium or 60% and high or 26.7%, respectively. This shows the road district had difficulty correcting and reducing managing of overall asset problems for a long period in their current practice without the use of digitalized and modern technology.

6) The results of the condition assessment and other roads recorded in a computerized RAM system:

Table XV: Results of the condition assessment and other recorded in a computerized ram system

	Frequency	Percent	Valid Percent	Cumulative Percent
YES	6	40.0	40.0	40.0
NO	9	60.0	60.0	100.0
Total	15	100.0	100.0	

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Based on the result in above Table XV, 60% of the respondents responded saying 'No' to the condition assessment and other roads recorded in a computerized RAM (Road Asset Management) system in the Sodo district. This shows it was not good and is insufficient.

J. South Road Authority in Case of Sodo District Field Observation

The field observation employed in this study aimed at observing the targeted roads in their natural environment and the results of this observation were presented below.

1) Boditi to Badessa Road: Fig.4 Boditi to Badessa road field observation shows road asset management practice in the area is below the level expected. Roadside ditches have not been cleaned and maintained at the time. Roadway potholes have not been patched and maintained for mobility. The roadway cumber slope is not constructed well and adjusted to drain water from the road to the side drain. Overall road assessment management in the study area is below the standards.

Fig.4: Road condition survey of Boditi to Badessa

(Source: own Field survey, 2023)

Based the field observation data, as demonstrated in the above figures, the Boditi to Badessa Road and its minor drainage structures were not suitable and stable for the use of transportation systems although motor bicycles were used on the road for transportation most of the time. The road asset management system was not maintained for a prolonged time properly. For three years, there were no maintenance programs with an absence or inadequate funding budget from a higher hierarchy level. So, the road set valuation practice currently was poor or not in good status.

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1) Areka to Bomebe Road: Figure 5 illustrates the field observation along the Areka to Bomebe Road, indicating that road asset management practices in the area are below the expected standard. Roadside ditches were cleaned and maintained at the time of inspection. Potholes on the roadway had been patched to ensure mobility. The roadway camber slope was properly constructed and effectively directed water toward the side drains. Overall, the field survey suggests that road asset management in the study area is approaching acceptable standards but still requires improvement.

Fig.5: Road condition survey from Areka to Bomebe

(Source, Field survey, 2023)

According to the above field observation Fig. 5, the road asset management practices were good compared to the Boditi to Badessa road. Because, the road took maintenance with available budget funding frequently, Bajaj, Isuzu, and Buses were used on the road comfortably.

K. Best Framework for Road Asset Management for South Roads Authority, Sodo District

An integrated and holistic approach to road management is needed to align funding, management systems, and procedures. The Road Asset Management System (RAMS) is a powerful tool for achieving optimal road conservation while minimizing costs. RAMS blends solid engineering with smart financial management and economic reasoning and includes digital tools for decision-making. Implementing RAMS benefits decision-makers, road authorities, funds, and road users by improving asset performance, allocating funds efficiently, reducing costs, improving road conditions, increasing safety, and reducing environmental impacts.

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Road asset management involves analyzing various road data including inventory, condition, traffic, unit costs, and road deterioration models. This data is put into a Road Asset Management System (RAMS) for analysis, helping determine optimal budget levels and allocations. The term "framework" encompasses the processes, procedures, support systems, organizational roles, responsibilities, and policies required to facilitate asset management decisions. The five key constituents of asset management are asset inventory, level of service (LOS) which defines performance expectations, critical assets, revenue structure, and an improvement project plan.

The four-step guideline for RAMS implementation

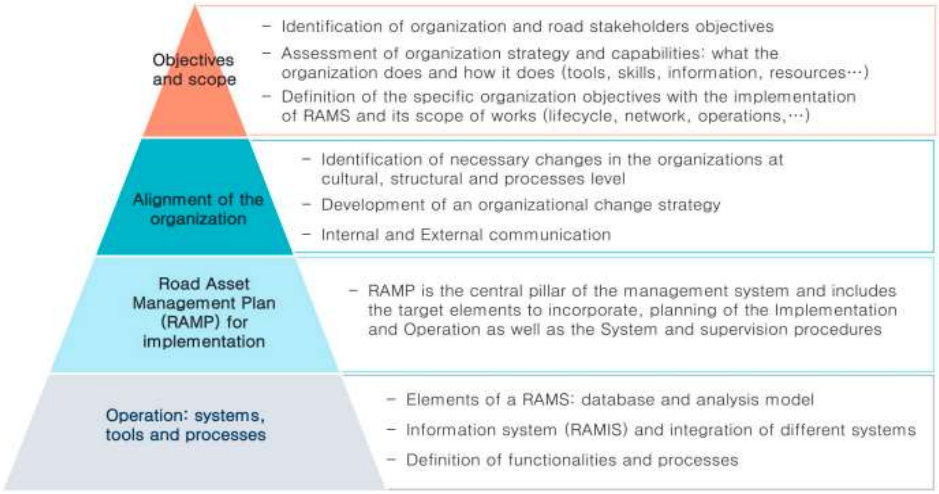

Fig. 6: RAMS implementation guidelines

Source: Framework for the implementation of Road Asset Management System 2023

IV. Conclusion

The major objective of this research is to investigate the Road Asset Management (RAM) and the current practices in the case of the Sodo district and give recommendations by preparing frameworks from the findings. Organizational challenges, financial challenges, political awareness, overall asset management system, performance monitoring, condition assessment, planning of implementation of asset management, and expert competency were the major reasons of the problems identified in the study area's road asset management.

Based on the research assessment the researcher concluded:

- There is an absence of asset management constituents' application practice in its adequate form or sense in the Sodo district. The implementation stage of an asset management system is still at the planning

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stage. Most of the individual management systems have not been utilized, and data collection decisions were not based on the standards and input needs of management systems or processes behind the rationalization of data collection. The Sodo district does not formally identify and document existing links between the data they collect and the project selection decisions they support. The main problems faced in applying asset management practice are a lack of an organized asset management department, a lack of professional employees, inadequacies of digitalized asset management system, and the absence of short courses to acquire state-of-the-art techniques of road asset management.

- Therefore, this study strictly underlines the necessity of well-defined government road asset management policies, regulations, and strategies as the basis for better road asset management which treats roads as capital assets of both the nation and the study area. Moreover, the study tries to come up with a rational solution for a modern asset management system by investigating the current road asset management system in the study area and then recommending a better way of road asset management for the sustainable social and economic development of the districts as well as the region.
- Furthermore, the study recommends the best framework for decision-makers on how to make quality decisions between alternative maintenance strategies. Also, road operators at different levels should take into consideration the impacts of poor road asset management on the socio-economic life of their society. An integrated and holistic approach to road management is needed to align funding, management systems, and procedures.
- Moreover, the study offers pertinent issues and imminent challenges for Road Asset Management. It also recaps the up-to-date matters pertaining to road infrastructure maintenance and frames new issues for future investigation.

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Customer Satisfaction Assessment in the Public Transportation System of Anbessa City Bus Services

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Abstract

Assessing public transportation services can significantly contribute to improving their quality, thereby attracting more commuters over time. In the capital city of Ethiopia (Addis Ababa), transportation is mostly facilitated by the publicly owned transportation service providers. These public service providers are the Anbessa City Bus Service Enterprise, popularly known as ACBSE Transport, Alliance Bus Services, and Sheger Bus Services. In addition, various other privately owned vehicles, including minibuses and taxis, are also available in the city for public transportation. This study aimed to analyse customer satisfaction with Anbessa city bus services in Addis Ababa using the SERVQUAL model, considering five service attributes, i.e., parameters: Service Responsiveness, Reliability, Tangibility, Assurance, and Empathy. To achieve this objective, a questionnaire was designed and distributed to 500 regular users of Anbessa city bus services in the city. The data obtained was sorted and analysed using SPSS 20.0 software. The research findings indicate that passengers are satisfied with ACBSE transport services based on responsiveness and tangibility, but they are unsatisfied with the reliability, assurance, and empathy dimensions of service quality. The study results are found to be useful for transport planners seeking to improve ACBSE bus services at selected terminals in Addis Ababa.

Keywords: ACBSE, Ambessa City Transport, Reliability, SERVQUAL Model, Tangibility

I. Introduction

A study focused on the "Anbessa City Bus Service" in Addis Ababa revealed that inadequate infrastructure, poor transport operation, and ineffective performance of stakeholders have resulted in an inaccessible service to the public transport service passengers [16]. This implied that the main constraints related to bus services in Addis Ababa city include poor service conditions as a major factor. Such waiting distances, delays on the way, overloading, long waiting for work residents, and manually controlled signals without having proper automated systems. On the other hand, the private transport services such as Sheger buses, Star Alliance buses, mini buses, and taxis are dominating the public transport services with their better services and lower travel cost [3]. A study [3] found that buses are too old, a high breakdown rate of buses

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on the way is a big issue, a very limited supply of buses is another concern, and the irregular operating schedule is also another big concern. As urbanization increases, the number of passengers obviously increases, and the bus services need to improve to attract passengers. This has become a challenging task for the transport planners in the city, which needs a lot of attention to improve the services of ACBSE. The improvement of customer satisfaction in Anbessa city service buses should be given priority to attract passengers from all directions.

The current study scientifically evaluates the Anbessa City Service bus service customers' satisfaction by considering five major parameters, such as 'Responsiveness', 'Reliability', 'Tangibility', 'Assurance', and 'Empathy', and using the SERVQUAL model and employing SPSS 20.0 Software. In our study, numerous Regression models were developed and analysed by considering Customer satisfaction as the ‘dependent variable’ and the influencing parameters as the ‘independent variables.’ In this regard, the study [3] overlooked a scientific approach without rigorously employing statistical regression analysis. Further, the study was focused only on the evaluation of the three parameters, i.e., 'Safety', 'Security', and 'Comfort' of the passengers by calculating the percentage of customers' opinions from the numerical data collection, and does not possess any scientific approach. On the other hand, the prime objective of the study [3] was to identify major challenges of the ACBSE bus service, create awareness among concerned bodies, evaluate the demand of ACBSE customers, and provide hints to solve the problem. Our study considered the scientific sampling strata (random sampling), such as the 'Cooper and Sehindler' sampling method, but the [3] study overlooked the sampling techniques as a paramount activity of the research for revealing the hidden insights in the data collected.

A. Statement of the Problem: Addis Ababa city is the economic and political capital of the Federal Democratic Republic of Ethiopia. Having the Head Office of the African Union, Addis Ababa, is also the diplomatic centre of Africa, and the nodal city for many international organisations. The population of Addis Ababa is rapidly increasing due to the fast urbanisation, and the size of the city is expanding both vertically and horizontally day by day. When the size of the population increases, the number of passengers dependent on public transport also increases in proportion. To accommodate these passengers, transport services are required to be expanded within the city limits. As a matter of fact, the existing state of transportation and the supply of transport services are not proportionally balanced. Public transport is about to fail in the city for the people who need it most. A typical scarcity of buses and routes means those with poor economic capacity who can’t afford taxis or cars are stuck walking long distances and facing frustratingly long travel distances and waiting times. This is happening during peak hours, when the bus service systems are completely collapsing. The huge demand far outweighs the available service, which

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reasonably discourages people from using public transport. During these crucial timing hours, it's a horrible journey to catch a private ride after an endless wait. A study [17] revealed that a typical solution of a two-fold affordability metric, both in terms of observed and potential affordability, can provide an effective basis to improve the affordability of public transport in the capital city, Addis Ababa. Furthermore, it is observed that buses are found to be overloaded and operate in dangerous conditions, such as without closing their doors properly, which may expose passengers to accidents, suffocation, pickpocketing, and transmissible diseases. Also, it becomes difficult for the old age people, pregnant, sick, and people with disability to get the transport services conveniently and on time.

Under these circumstances, the present research is carried out to understand the difficulties of bus passengers with ACBSE bus services and to find out certain amicable solutions to improve the transportation services that benefit the majority of employees, business people, visitors, students, and other members of the public. The research aims to analyse the complete level of satisfaction of transport customers, taking quality indicators of bus transportation service as parameters, and recommend numerous solutions for improvement.

B. Objective of the study: The primary objective of the paper is to evaluate customer satisfaction with the Anbessa city bus service and provide recommendations for improving the public transportation system to significantly contribute to producing safe, long-term term sustainable, and judiciously equitable urban mobility in the capital city, Addis Ababa.

II. Literature Review

In a study the transportation domain, customer satisfaction can be assessed for transportation services based on a comparison of their perceptions of service delivery with their prior expectations. Suppose customers' perception about the actual service is below their expectation, a service gap is considered to have happened, and their satisfaction level is rated as poor [3]. On the other side, the satisfaction or dissatisfaction with facilities is influenced by prior expectations regarding the level [1]. For numerous organisations of the public sector, customer satisfaction will itself be the measure of success. In a study [18], satisfaction is defined as the customer's need fulfilment.

