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Assessment of Deferred Maintenance Impacts on Flexible Pavements in Hawassa City and Countermeasure Strategies Using the HDM-4 Mode

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Abstract

Highways are critical assets that play a vital role in a nation's socio-economic activities. Ensuring their effective and efficient maintenance is essential to sustaining the required level of service. However, the absence of proper and scheduled condition surveys, as well as delayed maintenance, leads to unnecessary costs and public inconvenience. This study examines the road maintenance management system of the Hawassa City Municipality Office with the objective of establishing an improved framework to mitigate issues arising from deferred maintenance. The research identifies various types of road damage and corresponding repair techniques that can help the city avoid excessive economic expenditures. The investigation reveals multiple surface pavement deteriorations along the study area's road segments, including potholes, raveling, alligator (crocodile) cracking, and edge breakage. The study evaluates the impact of deferred maintenance on Hawassa's flexible pavements by selecting highly deteriorated road sections based on key performance indicators and assessment criteria such as pavement condition surveys and traffic volume analysis. The research further examines the existing maintenance practices and management system, assesses the consequences of deferred maintenance, and recommends minimum maintenance strategies to prevent the need for costly rehabilitation or reconstruction, which poses a significant financial burden for Ethiopia. Data for this research were gathered using both primary and secondary sources, including interviews, visual analysis techniques such as photographic documentation, and examinations of international standards and manuals. The gathered data were examined through descriptive, exploratory, and HDM-4 models. Following the study's results, corrective actions were recommended for the Hawassa City Municipality Office. Additionally, the research assesses the economic consequences of poor maintenance using the Highway Development and Management model, which quantitatively analyses impacts by incorporating

road network conditions, vehicle features, and maintenance schedules. The study emphasizes that effective maintenance considerably prolongs the lifespan of road infrastructure. Neglecting timely maintenance not only reduces service levels and accessibility but also leads to a substantial increase in the total lifetime cost of transport infrastructure. This in turn, negatively impacts the overall economic growth of the country. Therefore, road sections in the study area require reconstruction, and selecting an appropriate project case scenario is crucial for sustainable infrastructure management.

Keywords: Deferred Pavement Maintenance; Pavement Deterioration; Road Condition Survey; HDM-4 Model; Economic Factors.

1. Introduction

An urban road is a roadway located within the limits of a certain area. These roads typically feature street lighting, curbs, and roadside elements next to the pavement edge. According to the 2001 Communities and Local Government definition of Urban Settlements, a road is classified as urban if it caters to a population of 10,000 or more. Maintenance for urban roads involves activities such as snow clearing, applying road markings, mowing grass, clearing brush, installing traffic signs, repairing cracks and potholes, along with other related maintenance tasks (Debarshi, 2020).

Maintenance spending represents a balance between capital investment and upkeep costs. Insufficient maintenance funding can lead to significant rehabilitation expenses, often requiring urgent interventions to restore essential infrastructure functionality. Conversely, nations with extensive capital investment programs may have limited funds available for routine road maintenance. By analyzing the relationship between maintenance expenditure per kilometer of the main road network and capital investment per kilometer, it is possible to determine whether such a trade-off exists (Debarshi, 2020).

With the continuous rise in global population and infrastructure development, the demand for efficient transportation systems has become indispensable. To address this demand, urban road construction, maintenance, and management technologies have steadily advanced over the years. Urban road maintenance management primarily focuses on tackling challenges so as to establish an effective system that can deliver the best possible solutions within a specified time frame. (Wang, 2009).

Road maintenance practices in developed countries like the USA involve substantial funding. In 2013, the United States Department of Transportation (DOT) was allocated $74 billion for nationwide road construction and maintenance (USDOT 2013). Each year, state DOTs dedicate a large portion of this budget to upkeep their road networks (Shrestha & Shrestha, 2014).

According to Asian Development Bank (2012), the Ministry of Transport (MOT) is responsible for issuing technical standards, specifications, and relevant guidelines for road maintenance at the central government level. The MOT also establishes a five-year road maintenance administration plan to guide road maintenance work in each of the provinces.

In 2005, China introduced the Plan of Reform of Management and Maintenance System for Rural Roads, initiating a new phase in rural road upkeep. This plan, along with the 2008

Management Methods of Rural Road Maintenance and the 2010 Technical Regulations of Road Maintenance, establishes the responsible parties, technical standards, and subsidy allocation for rural road maintenance (Fan, 2011).

Maintenance expenditures involve a balance between capital investments and upkeep costs. Countries that allocate insufficient funds for maintenance may face significant rehabilitation expenses later, often requiring urgent interventions to restore critical infrastructure. Conversely, nations with extensive investment programs may have limited resources available for road maintenance. A comparative analysis of maintenance spending per kilometer of the main network against capital expenditure per kilometer can help determine whether this trade-off exists (Debarshi, 2020).