Transportation means moving people and goods from one place to another. Road transport is often called the "engine" of society because it keeps everything moving and connected [4]. Quality refers to how well a service meets what customers expect [5]. One of the main reasons customers change service providers is poor service. Research shows that when a provider takes responsibility and solves customer problems, it builds loyalty [6]. Customer satisfaction is a key concern in transport services. It influences travel demand and helps public transport providers remain sustainable and profitable [18]. The quality of transport services

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can be judged by factors like reliability, convenience, safety, security, and comfort [12]. Speed, punctuality, accessibility, reliability, and frequency are also important indicators that reflect how satisfied passengers feel with their travel experience [13].

According to studies [19], customers evaluate service quality based on ten factors. These were later combined into five main dimensions: reliability, responsiveness, assurance (which includes competence, courtesy, credibility, and security), empathy (which includes access, communication, and understanding), and tangibles.

III. Materials and Methods

A. Study Area

Addis Ababa is the capital and the largest city in Ethiopia and in Africa. It covers an area of 527 sq. km and has a population of about 4 million. The city is located at an elevation of 2355 meters above sea level and is associated with political, economic, and cultural activities. Anbessa bus, Higer bus, and Star Alliance bus are the popular buses in Addis Ababa city. The other transportation services include cars, taxis, motorcycles, bicycles, and a light rail transit system.

Fig. 1: Addis Ababa City

Fig. 2: Double-decker Anbessa bus

Rapid urbanization, along with inadequate public transport services and poor infrastructure facilities in the city, causes frequent traffic congestion and road safety issues. Fig 1 & 2 depicts the city transportation facilities.

B. Anbessa Bus Transport System in Addis Ababa City

The Anbessa City Bus Service Enterprise (ACBSE) is the public transport system of Addis Ababa and is owned by the Federal Government of Ethiopia. Its operations are financially supported by the city administration (Eshetie Berhan, Birhanu Beshah, & Daniel Kitaw, 2013). The enterprise runs a fleet of 1,006 buses across 121 routes, carrying around 600,000 passengers every day. During peak hours, 34 of

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these routes get additional services. There are about 1,440 bus stops across the city. The buses can carry up to 100 passengers (i.e. 30 seated and 70 standing) while the newer double-decker buses can accommodate up to 140 passengers, with 80 seats and space for 60 standing passengers. The fare system is flat but varies depending on the route.

C. Terminals

The Addis Ababa City Bus Enterprise operates through four main terminals located at Addis Ketema (Merkato), Legahar, Megenagna, and Menelik II Square. In addition to these, it also has several minor terminals at Gerji, Balcha Hospital, Kera, Bole Michael, Menelik Hospital, Shiro Meda, Ayertena, Saris Abo, Arat Kilo, and Sidist Kilo.

D. Questionnaire Design

A self-completion questionnaire with closed questions was prepared by referring to the five SERVQUAL Model Scale constructs. The questionnaire was designed to collect relevant data and information intended to address the objectives of the study. A list of questions was prepared and distributed to the selected respondents. The questionnaire forms were then distributed to the respective drivers, passengers, pedestrians, and commuters in all the selected bus stop locations. All of the items were measured by using a five-point Likert-type response scale anchored at 5 strongly satisfied and 1 strongly unsatisfied. Questionnaires are administered in different ways: face-to-face, by telephone, and by email. The target group for this study includes all types of passengers such as those traveling short, medium, and long distances. It also covers public transport staff working at the selected Legehar terminal, technical employees at the Yeka depot, key informants, the general manager, and the public transport core process owner of the enterprise.

E. Sampling Method

According to a study [14], the sampling method selected for a given research depends on the requirements of the project, its objectives, the funds available, and time constraints. Two types of sampling methods are recommended: namely, probability (or random) sampling methods and non-probability sampling methods by [10]. According to a study [15], probability sampling involves four considerations. Firstly, the target population must be specified. Secondly, the method for selecting the sample needs to be developed. Thirdly, the sample size must be determined. Employing the 95 percent confidence level and confidence interval, the following algorithm used in a study [20] was adopted to ascertain the minimum sample size for each of the case studies. Given the confidence level = 95%, and e = 0.05

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$$n = \frac{N}{1+N(e^2)} \frac{51{,}450{,}796}{1+51{,}450{,}796(0.05^2)} = 499.99, \quad n=499.99= 500 \text{ people}$$

Where n = sample size, N = population, e = margin of error set at 5%

The study thus targeted a minimum of 500 samples to collect the customer data that will support the research to determine the customer satisfaction over the public transport service in Addis Ababa city.

F. Variables and their Measurements

This research analyzes Customer Satisfaction with the Anbessa city Bus service using existing bus service conditions. The study thus determined dependent and independent variables for assessing the quality of customer service by the respective bus department organization. Table I below describes the independent and dependent variables with their measurements.

Table I: Measurement of independent and dependent variables

Variables	Dimensions	Indicators	Code
Independent Variables	Responsiveness (X1)	Ease of access for booking/ ticketing	C1
		Willingness to accept criticism and suggestions	C2
		Friendliness and employee comfort	C3
		Customer facilities around the station	C4
		Frequency Services so that waiting times are short	C5
	Reliability (X2)	Service's punctuality	C6
		Service regularity	C7
		Waiting time at bus stops during off-peak hours	C8
		Waiting time at bus stops during the peak times	C9
		Frequency of service on weekends	C10
	Tangible (X3)	Comfort of seats on the bus, temperature on the buses	C11
		Bus stops and shelters	C12
		Crowding inside the bus	C13
		Cleanliness inside the bus	C14
		Cost effectiveness, affordability, and value	C15
		Buses are well-maintained	C16
		The buses are good in their technical capacity, and the Frequency of technical failures during the journey	C17

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		Physical comfort of the service environment	C18
		Ability to assist customers with difficulties	C19
		Giving individual attention	C20
	Empathy(X4)	The ability to get service locations, visible, and signage	C21
		Staff behavior	C22
		Feel safe and comfortable using the services	C23
	Assurance(X5)	The employees speak with you by using the appropriate address form	C24
		Buses carry as per the specified capacity	C25
		Not afraid of a pickpocket on the buses	C26
Dependent Variable	Customer Satisfaction (Y)	Customer Satisfaction of Anbessa City Service Bus Service	Y

G. Data Collection

The data was collected in the study with two components: primary and secondary. Primary data was collected by utilizing questionnaire forms. The information was collected from the field, through the drivers of Anbessa city bus service, conductors, normal people (passengers) and students, and Anbessa city bus service enterprise management. The secondary data was collected by means of consulting available literature on the subject under investigation. Tables II to VI show a sample of data collected in the field using data collection tools on Responsiveness, Reliability, Tangible, Empathy, and Assurance service quality attributes, respectively.

Table II: Sample data collected for estimating responsiveness attribute

Items	Strongly Unsatisfied		Unsatisfied		Neutral (No opinion)		Satisfied		Strongly Satisfied	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Responsiveness										
Ease of access for booking/ticketing	90	**22**	120	**26**	30	**6**	160	**28**	100	**18**
Willingness to accept criticism and suggestions	90	**18**	110	**24**	70	**14**	135	**25**	95	**19**
Friendliness and employee comfort	80	**16**	200	**40**	40	**8**	100	**20**	80	**16**
Customer facilities around station	85	**17**	175	**35**	15	**3**	160	**32**	65	**13**

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Table III: Sample data collected for estimating reliability attribute

Items	Strongly Unsatisfied.		Unsatisfied		Neutral (No opinion		Satisfied		Strongly Satisfied	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Reliability										
Frequent Services so that waiting times are short	120	**24**	155	**31**	5	**1**	135	**27**	85	**17**
Service's punctuality	110	**22**	160	**32**	15	**3**	115	**23**	100	**20**
Service regularity	90	**18**	100	**20**	0	**0**	200	**40**	110	**22**
Waiting time at bus stops during off-peak hours	40	**8**	70	**14**	10	**2**	280	**56**	100	**20**
Waiting time at the bus stop during peak times	180	**36**	200	**40**	2	**0.4**	100	**20**	18	**3.6**
Frequency of service on weekends	120	**24**	210	**42**	10	**2**	110	**22**	50	**10**

Table IV: Sample data collected for estimating tangible attribute

Items	Strongly Unsatisfied		Unsatisfied		Neutral (No opinion)		Satisfied		Strongly Satisfied	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Tangible										
Comfort of seats on the bus, temperature on the buses	70	**14**	190	**38**	0	**0**	180	**36**	60	**12**
Bus stops and shelters	110	**22**	120	**24**	20	**4**	160	**32**	90	**18**
Crowding inside the bus	140	**28**	220	**44**	10	**2**	100	**20**	30	**6**
Cleanliness inside the bus	90	**18**	200	**40**	30	**6**	120	**24**	60	**12**
Cost effectiveness, affordability, and value	20	**4**	40	**8**	0	**0**	240	**48**	200	**40**
Buses are well-maintained	130	**26**	140	**28**	20	**4**	170	**34**	50	**10**
The buses are good in their technical capacity and Frequency from technical failure during the journey	50	**10**	100	**20**	40	**8**	220	**44**	90	**18**
Physical comfort of the service environment	40	**8**	170	**34**	20	**4**	180	**36**	50	**10**

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Table V: Sample data collected for estimating empathy attribute

Items	Strongly Unsatisfied		Unsatisfied		Neutral (No opinion)		Satisfied		Strongly Satisfied	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
					Empathy					
Ability to assist customers with difficulties	90	**18**	150	**30**	10	**2**	200	**40**	50	**10**
Giving individual attention	180	**36**	200	**40**	0	**0**	60	**12**	60	**12**
The ability to get service locations, visible, and signage	170	**34**	190	**38**	20	**4**	80	**16**	40	**8**

Table VI: Sample data collected for estimating assurance attribute

Items	Strongly Unsatisfied		Unsatisfied		Neutral (No opinion)		Satisfied		Strongly Satisfied	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
					Assurance					
Staff behavior	90	**18**	120	**24**	80	**16**	160	**32**	50	**10**
Feel safe and comfortable using the services	30	**6**	60	**12**	10	**2**	260	**52**	140	**28**
The employees speak with you by using the appropriate address form	170	**34**	230	**46**	30	**6**	40	**8**	30	**6**
Buses carry as per the specified capacity	200	**40**	210	**42**	0	**0**	60	**12**	30	**6**
Not afraid of pickpocket in buses	190	**38**	210	**42**	2	**0.4**	50	**10**	48	**9.6**

H. Statistical Analysis

The results of the survey were analyzed using descriptive statistics and multiple linear regression analysis. The SERVQUAL SOFTWARE was applied to determine perceptions and quality of service using the five dimensions of service quality, namely empathy, responsiveness, reliability, tangibles, and assurance, as was done by [20].

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IV. Data Analysis And Discussion

A. Customers' Responses on Responsiveness Attribute of Service Quality

Responsiveness attribute is concerned with the willingness and readiness of employees to provide a service to satisfy the needs and desires of customers. Customers were asked to give their opinions on the responsiveness dimension of the service quality of the enterprise. The result obtained is summarized in Table VII.

Table VII: Field survey (Feb. 2018) - responsiveness dimension of service quality attributes (n=500)

Code	Items	Strongly Unsatisfied		Unsatisfied		Neutral (No opinion)		Satisfied		Strongly Satisfied		Mean
		Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
	Responsiveness											
C1	Ease of access for booking/ Ticketing	90	**22**	120	**26**	30	**6**	160	**28**	100	**18**	**3.12**
C2	Willingness to accept criticism and suggestions	90	**18**	110	**24**	70	**14**	135	**25**	95	**19**	**3.07**
C3	Friendliness and Employee comfort	80	**16**	200	**40**	40	**8**	100	**20**	80	**16**	**2.80**
C4	Customer facilities around the station	85	**17**	175	**35**	15	**3**	160	**32**	65	**13**	**2.89**

Table VII above shows that out of 500 respondents, 80 to 90% of the respondents are strongly unsatisfied, 24 to 40% are unsatisfied, 20 to 32% are satisfied, whereas 13 to 19% are strongly satisfied with the ease of access for booking/ ticketing.

B. Customers' Responses on Reliability Attribute of Service Quality

Customers could measure the reliability of the enterprise by considering safety during the service provision process, timely provision of service, and informing them of bus delays in advance. Customers are asked to rate the reliability of the enterprise by taking into account its activities. Their responses are illustrated in the following Table VIII.

Table VIII: Customers' responses on the reliability dimension of service quality

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Code	Items	Strongly Unsatisfied		Un-satisfied		Neutral (No opinion		Satisfied		Strongly Satisfied		Mean
		Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
						Reliability						
C5	Frequency Services so that waiting times are short	120	**24**	155	**31**	5	**1**	135	**27**	85	**17**	**2.82**
C6	Service's punctuality	110	**22**	160	**32**	15	**3**	115	**23**	100	**20**	**2.87**
C7	Service regularity	90	**18**	100	**20**	0	**0**	200	**40**	110	**22**	**3.28**
C8	Waiting time at bus stops during off-peak hours	40	**8**	70	**14**	10	**2**	280	**56**	100	**20**	**3.66**
C9	Waiting time at bus stops during the peak times	180	**36**	200	**40**	2	**0.4**	100	**20**	18	**3.6**	**2.15**
C10	Frequency of service on weekends	120	**24**	210	**42**	10	**2**	110	**22**	50	**10**	**2.12**

Table VIII shows that out of 500 respondents, 8 to 36% of the respondents are strongly unsatisfied, 14 to 42% are unsatisfied, 20 to 56% are satisfied, whereas 3.6 to 22% are strongly satisfied towards punctuality, regularity, waiting time at bus stops, and Frequency of services on weekends.

C. Customers' Response on Tangible Attribute of Service Quality

According to a study [20] tangible dimension of service quality focused on physical facilities, equipment, and the appearance of the employees. To measure the service quality from the tangible dimension, the following questions were raised for the respondents

Table IX: Field survey (Feb. 2022)- tangible dimension of service quality

Code	Items	Strongly Unsatisfied		Un-satisfied		Neutral (No opinion)		Satisfied		Strongly Satisfied		Mean
		Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
				Tangible								

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C11	Comfort of seats in the bus, Temperature on the buses	70	14	190	38	0	0	180	36	60	12	2.58
C12	Bus stops and shelters	110	22	120	24	20	4	160	32	90	18	3.00
C13	Crowding inside the bus	140	28	220	44	10	2	100	20	30	6	2.32
C14	Cleanliness inside the bus	90	18	200	40	30	6	120	24	60	12	2.72
C15	Cost effectiveness, affordability, and value	20	4	40	8	0	0	240	48	200	40	4.12
C16	Buses are well-maintained	130	26	140	28	20	4	170	34	50	10	2.72
C17	The buses are good in their technical capacity and Frequency from technical failure	50	10	100	20	40	8	220	44	90	18	3.40
C18	Physical comfort of the service Environment	40	8	170	34	20	4	180	36	50	10	2.82

Table XI clearly indicates that out of 500 respondents, 4 to 28% of the respondents are strongly unsatisfied, 8 to 42% are unsatisfied, 20 to 48% are satisfied, whereas 6 to 40% are strongly satisfied towards comfort of seats, bus shelters, crowding, cleanliness, cost effectiveness, maintenance.

D. Customers' Responses on the Empathy Dimension of Service Quality

This refers to the ability of the service provider to understand the customers' needs and then provide the required dimension of service quality.

Table X: Field survey (Feb. 2022) - customers' responses on empathy service quality

Code	Items	Strongly Unsatisfied.		Un-satisfied		Neutral (No opinion)		Satisfied		Strongly Satisfied		Mean
		Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
						Empathy						
C19	Ability to assist with customer difficulties	90	18	150	30	10	2	200	40	50	10	2.94

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C20	Giving individual attention	180	36	200	40	0	0	60	12	60	12	2.12
C21	The ability to get service locations, visible, and signage	170	34	190	38	20	4	80	16	40	8	2.26

Table X above shows that out of 500 respondents, 18 to 36% of the respondents are strongly unsatisfied, 30 to 40% are unsatisfied, 12 to 40% are satisfied, and 8 to 12% are strongly satisfied with the individual attention, accessibility, etc.

E. Customers' Responses on Assurance Dimension of Service Quality

Table XI below shows customers' responses about employees related to the assurance dimension of the service. Substantial customers are not satisfied with the employees during service provision.

Table XI:: field survey (Feb. 2022)- assurance dimension of service quality (n= 500)

Code	Items	Strongly Unsatisfactory.		Un-satisfied		Neutral (No opinion)		Satisfied		Strongly Satisfied		Mean
		Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
	Assurance											
C21	Staff behavior	90	18	120	24	80	16	160	32	50	10	2.92
C22	Feel safe and comfortable using the services	30	6	60	12	10	2	260	52	140	28	3.84
C23	The employees speak with you by using the appropriate address form	170	34	230	46	30	6	40	8	30	6	2.06
C24	Buses carry as per the specified capacity	200	40	210	42	0	0	60	12	30	6	2.02
C25	Not afraid of a pickpocket on buses	190	38	210	42	2	0.4	50	10	48	9.6	2.11

Table XI above shows that out of 500 respondents, 6 to 40% of the respondents are strongly unsatisfied, 12 to 46% are unsatisfied, 8 to 52% are satisfied, and 6 to 28% are strongly satisfied with staff behavior, carrying capacity, picketers, and so on.

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F. Customers' Response on the Overall Satisfaction with the Service Delivery Process

As service quality has a significant impact on customers' satisfaction level. Johnston and Clark (2008) indicated that customer satisfaction is a good measure of how effective the service delivery system is because it links to the level of service that the company is currently providing to its customers. Then, customers evaluate their level of satisfaction based on the processes that exist in the enterprise.

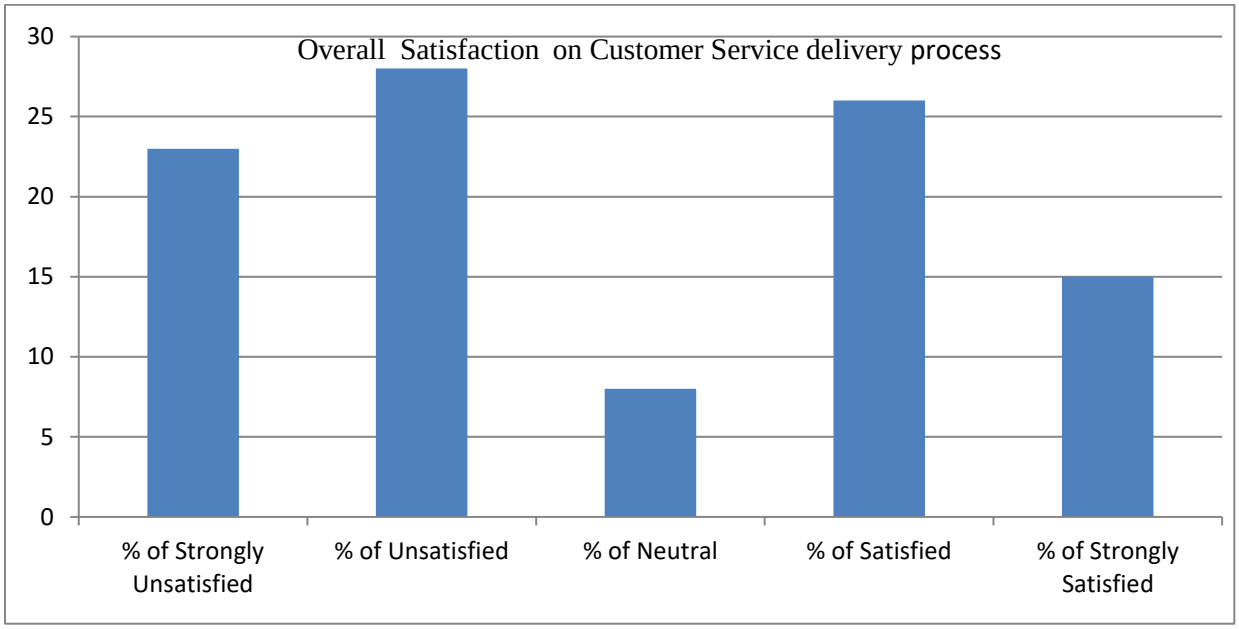

Fig. 3: Overall customer satisfaction level on Anbessa bus service delivery process (Field survey data)

Fig. 3 shows the overall satisfaction level of the customers with Anbessa city service buses in Addis Ababa city. Out of 500 respondents, 23% % of the respondents are strongly unsatisfied, 28% are unsatisfied, 26% are satisfied, whereas 15% are strongly satisfied with the ease of access for selecting the Anbessa city service buses. This clearly indicates that the majority of regular customers of the Anbessa bus service enterprise in Addis Ababa city are not satisfied with the facilities, travel behavior, and ticket price, etc., and this needs strategic solutions to improve customer satisfaction by proper management measures and customer choices.

G Regression Analysis

In this study, multiple linear regression analysis is employed to test whether customers of Anbessa bus city were satisfied or not by five service quality dimensions, namely reliability, responsiveness, assurance, empathy and tangibles, and different models are developed by considering Customer Satisfaction as the dependent variable and the quality attributes as independent variables.

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The general form of the Multiple Linear Regression equation is

$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + Ɛ$, or

Hence, Customer satisfaction= B_0 + B_1 (Responsiveness) + B_2 (Reliability) + B_3 (Tangible) + B_4 (Empathy) + B_5 (Assurance)

Multiple linear regression equations are developed using SPSS 20.0 software, for each evaluation parameter by considering the customer satisfaction on the respective parameter as the dependent variable and the factors responsible for the evaluation of the parameter as the independent variables. The equations are found to be logically good and are validated properly. The following are the developed customer satisfaction models.

Model 1: Customer satisfaction on Responsiveness service quality = 69.140 +**0.731***(Ease of access for booking/ticketing) + **0.885***(Willingness to accept criticism and suggestions) + **0.798***(Customer facility around stations) + **0.041***(Friendliness and Employees comfort) -- Equation (1)

Therefore, overall customer satisfaction on Responsiveness service quality**=** 69.140 **+ 0.731**(3.12) + **0.885** (3.07) + **0.798** (2.80) + **0.041** (2.89) = **76.49%**

The above equation shows that the slope of the regression line is clearly above zero. This means that overall satisfaction rises as the four main factors increase. Slope of the regression line indicates the rate of change in the dependent variable (y) for every one-unit increase in the independent variable (x), which is verified in these developed models. The coefficients of the developed model are the indicators for better output and are found to be more appropriate. The equation shows that the overall satisfaction of Anbessa bus transport services by passengers in Addis Ababa will be 76.49% when all 4 service quality attributes are at the zero level. Again, the equation obtained denotes that customers' satisfaction with Ethiopian Anbessa city bus service, taking Responsiveness quality indicator as a whole, will increase when their satisfaction with Ease of access for booking/ticketing, Willingness to accept criticism and suggestions, Friendliness, and Employees comfort, and Customer facility around stations increases. Thus, it indicates that if satisfaction with all the above variables increases by one unit, overall satisfaction increases by 0.764, 0.240, 0.059, and 0.281 percent, respectively.

Model 2: Customer satisfaction on Reliability Service Quality = 37 + 0.170*(Service punctuality) + 0.148*(Waiting time at bus stops off-peak hours) + 0.258*(Waiting time at bus stops during the peak hours) +0.076*(Frequency of services on weekends) + 0.223*(Frequency service so that waiting time is short) + 0.321 *(Service Regularity) -------- Equation (2)

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Therefore, overall customer satisfaction on Reliability Service Quality =37.084 + 0.170 (2.82) + 0.148 (2.87) + 0.258 (3.28) + 0.076 (3.66) + 0.223 (2.15) + 0.321(2.12) = 40.27%

The above equation indicates that the overall satisfaction of Anbessa bus transport services by passengers in Addis Ababa will be 40.27% when all 6 service quality attributes are at the zero level. Again, the equation obtained denotes that customers' satisfaction with Ethiopian Anbessa city bus service, taking the Reliability quality indicator as a whole, will increase by 0.216, 0.337, and 0.140 percent, and decrease by 0.561 percent, respectively, when five variables increase by one unit, and one variable decreases by one unit. The coefficients of the developed model are appropriate to get the best output from the model.

Model 3: Results of Regression Analysis on Tangible Dimension of Service Quality

Customer satisfaction on Tangible service Quality = 58 +0.493*(Comfort of seats on the bus, Temperature on the buses) + 0.671*(Crowding inside the buses) + 0.562*(Cleanliness inside the bus) +0.321*(Bus stops and shelters) + 0.286*(Cost effectiveness, affordability, and value)+ 0.433(Buses are well maintained)+ 0.234*(The buses are good in their technical capacity and Frequency from technical failure during journey) + 0.088*(Physical comfort of the services environment) ---------- Equation (3)

Therefore, overall customer satisfaction on Tangible service Quality= 58.013 + 0.493 (2.58) + 0.671 (3.00) + 0.562 (2.32) + 0.321 (2.72) + 0.286 (4.12) + 0.433 (2.72) + 0.234 (3.40) + 0.088 (2.82) = 66.90%

The above equation shows that the overall satisfaction of Anbessa bus transport services by passengers in Addis Ababa will be 58.01% when all 8 service quality attributes are at the zero level. Again, the equation obtained denotes that customers' satisfaction with the Ethiopian Anbessa city bus service, taking the Tangible quality indicator as a whole, will increase when their satisfaction with seven service quality indicators increases and crowding inside the buses decreases. The developed model has appropriate coefficients to explain a better relationship between dependent and independent variables.