In South Africa, road maintenance is managed by the South African National Road Agency Ltd (SANRAL), established in 1998 as part of the government's effort to reform the public sector. SANRAL oversees 92% of the national road network, with 81% being non-toll roads and the remainder tolled, totaling over 19,000 km. The other 8% of the network is also tolled and developed and managed by private entities through public-private partnerships. SANRAL supervises these private operators under concession contracts, which last for thirty years, after which the roads are transferred back to SANRAL (Mostafa, 2018). South Africa boasts the largest road network in Africa and ranks 10th worldwide in total road length, as well as 18th for the longest paved road network. Its road system covers about 746,978 km, with just 21% (153,719 km) paved. Although South Africa is the continent's leading economy, approximately 38% of its roads are in fair to poor condition, partly due to maintenance shortcomings. However, the country's road conditions are still better than those in many other African nations (Mostafa, 2018).

As discussed by Heggie (2005), many countries, particularly in Sub-Saharan Africa, lack a well-developed maintenance plan. The primary challenges are institutional, including weak frameworks, limited human resources, unclear roles, ineffective management structures, poor management systems, and insufficient funding arrangements. These issues highlighted in Heggie’s (2005) study remain significant obstacles.

The Ethiopian government has initiated the Road Sector Development Program (RSDP) from Phase-I to Phase-V to rehabilitate, upgrade existing roads, and expand the road network. As a result of RSDP, the federal road network has increased from 13,000 km to 29,106 km, with about 60% paved and 40% unpaved according to the ERA road asset database (2019/20). These roads represent one of the country's largest national assets that require preservation. The Ethiopian Roads Authority (ERA) is tasked with maintaining, improving, replacing, and protecting these assets. To ensure the ongoing preservation, maintenance, and enhancement of the road network for safe and efficient traffic use, ERA established the Road Asset Management (RAM) department to carry out these responsibilities.

A major and widespread problem is the neglect of roads without any maintenance after construction. This neglect causes newly built roads to deteriorate within a few years. Without maintenance, roads designed to last for decades may require replacement or significant repairs much sooner. Regular maintenance is essential to restore roads to a condition close to their original state. Without it, roads will keep worsening, leading to more difficult, uncomfortable, and costly travel for users (ERA, 2013).

2. Materials and Methods

2.1. Description of the Study Area

Hawassa is the capital of the Sidama Regional State Government and is divided administratively into eight sub-cities and 32 kebeles, with 20 urban and 12 rural kebeles. The city covers a land area of 15,720 hectares, and its municipal boundary, which includes the urban kebeles, spans 65 km². About twenty years ago, the Ethiopian Central Statistical Agency estimated Hawassa's population at 351,469, growing at an annual rate of 4%. The population is largely young, with 65% under 25 years old and around 5.5% over 50. Located on the shores of Lake Hawassa in the Great Rift Valley, the area's geology features volcanic rock from the Pliocene period, marked by extensive faults and cracks. This results in highly permeable soils and unconfined aquifers, with groundwater depths ranging from just below the surface in low areas to up to 40 meters in higher elevations. Hawassa receives an average yearly rainfall of approximately 950 mm and has an average temperature of 20°C. The main rainy season occurs between June and October. Ethiopia's National Constitution stresses public health protection, supported by various policies and guidelines for water and sanitation programs (World Bank, 2016).

2.2. Location

Hawassa, situated 275 km south of Addis Ababa, is the capital of the Sidama Regional State Government. Its geographic coordinates are approximately 7°0′ North latitude and 38.5° East longitude. The city experiences a climate that ranges from dry to sub-humid. Temperatures throughout the year fluctuate between 9°C and 29°C, with an average monthly temperature of 19.7°C. Hawassa has a long rainy season from March to October, where monthly rainfall averages between 85 mm and 133 mm, with June to September contributing 44% of the total yearly precipitation (Muluneh, 2018).



Figure 1. Wolde Amanuel to Wanza



Figure 2. Location map of the study Area (Google map, 2022)

2.3. Research Materials

In order to achieve the objectives, the tools utilized in this study included checklists and a photo camera for assessing the road conditions in the study area, along with reports from the city administration and maintenance manuals. These resources helped evaluate maintenance practices. Additionally, Average Annual Daily Traffic (AADT) data was used for HDM-4

model analysis. To determine the types of pavement in the study area, a digital camera was employed to document the locations and types of distress, as well as to assess the existing condition rating. Additionally, the study was carried out using survey data gathered by the researchers.

Table 1. Basic characteristics of each vehicle for HDM4 Input

Vehicle type	**Small Car**	**Landover**	**Small Bus**	**Large Bus**	**Small Truck**	**Source**
Base type	Car light	Car medium	Bus light	Bus large	Small Truck	(ERA, 2002); Pavement Design Manual with slight modification
Class	Cars	Cars	Buses	Buses	Truck	
Description	Cars up to 4 passenger seats	Cars with 7 passenger seats	Buses over 12 passengers seat	Buses with over 60 passengers	Trucks of capacity > 7.5 tones load	
Passenger Car space equivalence	1.4	1.6	2	1.8	2	TCD Consulting PLC
No. wheels	4	4	6	6	6	Feasibility report
No. axles	2	2	2	2	2	
Tyre type	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Field observation
Base no. of recaps	1.3	1.3	2.4	2.4	2.4	
Retreated cost	15%	15%	15%	15%	15%	
Annual Km	24,000	34,000	36,000	10,800	10,800	
Working Hrs.	1880	2880	2880	1,500	1,500	
Average service life	17	20	18	20	20	
Private use	100%	60%	0%	0%	0%	
Passengers	4	6	25	60	1	
Work related trips	80%	80%	100%	100%	100%	

2.4. Research Methods

This study employed a descriptive research approach. The descriptive method was used to identify various types of pavement distress, while a qualitative approach assessed conditions through visual inspection. A survey method was also applied, using a 500-meter interval to identify severely deteriorated homogeneous areas and evaluate their condition based on the severity of each distress type. The research involved several essential stages: collecting data, analyzing it, interpreting the outcomes, and discussing the results. Ultimately, conclusions were made based on the findings, followed by relevant recommendations.

2.5. Data Collection types and Source of Data

This study employed data from both primary and secondary sources. Primary data were collected by identifying various types of flexible pavement distress, capturing images using a digital camera, and applying a representative sampling method to focus on highly deteriorated areas within the study road segment. Additionally, data on representative vehicles and key characteristics of the vehicle fleet were gathered from the study area road segments. Secondary data provided essential inputs for assessing the existing pavement condition and conducting HDM-4 analysis, which was crucial for evaluating the study road segments. These data were obtained from various manuals and reports.

2.6. Study Subject and Design Strategy

Roads are essential public assets in many countries. Improving road infrastructure offers immediate benefits, including easier access to important services such as hospitals, schools, and markets, along with enhanced comfort, speed, and safety for travelers. Moreover, better roads lower vehicle operating expenses. However, to maintain these advantages over time, a well-organized maintenance program is necessary after any road upgrades. Without regular maintenance, roads can rapidly decline, limiting their long-term impact on development (Sally & Natalya, 2005).