Model 4: Result of Regression Analysis on the Empathy Dimension of Service Quality

Customer satisfaction of Anbessa city bus services on Empathy service quality indicator = 39.66 + 0.406*(Ability to assist customer difficulty) + 0.358*(Giving individual attention) + 0.160*(The ability to get service locations, visibility, and signage) ---------- Equation (4)

Therefore, overall customer satisfaction on Empathy service quality indicator = 39.664 + 0.406 (2.94) + 0.358 (2.12) + 0.160 (2.26) = 41.98%

The equation above shows that the slope of the regression line is clearly above zero, meaning overall satisfaction increases as the three key factors rise. It also indicates that passenger satisfaction with Anbessa bus services in Addis Ababa would be 39.66% even if all three service quality factors were at zero. Again,

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the equation obtained denotes that customers' satisfaction with Ethiopian Anbessa city bus service, taking empathy quality indicator as a whole, will increase when their satisfaction with the Ability to assist customer difficulty, giving individual attention, the ability to get to service locations, and visible signage increases. The model coefficients indicate that the relationship between dependent and independent variables is close to reality.

Model 5: Result of Regression Analysis on Assurance Dimension of Service Quality

Customer satisfaction on Assurance service quality indicator = 36.942 +0.247*(Staff behavior) + 0.220*(Feel safe and comfort using the services) + 0.083*(The employees speak with you by using appropriate address form) + 0.301*(Not afraid of pick pocket on the buses) +0.321*(Buses carry as per the specified capacity) ---------- Equation (5)

Therefore, overall customer satisfaction on Assurance service quality indicator = 36.942 + 0.247 (2.92) + 0.220 (3.84) + .083 (2.06) +0.301 (2.02) + 0.321 (2.11) = 39.96%

The above equation indicates that the overall satisfaction of Anbessa bus transport services by passengers in Addis Ababa will be 36.94% when all 5 service quality attributes are at the zero level. Again, the equation obtained denotes that customers' satisfaction with Ethiopian Anbessa city bus service taking Assurance quality indicator as a whole will increase when their satisfaction with feel safe and comfort using the services, staff behavior, the employees speak using appropriate address form, bus carry as per the specified capacity, and tot afraid of pick pocket on the buses increase. The coefficients in the model are true representatives for getting an appropriate output.

General evaluation of the services provided by the Anbessa City bus Transport Service by the customers

Customers were asked to evaluate their level of satisfaction in general based on the service attributes, and the results obtained are as follows:

Table XII: Responses of passengers on service quality indicators (n= 500)

Cod	Variables	Strongly unsatisfied		Unsatisfied		Neutral		Satisfied		Strongly satisfied		Mean
		Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	
X_1	Responsiveness	40	8	80	16	10	2	290	58	80	16	3.58
X_2	Reliability	150	30	216	43.2	55	11	60	12	19	3.8	2.17
X_3	Tangible	66	13.2	105	21	36	7.2	207	41	86	17	3.28

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X_4	Assurance	118	23.6	200	40	25	5	125	25	32	6.4	2.51
X_5	Empathy	120	24	203	40.6	37	7.4	90	18	50	10	2.49

The results indicate that the respondents are strongly unsatisfied with the service attributes at the range of 8 to 30%, followed by satisfied at the range of 12 to 58%, and strongly satisfied at the range of 3.8 to 17%.

Variation in Overall Customer Satisfaction of Anbessa City Bus Service

In order to observe the variation of customer satisfaction with bus service attributes, different graphs are plotted by considering customer satisfaction on x – x-axis and the corresponding bus service attributes on y – y-axis, and are as shown in Fig. 4 to 8.

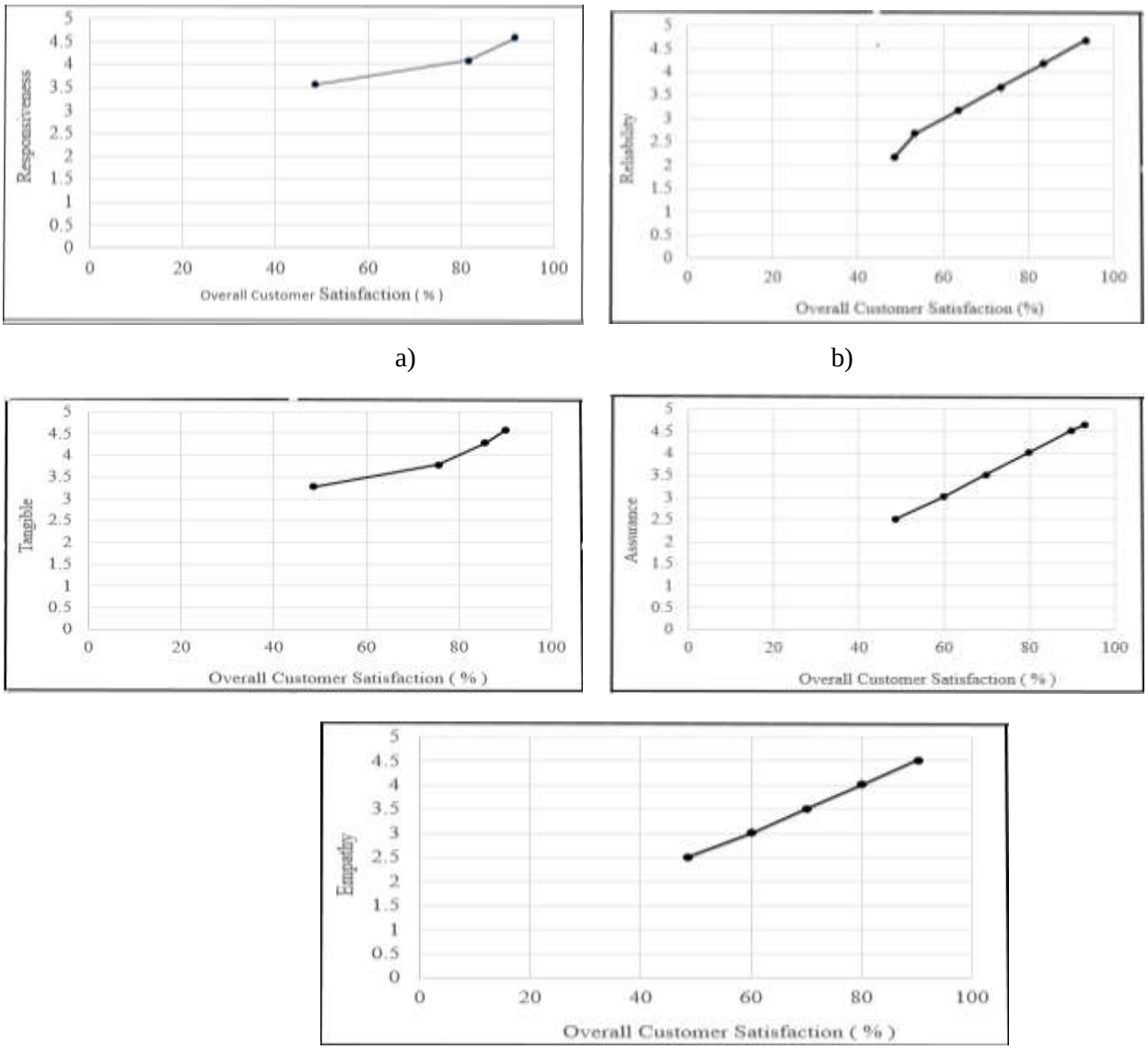

Fig.4. - 8: Variation of Bus service attributes with Customer Satisfaction

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The above graphs indicate that customer satisfaction increases as the bus service attributes increase. To achieve a customer satisfaction of 60%, the responsiveness attribute shall range between 3.5 to 4, whereas the other attributes shall range between 3 to 3.5. In order to achieve 90 % to 100% satisfaction, all the bus service attributes shall range between 4.5 to 5.

V. Conclusions

The main objective of this thesis is to study the Road Asset Management (RAM) and the existing practices taking the Sodo district as a case study and making recommendations by preparing frameworks based on the findings. Organizational challenges, financial challenges, political awareness, overall asset management system, performance monitoring, condition assessment, planning of implementation of asset management, and professional competency were the major causes of problems identified for road asset management practice in the Sodo district.

Based on the research assessment the researcher concluded:

- There is a lack of asset management components implementation practice in its adequate form or sense in the Sodo district. The implementation stage of an asset management system is still at the planning stage. Most of the individual management systems have not been utilized, data collection decisions were not based on the standards and input needs of management systems or processes behind the rationalization of data collection. The Sodo district does not formally identify and document existing links between the data they collect and the project selection decisions they support. The main problems faced in applying asset management practice are a lack of an organized asset management department, lack of professional employees, inadequacies of digitalized asset management system, and absence of short courses to acquire state-of-the-art techniques of road asset management.
- Therefore, this study strictly underlines the necessity of well-defined government road asset management policies, regulations, and strategies as the basis for better road asset management which treats roads as capital assets of both the nation and the study area. Moreover, the study tries to come up with a rational solution for a modern asset management system by investigating the current road asset management system in the study area and then recommending a better way of road asset management for the sustainable social and economic development of the districts as well as the region.
- Furthermore, the study recommends the best framework for decision-makers on how to make quality decisions between alternative maintenance strategies. Also, road operators at different levels should take into consideration the impacts of poor road asset management on the socio-economic life of their

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society. An integrated and holistic approach to road management is needed to align funding, management systems, and procedures.

- Moreover, the study presents relevant topics and future challenges for Road Asset Management. It also summarizes the latest issues related to road infrastructure maintenance and outlines new themes for future research.

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A Lesson from Existing Parks of Addis Ababa

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Abstract

Park development must consider public input, as they are the primary users. To enhance recreational ecosystem services, cities should assess existing parks based on public feedback for future green space planning. This paper studied and analyzed the perceived capacity of two parks in Addis Ababa, Ethiopia, selected for their land use and size, which influence their recreational capacity. Data were collected through a questionnaire from 797 visitors to examine factors like visit frequency, desired amenities, time spent, and travel time to the parks, along with suggestions for improvements. Results indicate medium satisfaction among visitors in both parks, with cleanliness identified as a key concern in Bihere Tsige Park. The majority of respondents in both parks highly favor amenities that support passive recreational activities. Recommendations include enhancing cleanliness in Bihere Tsige Park and increasing greenery in Tekle Haimanot Park. The paper recommends that park managers, policymakers, and planners utilize these insights to improve current parks and guide future developments.

Keywords: Bihere Tsige Park, Frequency of Visit, Level of Satisfaction, Park Amenities, Recreational Capacity, Suggestions, Tekle Haimanot Park

I. Introduction

Urban parks are essential sources of ecosystem services that are primarily developed for recreation but also offer various other benefits [1-3]. Parks are among the urban green spaces that connect people with nature by offering recreational ecosystem services [4]. Urban parks vary in design and distribution worldwide, influenced by historical events, design philosophies, and social class [3, 5]. They play a crucial role in delivering recreational ecosystem services and enhancing human well-being [3]. In developing countries like Ethiopia, urban planning must integrate parks into development. To improve parks, input from end-users, the visitors, should improve their desirability [6].

The location of urban parks is crucial for their ability to provide recreational ecosystem services [7] as surrounding land uses significantly influence the parks' capacity [8]. For instance, a study by Pacheco and Vasconcelos [9] found that parks in residential areas tend to be less visited, while those near commercial

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zones attract more visitors. A study by Kaczynski et al. [8] also pointed out that parks adjacent to busy roads may experience disturbances that affect recreational activities. In addition to recreation, urban parks offer vital ecosystem services like climate control. Research by Hamada et al. [10] shows that commercial areas disrupt the cooling effects of parks more than residential areas. Given the higher urban heat island effect in commercial zones, Gago et al. [11] recommended that urban green space development prioritize these areas to enhance climate regulation services.

The size of urban parks also impacts their capacity to provide recreational ecosystem services [12]. For example, Liu et al. [12] indicated that larger parks with diverse amenities, particularly those featuring playgrounds, attract visitors from greater distances. In this paper, park size is highlighted as a key criterion, supporting the Addis Ababa City structure plan, which classifies parks based on size and features to enhance service provision [13].

Investigating the potential of existing parks to provide recreational ecosystem services is essential for appreciating and maintaining desired amenities [14] and identifying areas for improvement to enhance visitor satisfaction [1]. Understanding the perceived capacities and satisfaction of parks is also essential for assessing visitors' comfort levels in the spaces provided for them [6]. Assessing the recreational potential of parks requires investigating visitor preferences [14], satisfaction levels [6], and recreational activities, including what visitors do, their frequency of visits, and duration of stay [3, 15]. Another study by He et al. [15] provided recreational use behaviors as part of the indicators to describe urban green space use. They include *where,* which implies where the visitors recreate, *what* refers to what they like to do, *when,* which relates to when they preferred to visit, *how long,* which is the preferred time to stay, and *how often,* which is the frequency of visit within a specific period [15].

In this paper, the level of satisfaction in the sample parks [6], what people like from the amenities that the parks provide [3], how frequently people visit the sample parks [3, 15], how much time people spend in the sample parks and their motivation of stay [3, 15], how far people travel to get to the parks [3] are investigated to describe the park and the level of satisfaction in the park. Additionally, what the sample parks should improve and suggestions for forthcoming parks that we should learn from the existing parks were collected from the participants [6].

How many people enjoy parks shows the perceived recreational ecosystem service status and desirability of parks [6], while frequency of visit to parks indicates the quality and desirability of the parks by revealing how much people like to be present in the park [16]. The duration of stay in the park indicates whether people are happy to stay in the park or not. Time to travel to parks shows the availability of parks within a small distance, and it shows how dedicated people are to go to the parks because the park is worthy enough, even to travel long distances for longer distance travelers [3]. The desired amenities from parks tell the

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motivation of people to visit parks [3] while suggestions for improvement provide information on what is missing in the park and what people like to find in the parks [6]. Finally, by learning from the existing parks and from what people recommend for future park development, it is possible to use the information for parks to be developed in Addis Ababa and the urban areas of Ethiopia. This paper investigates the perceived recreation potential of two parks in Addis Ababa using a questionnaire. Research worldwide has examined perceived potential through visitors' motivations, visit frequency, and satisfaction levels. For instance, Goodarzi and Haghtalab [6] studied visitor satisfaction in an Iranian park, revealing dissatisfaction with recreational offerings and suggestions for improvement. Similarly, Breuste et al. [3] found that people in Buenos Aires primarily visit parks to enjoy nature. However, studies in Ethiopia on existing recreational ecosystem services and community suggestions for improvement are scarce. This paper aims to provide valuable insights for the sampled parks and establish a self-evaluation baseline information for other existing and future parks.

II. Methodology

B. Description of the Study Area

In this paper, the case study area is Addis Ababa, the capital city of Ethiopia, founded during the reign of King Menelik (1844-1913) and Queen Taitu in 1889 and named Addis Ababa or new flower due to its natural beauty and recreational spots [17, 18] as presented in Fig. 1. Currently, the Addis Ababa Beautification, Park, and Cemetery Agency is responsible for developing and maintaining the city's parks, which primarily offer passive recreational activities.

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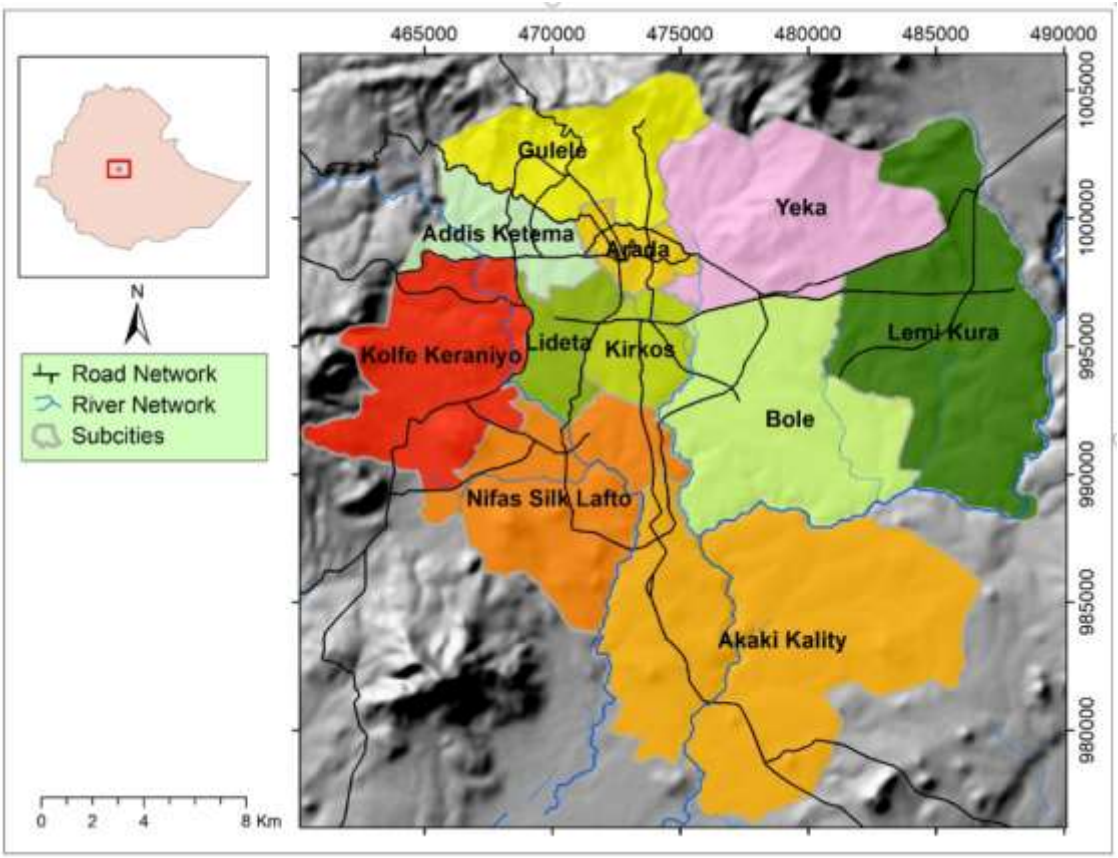

Fig. 1: Addis Ababa City Map

The sample parks in Addis Ababa were selected based on their surrounding land uses (residential and commercial) within a 500m radius [8] and their size, specifically City Park and Woreda Park. The chosen parks are Bihere Tsige and Tekle Haimanot parks, which are both managed by the Addis Ababa City Administration Beautification, Parks, and Cemetery Agency. Bihere Tsige Park, the largest (14 ha) and oldest (established in 1970), is surrounded by residential areas and features amenities like diverse plants for recreational, educational, and medicinal purposes, a children's playground, and a mini-zoo. It includes long walkways, numerous trees, diverse landforms, and is crossed by the polluted Little Akaki River. In contrast, Tekle Haimanot Park is a smaller Woreda Park (0.45 ha) located in a busy commercial area, providing a resting place from the city's hustle. Its limited size accommodates sitting areas, space for indoor games, and a cafeteria. The park is also used for socio-cultural activities, such as "Equb," a money-saving practice among members who pay an entrance fee for social gatherings.

The Structural Plan Project Office of Addis Ababa has a policy to establish parks throughout the city to meet recreational needs. Parks are categorized into four types: City Parks (>10 ha), Sub-City Parks (1-10 ha), Woreda Parks (0.3-1 ha), and Neighborhood Parks (0.1-0.3 ha) [13].

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C. Methods

The research method involved using a questionnaire directed at park visitors [3, 6]. Data were collected from January to May 2023, coinciding with the summer season and a peak wedding period, which typically attracts more visitors [19]. Respondents were randomly selected from the sample frame of park visitors, ensuring each individual had an equal chance of being represented. Background information about the sample population was gathered to better understand them. In total, 797 park visitors participated in the questionnaire.

The descriptive method of data analysis is utilized in this research to summarize and describe visitor preferences. This approach aims to provide foundational information that can enhance current parks and inform the development of future parks. The data is summarized and presented using tables for easy comprehension.

III. Results and Discussion

A. Level of Perceived Enjoyment in Sample Parks

As presented in Table I, in Bihere Tsige Park, 49.5% of visitors enjoy the park at a medium level, while in Tekle Haimanot Park, this figure is slightly higher at 52.3%. Additionally, those who enjoy the parks very much account for 37.5% in Bihere Tsige Park and 35.8% in Tekle Haimanot Park.

Table I: Level of satisfaction in sample parks

	Status of people enjoying Bihere Tsige and Tekle Haimanot Parks					
	Bihere Tsige Park		Tekle Haimanot Park		Total	
	No. of respondents	Percent	No. of respondents	Percent	No. of respondents	Percent
Very much	150	37.5	140	35.3	290	36.4
Medium	198	49.5	209	52.6	407	51.0
Low	52	13.0	42	10.6	94	11.8
I don't enjoy it	0	0	6	1.5	6	0.8
Total	400	100.0	397	100.0	797	100

B. Recreational Use Behaviors

***1)** Frequency of visits:* In Bihere Tsige Park, 41% of visitors reported visiting the park once a month, while in Tekle Haimanot Park, 22.5% of visitors reported visiting the park once a week. Additionally, Table II indicates that 31.5% of respondents in Bihere Tsige Park visit once a week. Also, this indicates that the majority of respondents in Bihere Tsige Park visit monthly, whereas the majority in Tekle Haimanot Park visit weekly.

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Table II: Frequency of visits to parks

Frequency of visits to parks						
	Bihere Tsige		Tekle Haimanot		Total	
	No. of respondents	Percent	No. of respondents	Percent	No. of respondents	Percent
For the first time	8		36	9.1	44	5.5
Everyday	10	2.5	56	14.1	66	8.3
Once a week	126	31.5	91	22.9	217	27.2
Once a month	164	41.0	58	14.6	222	27.8
Once in 2 or 3 months	13	3.3	3	.8	16	2.0
Whenever we can	47	11.8	75	18.9	122	15.3
When we want to feel good	2	.5	2	.5	4	0.5
Sometimes	5	1.3	38	9.6	43	5.45
Once in 6 months	10	2.5	3	.8	13	1.65
Once in two weeks	4	1.0	7	1.8	11	1.4
Twice a week	2	.5	4	1.0	6	0.75
Once a year	8	2.0	2	.5	10	1.25
three times a week	1	.3	22	5.5	13	2.9
Total	400	100.0	397	100.0	797	100

2) Amenities people enjoy in the sample parks: In Bihere Tsige and Tekle Haimanot parks, a significant majority of visitors enjoy amenities related to passive recreation, with 65.8% and 69.3%, respectively, and presented in Table III. These activities include watching plants and people, listening to birds, and reading while sitting or lying in the natural area. Tekle Haimanot Park lacks a children's playground and a mini-zoo, making those amenities irrelevant for its visitors. Additionally, the park does not feature diverse landforms. In contrast, Bihere Tsige Park includes various slopes, rendering gentle landforms less applicable.

Table III: Amenities people enjoy in the sample parks (note: np –not relevant)

Amenities people enjoy in Bihere Tsige and Tekle Haimanot Park				
	Bihere Tsige Park		Tekle Haimanot Park	
	No. of respondents	Percent	No. of respondents	Percent

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The children's playground	9	2.3	NR	-
Everything (the plants, seats, and shades)	64	16.0	9	2.3
Amenities for passive activities (seats, shades, the lawns for lying down, the plants that are resting places for the birds, the quiet reading areas)	263	65.8	275	69.3
The quiet areas	-	-	40	10.0
The landform	3	0.8	3	0.8
The mini zoo	56	14.0	NR	-
The areas for active activities (playing area)	2	.5	-	-
The sound from the nearby church	-	-	7	1.8
Nothing	3	0.8	19	4.8
The cafeteria	-	-	41	10.3
The outdoor interaction areas	-	-	4	1.0
Total	400	100.0	397	100.0

3) Time to spend in the park and reasons for staying that long: In Bihere Tsige and Tekle Haimanot parks, the most common duration of stay is between 30 minutes to 2 hours, accounting for 42% and 58% of visitors, respectively. The primary reason for longer stays in Bihere Tsige Park is the enjoyment of the greenery and the inspiration drawn from nature. In contrast, visitors to Tekle Haimanot Park primarily stay longer to interact with friends and family. Additionally, while 38.8% of people stay in Bihere Tsige Park for 2-4 hours, only 5.8% stay that long in Tekle Haimanot Park. Conversely, a larger portion of visitors (34.8%) in Tekle Haimanot Park stay for 0-30 minutes, compared to just 4.8% in Bihere Tsige Park.