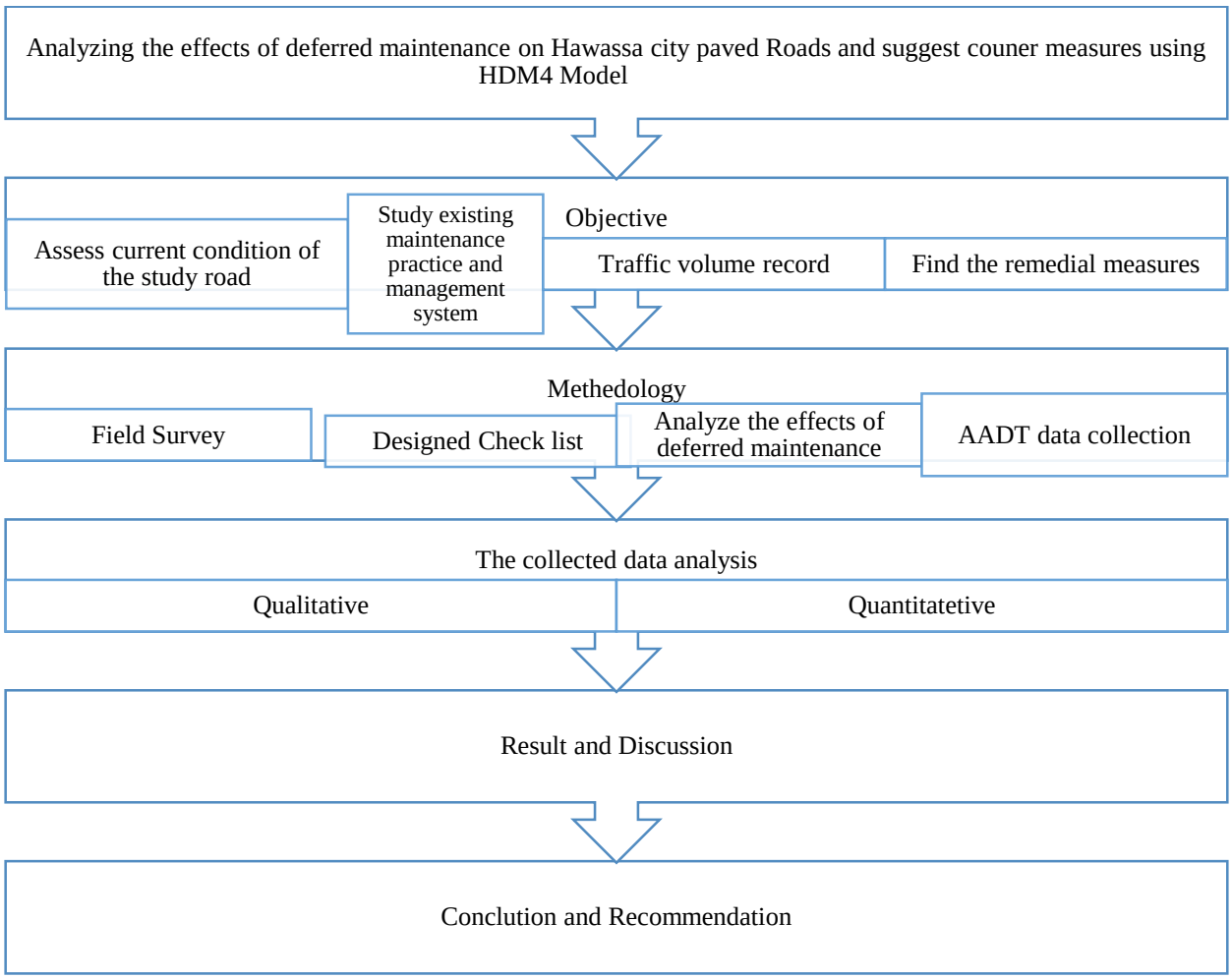


Figure 3. Design sequence of the research work flow chart

2.7. Study Type

This research used a mixed-methods approach, combining both quantitative and qualitative techniques. The quantitative approach was utilized to assess the geometric cross-sectional elements of the road and to calculate the average annual daily traffic (AADT) for various vehicle types along the selected routes. On the other hand, the qualitative approach was applied to evaluate aspects related to quality. This included examining the current condition of the flexible pavement roads using standard manuals and checklists, reviewing relevant documents used by stakeholders in accordance with international standards for flexible pavement construction, and identifying gaps in maintenance practices and available maintenance options. Overall, the study integrated both methodologies, requiring the researchers to apply different techniques and formulas to analyze the respective data.

2.8. Sampling Techniques (Procedure)

The population for this study includes the entire length of flexible pavement roads in Hawassa city. The researchers used a purposive sampling method based on the number of routes in the area to select the sample size. The focus was on asphalt-paved roads, specifically flexible pavements showing signs of deterioration. The main goal was to identify problems related to insufficient maintenance. Field observations were carried out to evaluate the current road conditions, document vehicle types, and gather data on cross-sectional road features for HDM-4 analysis. To achieve the study's goals, determining the extent of asphalt coverage during the site investigation using purposive sampling was crucial.

2.9. Data Analysis

2.9.1. Analysis on the Current Condition of Study Area Road

The study focuses on four selected flexible road segments in Hawassa city. It involves conducting traffic analysis alongside the HDM-4 analysis method.

2.9.2. Condition Data Analysis

Roughness data were collected using world bank report 46.The collected data were then analysed to determine different parameters such as Condition Index, which is used to classify roads according to the current condition. This Roughness data was used for HDM-4 analysis.

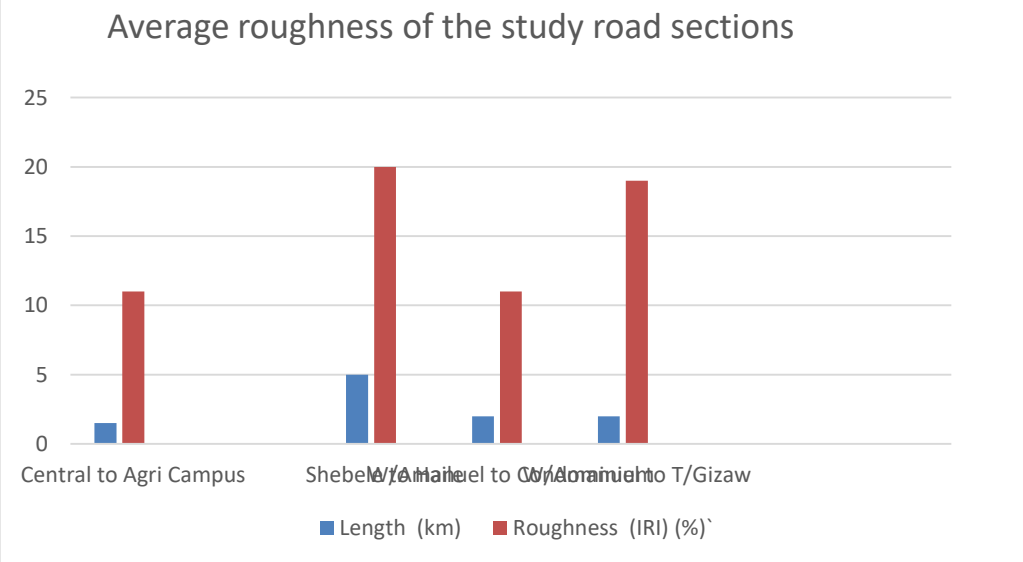


Figure 4. Average roughness of the study road sections.

The Average roughness (IRI) of the study route from central to Agriculture Campus and weldeamanuel to condominium (11%) is fair whereas Shebele to Haile (20%) is very poor, Weldamanuel to Tesfaye Gizaw (19%) is in poor condition (Fig. 4)

2.9.3. Distress Data with Rating Values

The types of distress found in the research area were carefully rated based on the ERA PMS manual.

For survey condition, each road segment was further rated through observing the actual condition survey and each segment was assessed and distresses were measured and rated through the condition index of the individual segment with respect to distress types.

Condition Index (CI)

The Pavement Condition Index (PCI) provides a summary of pavement conditions based on individual distresses, enabling the evaluation, prediction, and enhancement of pavement performance through appropriate treatments (Huang, 2004). The distress data collected were used to calculate a single Condition Index (CI) that reflects the overall state of a road section. This CI is expressed as a percentage from 0 to 100, where 0 indicates a road segment in very poor condition and 100 indicates a segment in excellent condition. Table 3.3 below shows the corresponding pavement condition indices.

$$\text{Density} = \frac{\text{Distress amount in m}^2(\text{ft}^2)}{\text{Sample Unit area in m}^2(\text{ft}^2)} \times 100 \qquad \text{Equ ... 1}$$

The other additional types of distress with their rating values on the study area road surfaces are shown in Tables 2 (ravelling), 2.3 (potholes) and 2.4 (edge breaks) below, respectively.

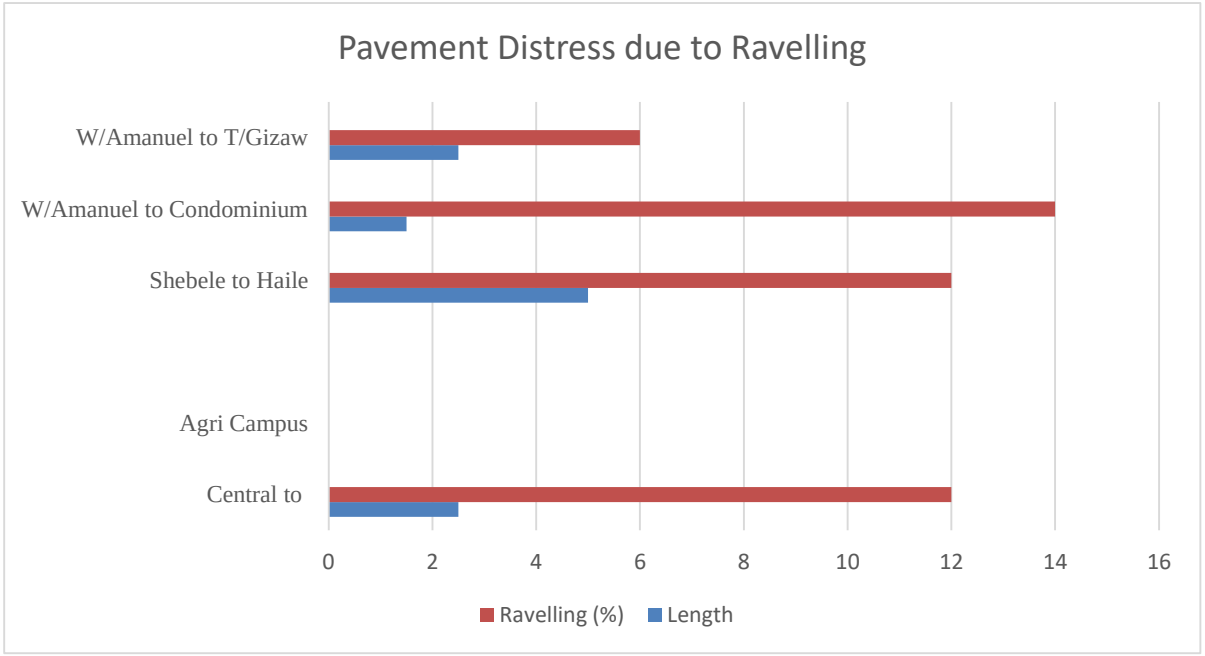


Figure 5. Pavement distress due to raveling

The study road from central to Agriculture, Shebele to Haile resorts and weldeamanuel to Condominium raveling is in warning condition and in the other way the route from weldamanuel to Tesfaye Gizaw is on moderate condition (Fig. 5)