4) Time to travel to get to the parks: The investigation of travel time to the parks was conducted under conditions of no traffic. As presented in Table IV in Bihere Tsige Park, out of 400 respondents, 283 (70.75%) used transportation to reach the park. Among these, the majority, 37.8%, reported taking 15-30 minutes to arrive, while 34.3% traveled for 30 minutes to an hour. In Tekle Haimanot Park, of the 397 respondents, 226 (56.9%) used transportation. Among these individuals, the majority (39.45%) took 30 minutes to 1 hour to reach the park. However, this result may be influenced by visitors who do not come specifically for recreation but rather pass through while conducting business because the park is located in a core commercial area of Addis Ababa.

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Table IV: Travel time to visit the sample parks

	Travel time to visit the sample parks						
	0-5 min.	6-15 min.	16-30 mins.	30 mins. - 1 hr.	1-2 hrs.	> 2 hrs.	Total
Time to travel to visit the Bihere Tsige park							
Number of respondents	9	36	107	97	31	3	283
Percent	3.18	12.72	37.8	34.3	10.9	1.1	100
Time to travel to visit Tekle Haimanot Park							
Number of respondents	19	29	47	89	29	13	226
Percent	8.4	12.8	20.8	39.45	12.8	5.75	100
Total number of respondents	28	65	154	186	60	16	509
Percent	5.79	12.77	29.3	36.88	11.86	3.4	100

C. Suggestions for improvement

1) Suggestions for improvements of the sample park: Out of the 400 respondents in Bihere Tsige Park, 309 (77.25%) provided suggestions for improvement, while in Tekle Haimanot Park, 233 (58.7%) did the same. It's important to note that some individuals offered multiple suggestions. Therefore, the total number of suggestions was calculated, resulting in 589 suggestions for Bihere Tsige Park and 329 for Tekle Haimanot Park. A small percentage of respondents indicated they did not have any additional suggestions, believing the parks should maintain their current state—1.19% for Bihere Tsige Park and 1.52% for Tekle Haimanot Park. The most frequently suggested improvement was for the parks to be cleaner, with 19.69% of suggestions for Bihere Tsige Park and 17.33% for Tekle Haimanot Park. Other notable suggestions included the establishment of a cafeteria in Bihere Tsige Park (15.62%) and the addition of more plants in Tekle Haimanot Park (12.16%).

2) Recommendations for future forthcoming parks: From the 400 visitors in Bihere Tsige Park, 177 (44.25%) provided suggestions for future parks, while 145 (36.5%) of the 397 visitors in Tekle Haimanot Park did the same. Notably, some individuals offered multiple suggestions, such as advocating for cleanliness, the inclusion of indigenous plants, and designs aligned with community preferences. This resulted in a total of 272 suggestions for Bihere Tsige Park and 208 for Tekle Haimanot Park. The most common suggestion for Bihere Tsige Park (20.96%) was that the park should be very clean. In contrast, the predominant suggestion for Tekle Haimanot Park (31.73%) was that the park should feature more greenery and vegetation.

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IV. Comparison of Findings and Discussion

Parks are among the most favored outdoor recreational areas in the community. This makes considering people's preferences and suggestions for improvements in their design necessary. This paper aims to gather foundational information from two sample parks in Addis Ababa, which will help enhance existing parks and provide a baseline for future developments. These parks, located amidst varied land uses, significantly influence their recreational capacity, while their size plays a crucial role in effectively meeting community needs.

The questionnaire results show that most visitors go to Bihere Tsige Park once a month, while Tekle Haimanot Park is visited weekly, making it more popular. This trend aligns with Pacheco and Vasconcelos (2007) indicate that parks near commercial areas attract more visitors, often for socio-cultural activities. Both parks receive medium satisfaction ratings, highlighting the need for improvements. Cleanliness is a primary concern for both, reflecting sanitation issues. Visitors suggest adding cafés to Bihere Tsige Park but not to Tekle Haimanot Park, which indicates different needs. Additionally, Tekle Haimanot Park requires more greenery, as visitors recommend adding plants, while Bihere Tsige Park is already sufficiently green. Overall, visitor suggestions can guide enhancements for both parks and inform improvements in other parks.

The findings reveal that most visitors spend between 30 minutes to 2 hours in the parks, mainly to enjoy the greenery and nature, which aligns with Breuste et al. [3], regarding visitor preferences in Buenos Aires. This suggests that park management should focus on enhancing natural elements that attract visitors. In Bihere Tsige Park, the second most common duration of stay is 2-4 hours, indicating that many visit for recreation. In contrast, Tekle Haimanot Park sees most visitors staying only 0-30 minutes, with a few staying longer. Factors such as its commercial location and a lack of facilities that promote longer visits may contribute to this trend. Further research is needed to understand the dynamics influencing visitor behavior in Tekle Haimanot Park.

Visitors enjoy the greenery and passive activities in parks, seeking respite from urban hustle for physical and mental relaxation. The quietness appreciated in Tekle Haimanot Park, absent in Bihere Tsige Park, is likely due to its busy commercial surroundings, which create a need for tranquil spaces. This makes Tekle Haimanot Park vital as it offers a natural escape from the hectic urban environment, providing essential recreational opportunities. The differences between the parks highlight the need for tailored amenities based on their specific contexts and visitor preferences.

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The results indicate that most people take 16-30 minutes to reach Bihere Tsige Park and 30 minutes to 1 hour for Tekle Haimanot Park, suggesting a willingness to travel for these destinations. However, few visitors come from nearby (0-5 minutes) or very far (over 2 hours) distances, indicating that most visitors are coming from moderate distances. The longer stay duration at Bihere Tsige Park, located in a residential area, implies that people travel significant distances for recreational purposes. In contrast, the shorter stay at Tekle Haimanot Park, situated in a commercial area, suggests that visitors may not be traveling specifically for recreation. It's possible that many stop by on their way to work. This finding, while needing further research, highlights the convenience of having parks in busy urban areas, as noted by Breuste et al. [3].

Visitor experiences and their familiarity with parks significantly influence suggestions for future developments. Despite this limitation, the feedback remains relevant, reflecting the reality of users' experiences. Cleanliness is a key concern in Bihere Tsige Park, while Tekle Haimanot Park visitors emphasize the need for more greenery and plant coverage. Future park developments should incorporate these suggestions to better meet the recreational needs of the community. Many visitors expressed a desire to be involved in the design process, highlighting the importance of including local communities in park development. Similar sentiments were noted in research by Cohen et al. [20] on parks in Los Angeles, where residents advocated for improvements such as organizing events, enhancing landscaping, and increasing sports facilities. Therefore, we recommend that the feedback from the community be integrated into park development in Ethiopia to effectively address societal recreational needs.

Future studies can explore strategies for creating quiet recreational spaces in bustling urban centers. Additionally, researchers may investigate methods to integrate built-up areas with natural green spaces. Further examination of the benefits of urban nature in Ethiopia's hectic urban environments is also warranted.

V. Conclusion

Park design should incorporate community input to enhance the provision of recreational ecosystem services. The indicators presented in this paper reflect the current state of the sample parks based on visitor attitudes. Most respondents reported medium satisfaction with these parks. While the frequency and duration of visits differ between the two parks, these differences likely relate to their size, surrounding land use, and available amenities. The travel time to each park also reflects the purpose of the visit. Findings indicate that Bihere Tsige Park is primarily visited for recreation, whereas Tekle Haimanot Park serves as a space for social interaction and a respite from the urban environment. Common suggestions for improvement, particularly regarding cleanliness, highlight existing sanitation issues in both parks. We

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recommend that park management utilize public feedback to enhance the parks and their capacity to provide recreational ecosystem services. Additionally, urban planners and policymakers should consider these suggestions in future park developments to create a sustainable urban environment that meets community needs.

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Market-Driven Acacia Mearnsii-Based Tanguay System for Sustainable Bioenergy Production in the Upper Blue Nile Basin, Ethiopia

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Abstract

As energy demand increases in urban areas of Ethiopia, the expansion of smallholder plantations, particularly Acacia mearnsii woodlots, has become essential in meeting bioenergy needs. However, small-scale farmers have been underrepresented in the value-added bioenergy production systems. This study explores factors influencing value addition and benefit distribution in the market-driven A. mearnsii-based Tanguay system for bioenergy production. A random sample of 148 producers and 52 traders was surveyed using snowball sampling, supplemented by 7 interviews, 6 focus groups, and field observations. The Heckman two-stage model analyzed participation and product volume in the bioenergy market. A. mearnsii woodlots cover 31,000 hectares, producing 145,000 tons of charcoal annually (equivalent to 8.3 million sacks of 17.4 kg), valued at $43 million. These plantations sequester 5.3 million tons of CO_2 and reduce deforestation on 93,000 hectares. Small-scale farmers earn $1,936 annually, accounting for 60% of their income, while traders earn between $5,000 and $30,000. The first-stage probit model revealed that age ($p<0.03$), experience ($p<0.003$), access to credit ($p<0.034$), and contract marketing ($p<0.000$) significantly influenced farmers' decisions to engage in value addition. The second-stage Heckman model revealed that training services ($p < 0.041$), livestock holdings ($p < 0.054$), and age ($p < 0.058$) were key determinants of the volume of bioenergy products for value addition. The total relative commercialization margin was 58%, indicating that marketing actors captured a larger share of the final market price, with farmers earning 42%. The study concludes that A. mearnsii woodlots support bioenergy production, income for smallholders, local revenue, job creation, and better rural livelihoods. Improving market access, forming cooperatives, and providing technical training are keys to achieving equity and sustainability in bioenergy production in Ethiopia.

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I. Introduction

Ethiopia's growing urban energy demand has increased the need for sustainable bioenergy production [1]. Charcoal, derived from biomass, plays an essential role in meeting this demand and has become a critical energy source for households and small enterprises [2]. The development of smallholder woodlots has emerged as a reliable system for the production of charcoal and firewood [3]. Among various species used in these systems, *Acacia mearnsii* (Black Wattle) has gained prominence due to its fast growth, adaptability, and high biomass yield, making it an ideal species for bioenergy production [4]. In the Upper Blue Nile Basin, smallholder farmers have increasingly adopted *Acacia mearnsii*, marking a significant shift from traditional agriculture to tree-based bioenergy systems [3, 5].

Deforestation and land degradation are serious challenges in Ethiopia's highlands, compounded by factors such as soil erosion, overgrazing, and unsustainable farming practices [6, 7]. To address these issues, many smallholder farmers in the region have adopted the *Acacia mearnsii*-based Taungya system, which integrates tree planting with agriculture. This agroforestry approach mitigates land degradation while enhancing economic outcomes by providing an additional source of income from charcoal production [2, 3].

Despite *Acacia mearnsii's* suitability for bioenergy production in Ethiopia, its full potential remains largely untapped due to limited engagement in value-added activities [4]. Most farmers primarily focus on basic biomass extraction, such as cutting wood for charcoal, without venturing into processing or marketing, which restricts their ability to realize the full economic benefits [5]. This lack of value addition hinders the development of a sustainable bioenergy market and limits opportunities for improved livelihoods [8].

As the demand for bioenergy continues to rise, establishing a comprehensive value chain that encompasses the production, processing, and marketing of value-added products is crucial for the long-term sustainability of bioenergy systems [9]. Research on the distribution of benefits within the *Acacia mearnsii* woodlot value chain is limited, especially regarding the role of value addition in improving livelihoods [8]. This study aims to explore the potential of value addition and the roles of smallholder farmers in bioenergy production, processing, and marketing. Ultimately, it seeks to unlock the full potential of *A. mearnsii* for sustainable bioenergy production and enhanced livelihoods in the Upper Blue Nile Basin and beyond.

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II. Materials and Methods

A. Study site

This study was carried out in the Upper Blue Nile Basin, located in the northwestern highlands of Ethiopia, a region that has become a prominent hub for *Acacia mearnsii*-based woodlot production. This trend has been largely driven by the growing demand for bioenergy, particularly charcoal and fuelwood. Geographically, the study area is situated between 10°57'23" to 11°11'21" N latitude and 36°40'01" to 37°05'21" E longitude, encompassing approximately 741 hectares. It lies at high altitudes ranging from 1,800 to 2,900 meters above sea level—with some areas reaching up to 3,200 m.a.s.l.—and is characterized by vegetation ranging from moist subtropical to cool highland climate. The region receives annual rainfall between 1,500 mm and over 2,000 mm, with mean annual temperatures ranging from 15°C to 24°C. These are conditions that favor the cultivation of fast-growing tree species like *Acacia mearnsii*. Introduced approximately more than 20 years ago, *A. mearnsii* is commonly grown using the Taungya agroforestry system, which combines tree planting with seasonal crop cultivation, helping to restore degraded lands while supporting local livelihoods.

The landscape was previously known for severe land degradation, acidic and nutrient-poor soils, high erosion risk, and chronic dependence on food aid, which collectively contributed to net emigration from the area. However, the introduction of *A. mearnsii* plantations has significantly altered land use dynamics, contributing to both ecological restoration and economic development. The region now hosts a rich mix of native and exotic tree species. Common native species include *Acacia abyssinica, Albizia gummifera, Croton macrostachyus, Combretum molle, Cordia africana, Schefflera abyssinica, Dovyalis abyssinica, and Entada abyssinica.* In forest remnants, species such as *Bersama abyssinica, Calpurnia aurea, Olea europaea,* and *Ficus thonningii* are frequently observed. Among exotic species, *Acacia mearnsii* and *Eucalyptus camaldulensis* are widely cultivated in woodlots due to their high biomass yield and economic importance. These efforts have played a pivotal role in reducing pressure on natural forests, enhancing soil fertility, and promoting sustainable land use across the degraded highlands of the Upper Blue Nile Basin.

B. Sampling Technique and Sample Size Determination

A multi-stage stratified random sampling technique was applied to identify representative households for the study. The Upper Blue Nile Basin was purposely selected due to its high potential for *A. mearnsii* woodlot production, particularly for charcoal and fuelwood. Its favorable altitude, rainfall, and soil conditions have made it a major area for bioenergy development. Three kebeles are known for active *A. mearnsii* cultivation was chosen. Before the main survey, a pre-test was carried out from December to

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March 2020 using 15 questionnaires to refine the data collection process. From the household list, 148 producers were randomly selected, and the sample size was determined using Cohen's formula to ensure reliable and representative findings.

$$n = \left(\frac{(Z_{\alpha/2} + Z_{\beta})^2 \cdot 2 \cdot \sigma^2}{\Delta^2} \right)$$

- n = sample size **per group**
- $Z_{\alpha/2}$ = z-score for the desired **confidence level** (e.g., 1.96 for 95%)
- Z_{β} = z-score for desired **power** (e.g., 0.84 for 80% power)
- σ = **standard deviation** (assumed or from pilot data)
- Δ = **minimum detectable difference** (effect size)

C. Data Collection Methods

Data were gathered using a mix of household surveys, interviews, FGDs, and field observation. A total of 148 producers (n=148) were randomly surveyed. Semi-structured interviews (n=52) were done with key actors: intermediaries (10), brokers (8), local collectors (12), wholesalers (9), and retailers (13), identified through snowball sampling. Six FGDs (n=6) were conducted with community elders, producers' group leaders, and residents to understand charcoal production and trade dynamics. Seven key informant interviews (n=7) were also held with agriculture experts, kebele leaders, and traders. Field observations helped cross-check the information collected.

D. Data Analysis Methods

The collected data were analyzed using various descriptive statistics and econometric techniques. Data analysis involved descriptive statistics (means, percentages, standard deviations) to summarize socio-economic and production data. Market analysis assessed price differentials through the relative commercialization margin. Econometric modeling used Probit regression to analyze adoption likelihood and Heckman's two-stage model to identify biomass production determinants for value addition. In the first stage, Probit regression examined factors influencing participation, and in the second stage, OLS regression analyzed participation levels, correcting bias using the Inverse Mill's Ratio (IMR). The participation equation is:

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$$Y_i = \chi_i \beta_i + \epsilon_i, \quad \epsilon_i \sim N(0,1)$$

In the second stage:

$$Y_i = \beta_i \chi_i + \lambda_i \mu_i + \epsilon_i, \quad \epsilon_i \sim N(0, \delta^2)$$

Where Y_i indicates participation, and λ_i is the IMR, calculated as:

$$\lambda_i = \frac{\phi(\chi_i \beta_i)}{1 - F(\chi_i \beta_i)}$$

III. Results Analysis

A. Sustainable Bioenergy Production of Acacia mearnsii-based Tanguay System

The market-driven *Acacia mearnsii*-based Tanguay system in the Upper Blue Nile Basin is a sustainable bioenergy production model that combines agroforestry, crop cultivation, livestock fodder, and charcoal production. As depicted in Fig. 1, this 4–5-year rotational system starts by planting teff (Eragrostis tef) alongside young *A. mearnsii* seedlings in the first year. The teff provides immediate income and food security, while the *A. mearnsii* seedlings begin to grow. By the second year, fodder grasses are planted between the rows of *A. mearnsii*, supporting livestock feed and increasing the land's productivity. The system benefits from improved soil fertility, moisture retention, and microclimatic conditions, which can increase crop yields by 2 to 4 times compared to monocropping. These environmental improvements contribute to higher farm outputs and enhanced resilience against climate impacts.

As the *A. mearnsii* trees mature in the third to fourth year, they enrich the soil through nitrogen fixation and stabilize the land. By the fourth or fifth year, the trees are harvested, and charcoal production is carried out on-site using traditional earth mound kilns. This charcoal is sold to local and urban markets, providing farmers with a source of income. After the harvest, the land is replanted at the onset of the rainy season, restarting the rotation cycle. The Tanguay system incorporates indigenous knowledge, such as the teff–*A. mearansi*–charcoal rotation, a climate-smart agricultural technology that integrates food, fuel, and fodder within a sustainable land-use model. By combining indigenous practices with market-driven strategies, the system not only generates bioenergy but also addresses land degradation, energy scarcity, and rural poverty in the Upper Blue Nile Basin. This approach supports climate resilience, sustainable livelihoods, and contributes to Ethiopia's green growth and climate adaptation goals.

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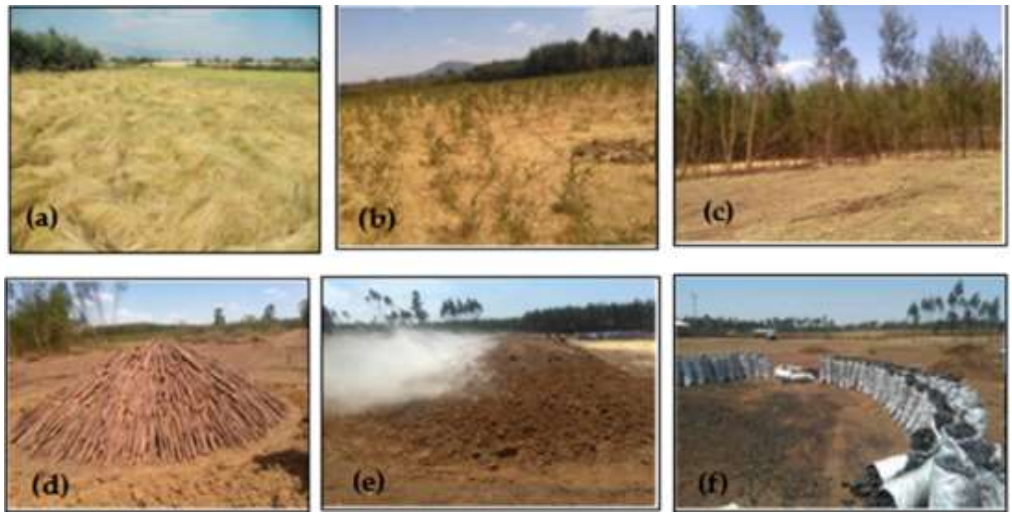

Fig.1. The photographs, adopted from Miftha Beshir, depict: (a) the teff monocropping system; (b) the teff–*Acacia mearnsii*–charcoal production (TACP) rotation system; (c) *A. mearnsii* seedlings planted with teff, showing *A. mearnsii* at the tree stage; (d) piles of *A. mearnsii* wood; (e) a charcoal production kiln; and (f) the harvesting of charcoal in the TACP system.

B. Revenue distribution, equity, and value added along the A. mearnsii bioenergy market

The results show various fees imposed on *A. mearnsii* woodlot products throughout the value chain in the Upper Blue Nile Basin. As depicted in Table I, the skilled local workers are paid a charcoal-making fee of $3.13 per quintal, while daily labor costs $4.00 per day for local workers. Transport fees depend on distance, with charges ranging from $0.937 for local transport to $5.00 for transporting to urban markets.

Brokers earn $0.313 per quintal, and cooperative members receive fees for loading/unloading and stripping, both valued at $0.937 and $0.313, respectively. Additionally, the regional government receives a royalty fee of $2.34, while the local government collects a locality fee of $0.457 and a sport/infrastructure fee of $0.156, indicating the diverse roles and financial contributions of both local workers and governmental bodies within the bioenergy production.

Table I: Local duties and workers' fees imposed on *a. Mearnsii* woodlot products

Fee	**Amount (USD/quintal)**	**Beneficiaries**	**Remarks**
Charcoal Making Fee	3.13	Skilled local workers	
Daily Labor Fee	4.00/day	Local workers	
Transport to Nearest Road	0.937	Local workers	Depends on distance

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Brokerage Fee	0.313	Brokers	3.13/Ql, informal
Transport to Urban Market	5.00	Owners of the trucks	Depends on distance
Loading and Unloading Fee	0.937	Cooperative members	
Striping Fee	0.313	Cooperative members	
Royalty Fee	2.34	Regional government	
Locality Fee	0.457	Local government	
Sport/Infrastructure Fee	0.156	Local government	

The results provide a comprehensive evaluation of the market-driven *A. mearnsii*-based Tanguay system for bioenergy production in the Upper Blue Nile Basin, Ethiopia, highlighting its potential to drive sustainable bioenergy production and economic growth via the charcoal value chain. Each actor in the value chain—producers, local intermediaries, wholesalers, and retailers—plays a crucial role in converting *A. mearnsii* biomass into an economically viable energy source. The analysis of net income, income per ton, profit margin, and volume handled provides valuable insights into each stage's contribution to the system's success.

Producers handle 34,050.72 tons of charcoal annually, earning a net income of $1,935.85 with an income per ton of $0.06. The 38% profit margin suggests efficient management of operational costs despite the labor-intensive nature of charcoal production. Local intermediaries, including collectors and brokers, manage 250,257.60 tons of charcoal annually, earning $6,040.65, with an income per ton of $0.02 and a 12.3% profit margin. Their role is crucial in linking production with regional markets.

Table II: Revenue distribution, value addition, and profit margins across *a. Mearnsii* wood

Actor	Volume Handled (Ton/Year)	Average Cost (USD/Ton)	Gross Revenue (USD)	Total Cost (USD)	Net Income (USD/Year	Value Added (USD/Ton)	Profit Margin (%)
Producers	34,051	92	85,143	56,022	1,936	58	38
Intermediaries	250,258	119	1,137,321	1,018,426	6,041	24	12
Wholesalers	696,984	129	1,062,587	897,122	30,188	43	17
Retailers	22,412	246	7,729	5,512	2,119	53	28
Total	1,003,705	-	2,292,780	1,976,082	40,284	-	-

NB: the volume in tons per year, assuming each sack weighs 17.4 kg

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Wholesalers manage 696,984 tons of charcoal annually, earning a net income of $30,188.07, with an income per ton of $0.04 and a 17.2% profit margin. As depicted in Table II, their larger volume of transactions allows for higher profitability, connecting regional markets to retail distribution. Retailers handle 22,411.60 tons of charcoal, earning $2,119.29 with an income per ton of $0.09 and a 27.5% profit margin. They provide value through packaging, marketing, and direct sales, capturing a larger share of the profit.

Aggregating all actors, the system handles 1,003,704.92 tons of charcoal annually, generating a total net income of $40,283.86, with an average income per ton of $0.04. The results indicate significant economic benefits, with profit margins reflecting varying levels of value-added processes, especially higher margins for retailers and wholesalers**.**

The market-driven *A mearnsii*-based Tanguay system in the Upper Blue Nile Basin offers a robust model for sustainable bioenergy production. The system involves the integration of *A. mearnsii* plantations, crop cultivation, and charcoal production, creating a multi-functional agroforestry approach. The biomass yield across the three sites (A, B, and C) in the basin ranges from 87.3 tons per hectare at Site A to 97.5 tons per hectare at Site C. On average, the biomass yield across all sites is 93.4 tons per hectare, highlighting the system's potential to generate substantial bioenergy resources.

The total biomass produced is consistent at 578,080 tons across all three sites, ensuring a steady supply for charcoal production. The system generates 145,000 tons of charcoal annually, which equates to 8.3 million sacks of charcoal, each weighing 17.4 kg. As depicted in Table III, this volume of production plays a crucial role in meeting the regional demand, with 85% of sales targeting Addis Ababa and 15% directed to other regional cities. The conversion efficiency of the system stands at 25%, meaning that 25% of the biomass produced is converted into charcoal, which aligns with typical conversion rates using traditional earth mound kilns.