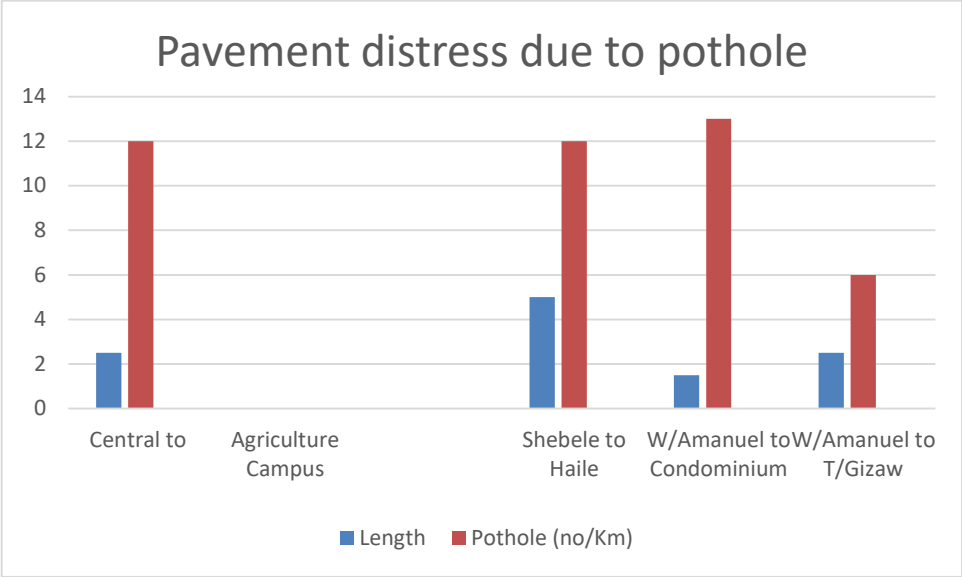


Figure 6. Pavement distress due to pothole

The Pothole numbers per kilometer from Central to Agriculture Campus, Shebele to Haile and Weldamanuel to Condominium (12 to 13%) is in warning condition Weldamanuel to Tesfaye Gizaw (6%) is on Moderate condition.

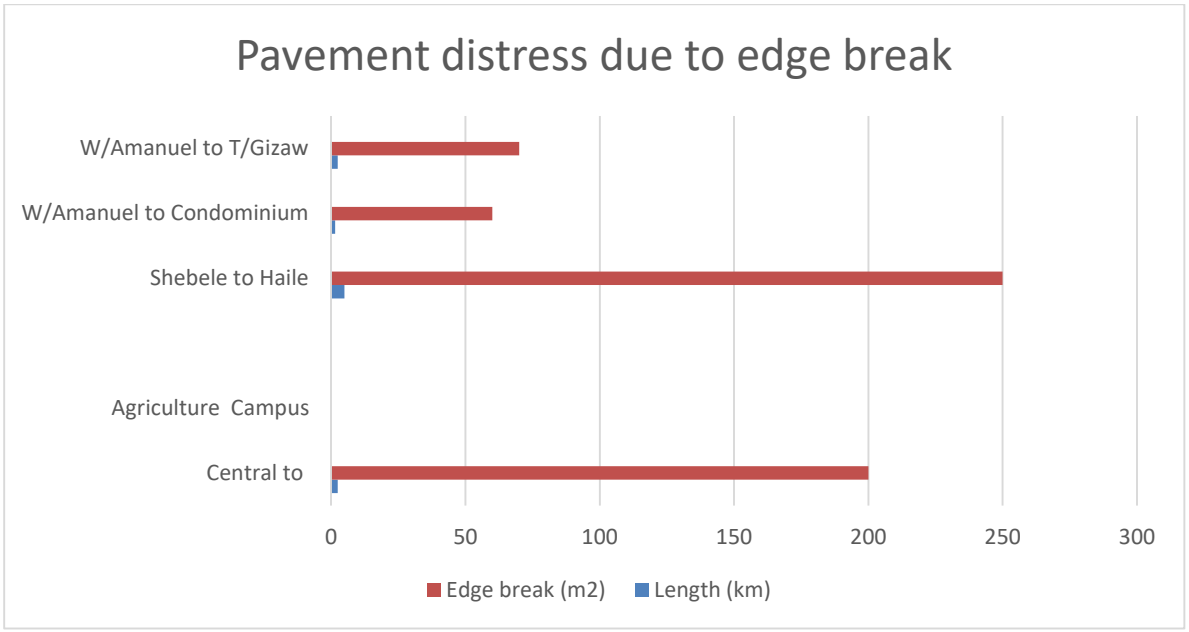


Figure 7. Pavement distress due to edge break.

The study route edge break for central to Agriculture campus and Shebele to Haile is in warning condition where as Weldeamanuel to Condominium and Wldeamanuel to Tesfaye Gizaw is in Moderate condition.

2.9.4. Traffic Volume Data

In this study, both video and manual counting methods were used to measure the total number of vehicles on the selected routes. Traffic data were collected over three days, capturing peak and normal traffic flows during morning and afternoon hours on two weekdays and one weekend day.

The current year traffic volume for each section of the road has been collected through field data collection, as indicated in Table 2 below.