Table III: Summary of woodlot and land use dynamics in the Upper Blue Nile basin

Parameter	**Site A**	**Site B**	**Site C**	**Overall Value**
BiomassYield (tons/ha)	87.30	95.40	97.50	93.4
Total Biomass (tons)	578,080	578,080	578,080	578,080
Charcoal Production (tons)	145,000	145,000	145,000	145,000
Charcoal Production (sacks)	8.3 million	8.3 million	8.3 million	8.3 million
Conversion Efficiency (%)	25%	25%	25%	25%

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Land Use Change (%)	42.1% *A. mearnsii*, 30% Cropland	42.1% *A. mearnsii*, 30% Cropland	42.1% *A. mearnsii*, 30% Cropland	42.1% *A. mearnsii*, 30% Cropland
Carbon Sequestration (tons CO_2/ha/yr)	5-10 tons	5-10 tons	5-10 tons	7.5 million tons (avg)
Income Increase (%)	75% (Charcoal Producers)	75% (Charcoal Producers)	75% (Charcoal Producers)	75% (Charcoal Producers)
Net Income per Sack (USD)	$0.62	$0.62	$0.62	$0.62
Total Charcoal Income (USD)	$5,140,000	$5,140,000	$5,140,000	$15,420,000

In terms of land use change, the system employs 42.1% *A. mearnsii* plantations and 30% cropland across all sites. This combination supports both bioenergy production and food security, as crops like teff are cultivated alongside the *A mearnsii* trees. The system's contribution to carbon sequestration is significant, with an estimated 5 to 10 tons of CO_2 sequestered per hectare per year. In total, the plantations sequester approximately 7.5 million tons of CO_2 annually, offering both climate resilience and improved soil health.

C. Econometric Results

1) *Determinants of household participation in Acacia mearnsii-based value addition for sustainable bioenergy production*: A Heckman two-step selection model was employed to analyze factors influencing household participation in *Acacia mearnsii* woodlot product value addition for sustainable bioenergy production. The market-driven *A. mearnsii*-based Tanguay system for bioenergy production in the Upper Blue Nile Basin is influenced by key factors affecting participation and value addition. Post-estimation of the selection equation was conducted to derive marginal effects, which provide a meaningful interpretation of variable impacts [10]. Among the twelve variables included in the model, four were statistically significant: age of the household head ($p = 0.030$), household experience in woodlot management ($p = 0.003$), access to credit services ($p = 0.034$), and engagement in contractual agreements ($p = 0.000$).

The age of the woodlot producer household head was found to be statistically significant at the 5% probability level, with a negative sign, indicating that each additional year of age decreases the likelihood of participation in *A.* mearnsii *w*oodlot product value addition by 0.8% ($p = 0.03$) (Table IV). This negative relationship may be explained by the labor-intensive nature of woodlot product processing, which can discourage older producers from participating. Additionally, older household heads may be more risk-averse and less willing to adopt new technologies such as improved kilns for processing *A.* mearnsi*i* products. This finding aligns with [11], who reported that older woodlot producers are less likely to engage

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in charcoal production due to labor constraints. Similarly, [12] noted that older individuals are generally less receptive to innovation and more cautious in adopting new practices compared to younger people. Conversely, the experience of the woodlot producer household head was significant at the 1% probability level with a positive sign, indicating that each additional year of experience increases the likelihood of participation in *A. mearnsii* woodlot product value addition for bioenergy production by 8.5% (p = 0.003) (Table IV). This suggests that more experienced producers are more likely to engage in activities such as converting standing woodlots into charcoal. Experienced households tend to understand the benefits of processing and are more skilled in using value-added techniques. This finding is supported by [13] who observed that experienced coffee farmers are more likely to adopt processing practices such as drying, which add value to the product. Similarly, experienced *A. mearnsii* producers are better equipped to handle production and processing technologies effectively.

Access to credit had a positive and significant influence on participation in *A. mearnsii* woodlot product value addition (p = 0.034). This implies that, other factors being constant, participation increased by 24.2% for households with credit access. This shows that credit helps woodlot producers improve their financial capacity to invest in key activities such as seedling preparation, planting, tree felling, disbranching, cross-cutting, charcoal production, and transportation. With improved access to finance, producers can afford better inputs and tools, making it easier to engage in processing activities. This result supports the findings of [1], who reported that credit access boosts farmers' ability to purchase inputs and enhances participation in value-added activities.

Contractual agreements of household heads in woodlot production were found to be highly significant but hurt participation in value addition (p = 0.000). Specifically, each additional contractual agreement reduced the probability of participation in *A. mearnsii* woodlot value addition by 60.8%, holding other factors constant. This negative relationship may be explained by producers entering contracts to sell their plantations or *A. mearnsii* woodlots before harvesting or sharing their woodlots, which reduces their involvement in value-added activities. Additionally, advance payments tied to contracts might encourage producers to sell their woodlots early, sometimes even before full maturity, to benefit from rising woodlot prices.

Table IV: The Heckman two-step selection equation result

Variables	dy/dx	Std. Err.	Z	P>|z|
Sex of household head	0.06706	0.17116	0.39	0.695
Age of household head	-0.0081	0.00377	-2.17	0.030**

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Educational level	0.14505	0.10263	1.41	0.158
Adult equivalent size	-0.0440	0.03889	-1.13	0.258
Woodlot size	0.08166	0.06951	1.17	0.240
Tropical Livestock Unit	-0.0195	0.01763	-1.11	0.268
Distance to market	-0.0975	0.12045	-0.81	0.418
Household experience	0.08598	0.02888	2.98	0.003***
Market information access	0.17764	0.11825	1.50	0.133
Credit access	0.24224	0.11449	2.12	0.034**
Contractual agreement	-0.60777	0.11657	-5.21	0.000***
Training access	0.01656	0.11649	0.14	0.887

***, ** and * are statically significant at 1%, 5% and 10% significance level respectively

2) *Factors Influencing the Volume of Participation in Value-Added Acacia mearnsii Woodlot Products for Bioenergy Production*: Factors influencing the volume of participation in value-added *Acacia mearnsii* woodlot products for bioenergy production were analyzed using OLS regression in the second stage of the Heckman two-step outcome equation. The results indicate that the volume of participation is significantly affected by the household head's age (p = 0.058), livestock holdings (p = 0.054), and access to training services (p = 0.041) (Table IV). Notably, the coefficient of the Inverse Mills' ratio (Lambda) is positive and statistically significant at the 10% level (p = 0.053), suggesting the presence of sample selection bias [14]. This means that unobservable producer characteristics influence woodlot producers' decisions to participate in value addition, which in turn affects the volume of value-added products. Overall, younger household heads, larger livestock holdings, and better access to training are associated with increased participation volume in value-added *A. mearnsii* woodlot products for bioenergy production.

The age of the Acacia mearnsii woodlot producer household head significantly affects the volume of participation in value-added products at the 10% significance level (p = 0.058), with a negative relationship. Specifically, for each additional year in age, the volume of value-added products decreases by 709.70 ETB. This suggests that younger producers are more energetic and actively engaged in the labor-intensive production and marketing processes, while older producers tend to reduce their participation due to decreased physical capacity. These findings are consistent with previous studies [15],[19],[20] indicating that older farmers often switch to less labor-intensive activities or rent out their land. Similarly,[21] reported a negative impact of household head age on the volume of value-added milk products, supporting the conclusion that younger producers contribute more to value addition in labor-intensive sectors. Livestock

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holdings, expressed in Tropical Livestock Units (TLU), showed a significant positive effect on the volume of participation in value-added bioenergy products at the 10% significance level (p = 0.054). Specifically, an increase of one TLU raises participation volume by 2,630.3 ETB, holding other factors constant. This indicates that livestock ownership provides essential cash income for rural woodlot producers, enabling them to purchase necessary inputs such as seedlings, nylon bags, and plastic tubes, and to finance value-adding activities including charcoal transportation from production areas to nearby roads or markets. These findings align with Tadie[21], who reported that farmers with larger livestock holdings tend to generate cash through sales, facilitating farm input purchases and meeting household needs. Livestock thus plays a key role in supporting participation in *A. mearnsii* woodlot product value addition for bioenergy production.

Access to training services has a significant and positive impact on the volume of participation in value-added *Acacia mearnsii* woodlot products for bioenergy production. The results show that those who received training increased their participation by 20,297.55 ETB (p = 0.041). This highlights the importance of training in providing producers with the necessary skills and knowledge to improve their production and marketing practices. Well-informed producers are better equipped to adopt effective techniques, which ultimately enhances their productivity and ability to compete in bioenergy markets.

Table V: The HECKMAN two-step outcome equation result

Variables	Coef.	Std. Err.	Z	P |>z |
Sex of household head	14713.61	17312.48	0.85	0.395
Age of household head	-709.702	373.73	-1.90	0.058*
Educational level	14971.24	9359.9	1.60	0.11
Adult equivalent family size	3181.62	3344.14	0.95	0.341
Tropical Livestock Unit	2630.27	1364.85	1.93	0.054*
Household experience	13479.74	11122.04	1.21	0.226
Market information access	-2333.87	11698.07	-0.20	0.842
Credit access	3526.67	10920.86	0.32	0.747
Contractual agreement participation	-17449.38	14934.4	-1.17	0.243
Training access	20297.55	9920.992	2.05	0.041**
CONST	16529.47	33012.76	0.50	0.617
Mill Lambda (IMR)	32314.91	16707.99	1.93	0.053*
Rho	0.88043			
Sigma	36703.72			

, **, * indicate significant difference at 10%, 5% and 1% probability level respectively*

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IV. Discussion of the Results

Charcoal production under the *A. mearnsii*-based Tanguay system provides substantial income across the value chain, though earnings are uneven. Producers, managing 34,050.72 tons/year, earn the lowest unit income (USD 0.06/ton) despite performing the critical task of biomass conversion. In contrast, wholesalers and retailers earn USD 0.04 and USD 0.09/ton, respectively, benefiting from market access, storage, and urban proximity [14]. Intermediaries, managing 250,257.60 tons/year, earn only USD 0.02/ton, reflecting minimal value addition [14]. The overall district-level value addition reaches USD 27.5 million annually, highlighting the system's economic potential, although income disparity calls for intervention. Recommended measures include direct market access, technology efficiency, and producer cooperatives [16].

Biomass yield ranges from 87.30 to 97.50 tons/ha, aligning with comparable bioenergy systems [17]. Total site yield stands at 578,080 tons, confirming *A. mearnsii* as a dependable energy source. A conversion efficiency of 25% falls within global norms (20–30%), depending on moisture content and kiln efficiency [18]. Land use change trends show a reduction in cropland (from 67% to 30%) and grazing land (from 19% to 12%), with a rise in Acacia woodlots (42.1%), indicating land restoration benefits [19]. The species supports soil fertility and erosion control, promoting sustainable land use [18].

The system boosts producer income by 75%, contributing to livelihood improvement and poverty reduction goals [21]. Its adaptability across Ethiopia and Zambia suggests suitability for broader regional adoption [19]. Household attributes influence engagement in value-added roles. Age negatively correlates with participation, as older farmers tend to avoid labor-intensive processes [20]. In contrast, experience positively influences involvement, indicating the value of skills and know-how [18].

Access to credit enhances participation by 24.2%, demonstrating the importance of financial resources for scaling value chains [19]. However, contractual engagement reduces participation by 60.8%, implying that restrictive conditions deter flexibility [21]. Livestock assets serve as liquidity sources for inputs and transport, further supporting engagement. Training exposure significantly increases value addition, underlining the need for capacity development [20]. The Heckman model affirms the presence of latent factors influencing participation decisions, highlighting the need for further inquiry [21].

V. Conclusions and Recommendations

The *Acacia mearnsii*-based bioenergy system in the Upper Blue Nile Basin provides essential economic support to rural communities, yet income disparities persist along the value chain. Producers, despite their

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crucial role, receive the lowest financial returns, while wholesalers and retailers capture larger profits. Addressing these disparities requires policy interventions to empower producers, improve market access, and ensure fair pricing.

To enhance sustainability, strengthening producers' bargaining power through cooperative organizations and direct market access is key. Adopting modern charcoal production technologies and sustainable harvesting practices will boost efficiency and reduce environmental degradation. Establishing a structured market with clear regulations can prevent price exploitation, while promoting responsible consumption through consumer awareness supports ethical behavior. The success of the system depends on fostering collaboration among stakeholders, including government, research organizations, and private enterprises. Policymakers should integrate economic incentives with environmental goals. Targeting younger producers and improving access to training, livestock, and credit will enhance participation in value-added activities. Expanding this bioenergy system, optimizing conversion technologies, and promoting its adoption across Ethiopia and sub-Saharan Africa will provide significant economic and environmental benefits.

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