Table 2. Base year AADT of Road section

Section Name	Length (km)	Small Car	Land Rover	Small Bus	Large Bus	Small Truck	Total AADT (2023)
Central to Agriculture Campus	2.5	1630	416	126	19	13	2204
Shebele to Haile	5	-	1210	113	36	11	3391
W/Amanuel to Condominium	1.5	1240	745	307	193	165	2650
W/Amanuel to T/Gizaw	2.5	1668	876	799	64	36	3443

3. Results and Discussions

3.1. Types of Pavement Distresses on the Study Area.

The types of pavement distresses that were observed during the research are alligator cracking, Block cracking, potholes, lacy edge, patching and raveling some of them types are presented below from Figure 4.1



Figure 8. (a) Raveling (b) Pathole

3.2. Pavement Condition of the Study Road Section

The pavement condition of the study road segment has high problem of roughness, and ravelling, and. Edge break and potholes, wide cracking texture and condition index.

The analysis result of pavement condition on the study area route segments Weldeamanuel to Condominium and Shebele Hotel to Haile resort is found in poor condition, Whereas the pavement condition on the routes of Central Hotel to Agriculture campus and Weldeamanuel to Tesfaye Gizaw is on fair condition based on the analysis result of pavement condition index (PCI).

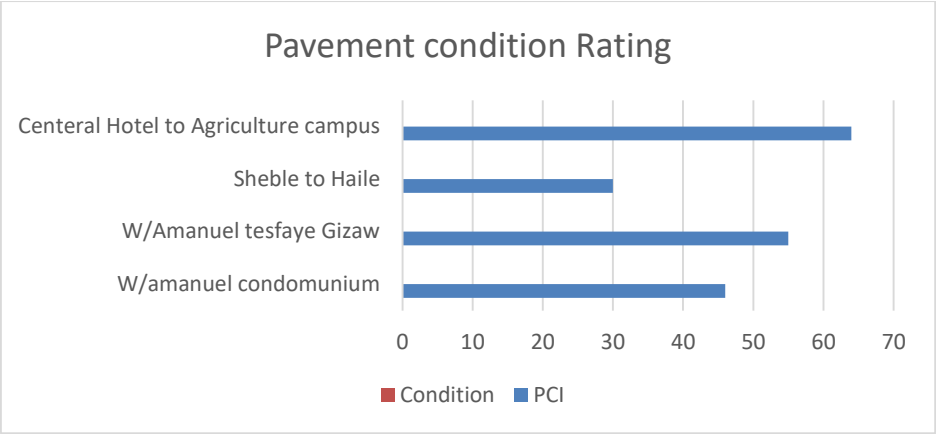


Figure 9. Pavement condition rating

The current maintenance practice and management system of the study area is very poor based on the investigation of the researchers The maintenance practice applied in Hawassa city is not based on the maintenance and rehabilitation treatments on subjective judgment and engineering experience rather its on occasional programs using random method of treatments without doing detail survey condition on the other hand the pavement maintenance management system was not yet established based on proper schedule of Hawassa city municipality office.

The HDM-4-based economic analysis clearly demonstrates the significant costs associated with deferring pavement maintenance. Using a 12% discount rate reflective of Ethiopia's capital cost, the model compared two scenarios: timely maintenance (base case) and deferred maintenance (project case).The Net Present Value (NPV) for the base case is positive, while the deferred maintenance scenario yields a negative NPV of ETB -3,226.17 million (discounted), confirming that delays in maintenance result in economic inefficiency. Also NPV to Capital Cost ratio (NPV/CAP) of 1,475.422 in the project case under timely maintenance underscores a high return on investment, while the ratio is zero for the no-maintenance base case. Pavement Condition Index (PCI) surveys identified segments in poor condition requiring full reconstruction, and those in fair condition where asphalt overlays would be sufficient. Delaying maintenance increases vehicle operating costs, rehabilitation needs, and user dissatisfaction, while severely reducing economic feasibility. In extreme deferred scenarios, projects fail to reach break-even, with no viable Internal Rate of Return (IRR) an indication of unsound investment.

Institutionalize a Pavement Maintenance Management System (PMMS) in Hawassa city to guide resource allocation. Base interventions on quantitative condition surveys and economic prioritization rather than reactive or ad-hoc practices (reactive and uncoordinated measures). Prioritize preventive maintenance to prolong infrastructure lifespan and reduce long-term costs.

Table 3. Analysis of Project Case vs Base Case

NPV (In millions ETB)	Undiscounted	5563.99
	Discounted	3226.17
NPV / CAP	Base Case1	0
	Project case1	1475.422

Table 4. Analysis of Base Case vs. Project Case

NPV (In millions ETB)	Undiscounted	-5563.99
	Discounted	-3226.17
NPV / CAP	Base Case2	0
	Project case2	1475.422

NPV/CAP stands for the net present value ratio relative to capital costs. The NPV measures the total welfare gain over the entire lifespan of an investment. As indicated in Table 3.3, the scenario where maintenance is postponed for five years results in a negative NPV compared to the baseline case.

In general, for a project or investment to be considered viable, the NPV should be positive (i.e., NPV ≥ 0), since this indicates a net welfare gain throughout the entire duration of the project.

For HDM4 analysis Upgrading earth roads twice a year (or once a year for roads with low traffic) is strongly justifiable compared to grading every three years, as it results in very high NPV and IRR values across all road categories. However, for high and medium-traffic roads, no IRR solution was found because the IRR requires the NPV to equal zero, which does not occur in this case. Similarly, this study could not determine an IRR for the same reasons in the Figure 9.

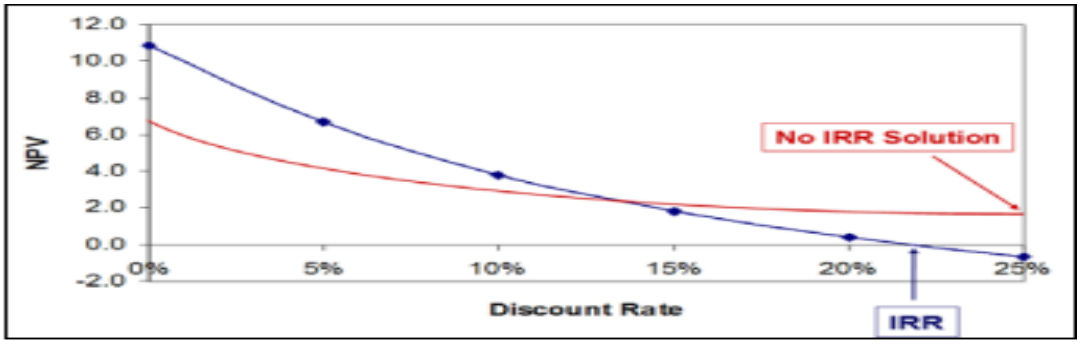


Figure 10. NPV vs Discount Rate

From the result of survey condition and taking weighted average values for the route segments of Weldemanuel to Condominium and Shebele Hotel to Haile Resort the recommended method is re-construction. In the other way for the routes of Weldeamanuel to Tesfaye Gizaw and Central to Agricultural Campus, the recommended value is asphalt overlay.

4. Conclusions and Recommendations

4.1. Conclusion

The condition survey reports indicate that the main road damages in Hawassa city are potholes, cracks, and ravelling. Based on the severity and extent of these damages, and considering the weighted average length of the distresses, the roads in the study area are generally classified as being in poor condition.

This research highlights the overall approach of the Hawassa City Administration Office toward road maintenance practices. Findings indicate that the municipality lacks a well-defined and structured procedure for pavement maintenance. Instead, the current system relies on

random interventions, where sections of the road network are strengthened each year without proper economic analysis of survey results, but rather based on ad-hoc programs.

The study also identifies the type and possibility of maintenance required to restore the condition of the roads. However, limited access to modern technologies (equipment) and financial constraints are cited as major obstacles to achieving quality outcomes. As a result, the municipality is unable to properly evaluate the economic benefits and costs associated with pavement maintenance, leading to reduced performance and serviceability.

Furthermore, delays in maintenance significantly increase costs due to inflation. Postponing repairs results in higher expenses for materials, equipment, and labor, and often necessitates extensive rehabilitation or even full reconstruction placing unnecessary financial burdens on both the city administration and the country at large.

The study concludes that the most economical maintenance approach is realized when the municipality is well-equipped to carry out timely repairs during the early stages of deterioration, which helps limit damage and lowers long-term expenses.

4.2. Recommendations

Based on the study result the following recommendations are suggested to enhance the existing road maintenance practices of the Hawassa City Municipality Office:

The municipality should prioritize periodic surveys of constructed roads to assess their condition before they reach an advanced stage of deterioration. This enables timely interventions that can prevent failures and extend the service life of roads. Maintenance decisions should shift from random actions to systematic, result-oriented responses. By identifying critical distress types through condition surveys and setting clear threshold values for intervention, the municipality can restore pavement performance before damages worsen.

Actions should be guided by condition survey data rather than irregular interventions. Instead of merely classifying road conditions as good, fair, poor, or very poor, the municipality should implement a structured maintenance schedule and respond promptly to visible surface damage or distress. Addressing issues at early stages is more effective and economical than waiting until they worsen.

Preserving existing roads should receive the same level of attention as new capital projects. Greater emphasis should be placed on preventive maintenance, which helps slow down deterioration and reduces the need for costly rehabilitation.

The municipality has to develop a well-defined maintenance schedule, implement procedures to evaluate work quality, and improve its overall road management systems. Additionally, it is essential to prioritize securing various funding sources to tackle the maintenance backlog. Budget limitations should not be an excuse for reducing service standards after roads have been constructed to a good condition.

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Competing Interests

The authors declare no competing interests.

Concerns to Publish

All the authors concern to the publication of this article.

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